

# An analysis of knowledge and knowledge gaps on K nutrition on non-sandy soils

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## Key words

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## Take home messages

- Potassium (K) deficiencies are becoming more prevalent in non-sandy soils throughout the Northern and Southern grain growing regions of eastern Australia, with the distribution of low K linked to combinations of soil type (mineralogy), years of cropping, intensity of K removal (crop rotations and incidence of forage/hay production) and tillage system
- Critical soil test K concentrations are poorly defined on non-sandy soils, but appear to be much higher than critical concentrations in sandy soils
- Crops accumulate as much, or more, K than nitrogen (N) in crop biomass, so overcoming K deficiencies requires substantial increases in crop K uptake (i.e. 10's of kgs, rather than kgs (phosphorus, P) or hundreds of mg (trace elements)). Ensuring large amounts of additional K uptake is challenging.
- Cotton and grain legumes remove much more K/t of harvested product than cereals and coarse grains, with lower K harvest indices in grain crops resulting in residue K enriching topsoil layers. Leaching does not redistribute topsoil K into deeper soil layers, except in sands.
- Fertiliser K application strategies need to enrich profile layers where there is a concurrence of high root densities and frequent/extended periods of available moisture during the growing season.
- Most plant available K is held on the negatively charged surfaces of clay and organic matter that are measured by the soil cation exchange capacity (CEC), with the size of this K sink increasing as CEC increases. In some soils, plant K uptake is limited by the rate of K release, rather than the amount of K that is potentially available.
- To overcome a K deficiency, fertiliser K can be mixed through large soil volumes to maximize root contact or applied in concentrated bands to create localised zones of high solution K concentrations. The former strategy maximizes the interaction with the soil CEC and can limit responses to K fertiliser applications in soils with high CEC, while the latter requires roots to be concentrated around the fertiliser band.
- Unknowns that are being addressed in the current project include determining the critical soil test K concentration that indicates a likely response to applied K fertiliser in soils with varying mineralogy and CEC, and optimising the K fertiliser application strategy to ensure good fertiliser K recovery in cropping systems with varying reliance on stored soil water.

## Introduction

The grains industry in southern and eastern Australia has typically been characterised by negative potassium (K) budgets, with most cropping enterprises removing more K in harvested product than is applied in fertiliser (Edis *et al.*, 2012). The largest deficits are where whole crop removal has occurred (as hay, mulch or for electricity co-generation) exacerbating the size of the deficits and the rate of soil K rundown. The productivity impact of these deficits varies with the initial soil K fertility and the intensity and duration of the K removal.

There are increasingly frequent reports of K deficiencies in the grains industry and a concurrent rise in the interest in fertiliser K strategies to address it. Surveys of the Queensland cereal soils for nutrients in the early 1980s reported many low subsurface K values, but few responses from glasshouse or field trials at that time (Grundon *et al.*, 1985). Initial reports of K deficiencies began in the sandy soils in West Australia, primarily in higher rainfall areas, but by the early 2000's there were reports of more widespread K deficiencies and responses to K applications became more frequent. One of the early indicators of K deficiency was improved performance of crops on header windrows from the previous crop, where extra K was available due to leaching of K from the concentrated crop residues (Pluske 1998). Critical soil test concentrations were derived for soils in that region (Brennan and Bell 2013) and a compilation of treatment strategies to address K deficiency in wheat were published in the GRDC Wheat GrowNotes™ (Scanlan 2015).

By this stage, similar observations of K infertility had begun to appear on non-sandy soils in the Southern (SA) and Northern (Qld) regions in particular soil types and land uses. In SA these observations tended to be associated with long term hay production, while in Qld they tended to occur on the well-structured red and brown Ferrosol soils in the inland Burnett region, where soil K reserves were low and forage or hay production occurred in poorer seasons. Research began on K deficiency in the inland Burnett region in the late 1990's-early 2000's (Bell *et al.*, 2009) and shortly after in SA (Wilhelm and White 2004), although in both cases this research was sporadic and used low intensity on-farm trials rather than establishing a research-intensive program.

The research on K management intensified in the Ferrosols in Qld and then spread onto Vertosols and Sodosols as sporadic reports of K deficiency (typically during dry periods) emerged in rainfed grain crops and irrigated and dryland cotton. Soil tests from responsive sites often exhibited strongly stratified reserves of plant available K, with moderate K concentrations in the topsoils but much lower concentrations in the immediate subsoil layers. The latter was especially problematic in the stored water cropping systems on these high clay soils, as in-crop rainfall can be quite erratic and topsoils can be dry for extended periods during the growing season. The early focus on K responses in these systems therefore focussed on managing K in both topsoils and subsoils, while the southern areas that relied more on in-crop rainfall tended to focus on topsoil K applications.

In this paper we focus on K responses on the clay soils supporting stored water cropping in northern NSW and Qld. Intensive studies from conventionally tilled Ferrosol soils of the inland Burnett have provided an understanding of crop K uptake dynamics, partitioning of K between harvested grains and residues and the comparative responses of different crop species within and between growing seasons. However, behaviour of soil-applied K in the alkaline clays with much higher CEC's and managed using minimum or zero tillage cropping systems differs substantially, and so soil test critical values and effective application strategies derived from the Ferrosol studies have limited application elsewhere. We discuss the results of more

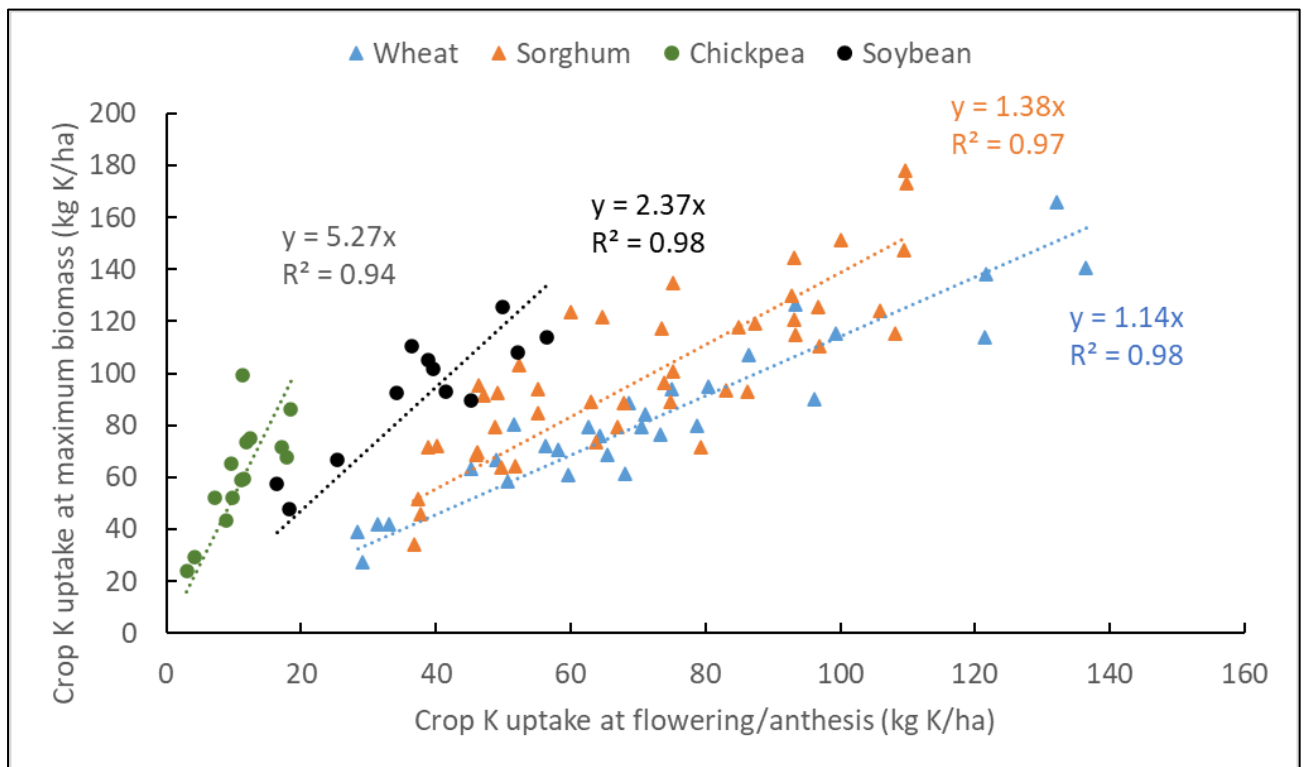
sporadic work conducted on Vertosols and Sodosols in the region, identify the key outcomes of those studies and the research gaps that need to be addressed to better equip the industry for a future in which K management becomes a more important part of cropping systems.

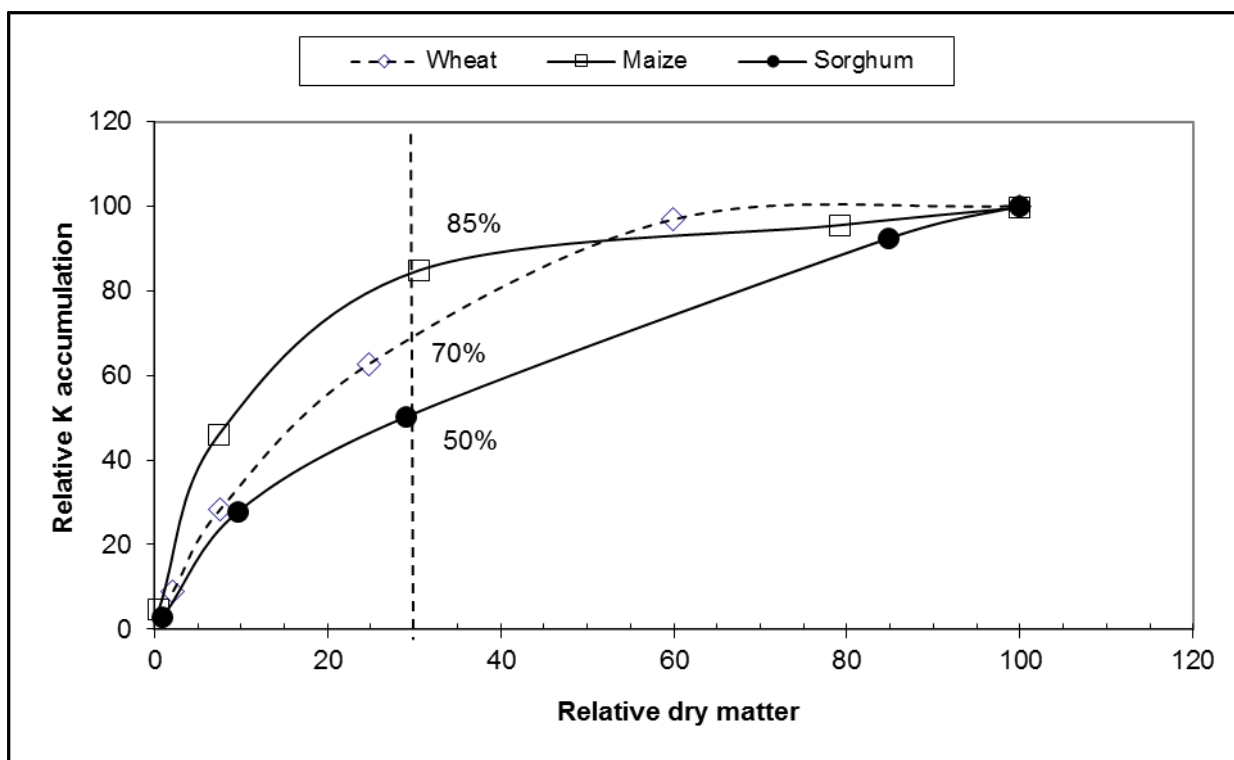
## What do we know – (i) Crop K requirements

### Crop K uptake dynamics

Unlike N and P, crops tend to rapidly accumulate K in biomass early in the growing season and redistribute that K around the plant during later growth stages. The extent to which this rapid early accumulation occurs varies between determinate cereal grain crops and indeterminate grain legumes/cotton, with the latter continuing to accumulate K until much later in the growing season. Crops like wheat accumulate almost all their K by anthesis (Figure 1a), with sorghum accumulating a little more K after anthesis. However, this pattern differs greatly in grain legumes like soybean and chickpea, which accumulate the majority of their K during the reproductive growth stages post-flowering.

The late-season accumulation of K shown by grain legumes, and to a lesser extent sorghum, is due to the continuation of vegetative growth throughout much of the growing season. This extends to differences between grain crops due to the timing of tiller addition and the accumulation of K and dry matter in them, as illustrated in Figure 1b. Using a reference point of the growth stage when 30% of maximum biomass has been accumulated, maize (no tillers) has accumulated 85% of total crop K uptake, wheat has accumulated 70% of total K uptake and sorghum only 50% (White *et al.*, 2021). If only the primary shoot was considered in each species (rather than primary shoots and tillers), the pattern of dry matter and K accumulation between species is identical to that of maize, showing that the delayed accumulation of K in sorghum, and to a lesser extent wheat, was the result of tiller addition. These dynamics are important. The short and intense period of K acquisition in crops like maize makes them more vulnerable to intermittent dry periods when K in relatively K-rich topsoils is unavailable for uptake.





**Figure 1.** (a top) The relationship between crop K uptake at flowering and that at maximum crop biomass in wheat, sorghum, soybeans and chickpeas; and (b bottom) Relative accumulation of biomass and crop K in maize, wheat and sorghum.

### Fate of K taken up by crops

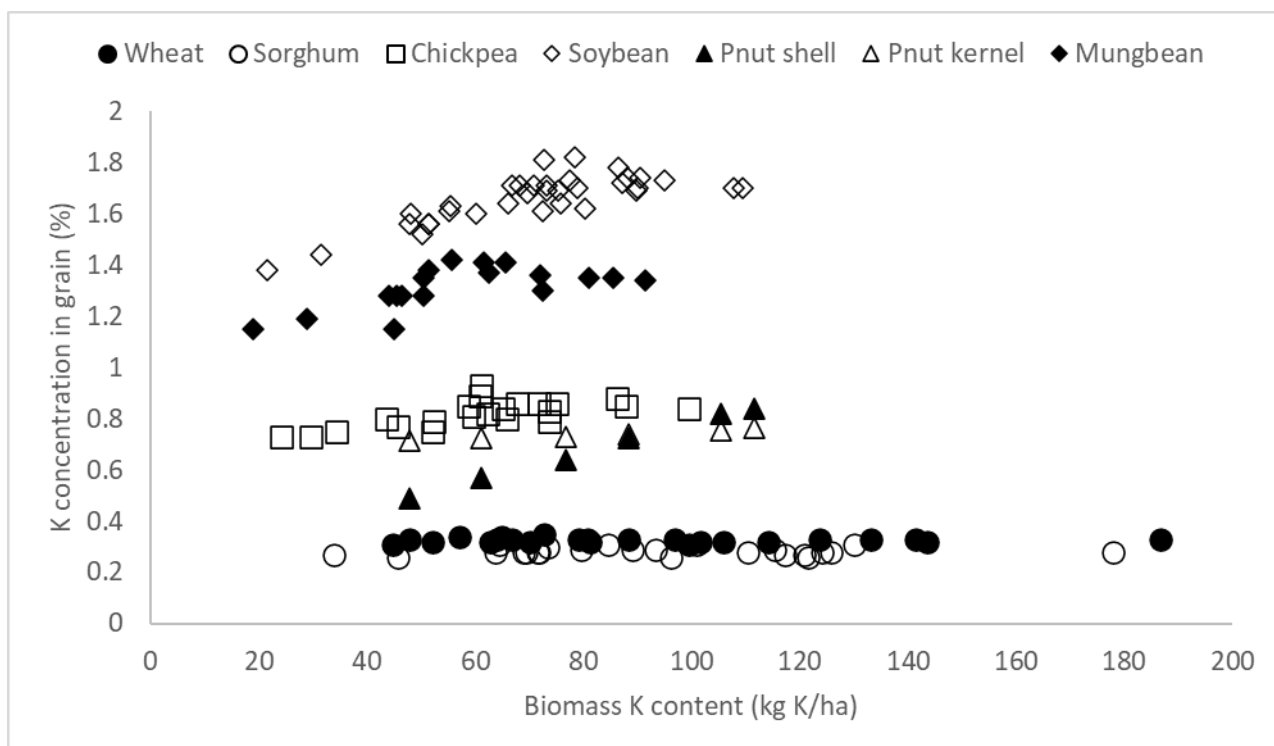
While crops harvested for forage or hay remove all the K accumulated in above-ground biomass, those harvested for grain or fibre only remove a fraction of the total crop K uptake. This fraction varies greatly between crop species and can also vary substantially with crop K status, as illustrated in Table 1. Cereals and coarse grains remove much lower proportions of accumulated K in grain than most grain legumes (mungbeans being an exception, although yields in these trials never exceeded 2 t/ha), and it is interesting to note the particularly high proportion of K that can be removed in crops like soybean when crop K status is low.

**Table 1.** The impact of crop species and K status on the percentage of total crop K accumulation that is removed from the field in harvested grain (i.e. K harvest index, or KHI). Data have been derived from a long-term study on a Ferrosol site near Kingaroy, Qld.

Crop K status	Accumulated crop K removed in grain (%)						
	Sorghum	Maize	Soybean	Mungbean	Wheat	Barley	Chickpea
Luxury K	10–15%	15–20%	60–70%	15–20%	10–15%	12–15%	25–35%
Severe K deficiency	15–25%	25–30%	85–95%	25–30%	25–30%	25–35%	35–50%

Interestingly, while the rate of K removal/t of harvested grain differs almost 5-fold between cereals and coarse grains like wheat and sorghum, compared to nutrient-dense grain legumes like soybean, there is much less variability in K concentration in grains with changing K status of the crop (Figure 2) – remembering that many of the plots in these trials had high K status and crops exhibited luxury crop K uptake. Grain crops exhibited almost no change in grain K concentration across a wide range of crop K contents, and while the grain legumes exhibited slow increases in grain K during the early increases in biomass K content (as crops moved from deficient to adequate K status), no species showed continuous increases in grain K concentration and did not exhibit luxury K accumulation in grain. Interestingly, accumulation of K in peanut shells, which are also removed at harvest in addition to the kernels inside, was more responsive to increasing crop K contents and could accelerate rates of K removal/t of harvested pods.

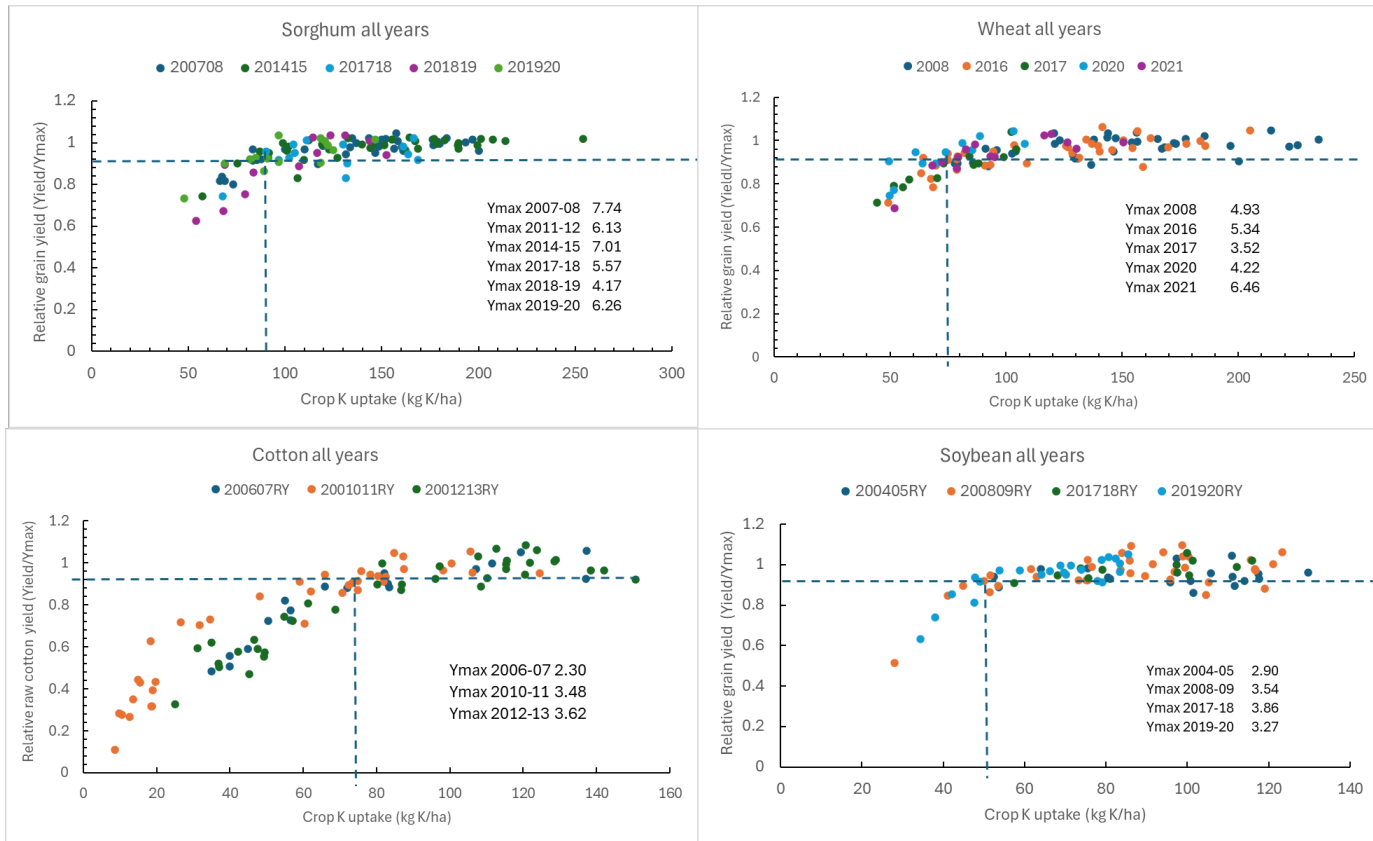
Collectively, these data suggest ‘average’ K removal rates/t of harvested grain can be used in K budgeting, and that occasional large inputs of K and luxury K uptake will not accelerate the rates of K export – unless biomass or residues are harvested. However, the low KHI shown for cereals and coarse grains in Table 1 suggests that soil K will rapidly be redistributed into the topsoils in crop residues, accentuating soil K stratification. Given the lack of leaching of K observed in clay soils, this re-stratification will increase the proportion of soil K supplies whose availability will fluctuate greatly as fluctuating soil moisture determines access to K-enriched topsoils.



**Figure 2.** Variation in K concentration in harvested produce (grains, kernels and shells) in response to increasing K availability and crop K uptake.

### Relationship between K uptake and grain yield

Most of the field experiments had crops which contained adequate K, with only a small proportion being severely K deficient. In Figure 3 we report the relationships between crop K uptake and relative grain yield (plot yields expressed as a proportion of the K-unlimited yields in that season;  $Y_{max}$ ) for sorghum, wheat, cotton and soybean. Relationships for other species are not reported due to poor relationships between grain yields and crop K uptake in existing data, due to either limitations in the number of plots where yields increased with increasing K uptake or the low frequency of crops grown. The cotton data illustrates how strongly that crop responds to sub-optimal K availability, but it should also be noted that the  $Y_{max}$  for cotton crops in this location was only 7–8 bales/ha (3500–4000 kg raw cotton/ha).



**Figure 3.** Relationship between crop K uptake and relative yields of grain or seed cotton (relative to  $Y_{max}$ ) for sorghum, wheat, cotton and soybean crops grown on a Ferrosol soil. Values of  $Y_{max}$  for each crop season are shown on each sub-figure.

Using the estimates of crop K uptake required to achieve 90% of the maximum yield ( $Y_{90}$ ) in each season for the various crops and seasons, we were able to derive estimates of the crop K content needed to achieve at least  $Y_{90}$  for each crop in each growing season (Table 2). We were also able to calculate the internal K use efficiency (KUE) that can be achieved for the different species when additional K is supplied to strongly K-responsive crops (i.e. kg additional grain produced/kg additional K uptake). While these numbers are tentative, they provide a useful indicator of the size of the challenge represented by severe K deficiencies, as the internal KUE appears relatively low. For example, to produce an additional tonne of grain yield in wheat or sorghum requires an additional 25–40 kg/ha crop K uptake. In comparison, only an additional 4–5 kg of extra crop P uptake/ha would be required to achieve the same yield response. Data for cotton has not been shown in this table due to the relatively low yields from this location, but the internal KUE of cotton was within the range shown for the grain species (i.e. 40–70 kg raw cotton and 20–30 kg lint/kg additional crop K uptake).

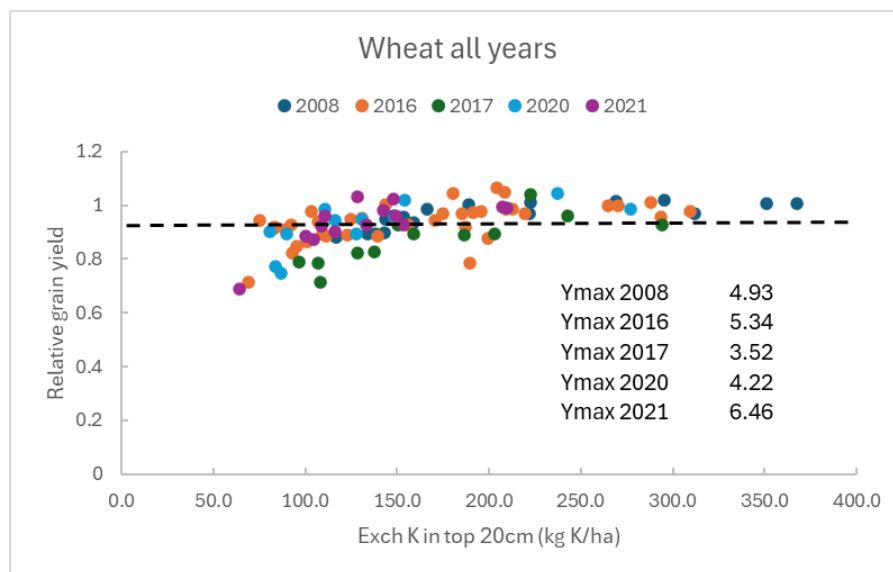
**Table 2.** Crop K uptake needed to achieve 90% ( $Y_{90}$ ) of seasonal yield potential ( $Y_{max}$ ) and KUE for yields less than  $Y_{90}$  for different crop species and growing seasons at the Kingaroy site. Values of  $Y_{max}$  for wheat, sorghum and cotton are shown in Figure 3, while those for maize and peanut ranged from 6–7 t grain/ha and 3.7–4.0 t pods/ha, respectively.

	Sorghum	Soybean	Maize	Peanut	Wheat
Crop K to achieve $Y_{90}$ (kg K/ha)	90–100	60–70	60–70	50–60	90–100
KUE for yields $<Y_{90}$ (kg extra yield/kg additional K uptake)	30–40	50–60	65–70	25–30	20–30

## What do we know – (ii) Soil K availability and diagnostic testing

### Measuring plant available K in soils

Both current commercial soil tests (exchangeable K or Colwell K) provide similar estimates of plant available K, and these estimates are good predictors of the K available to plants in the short term (e.g. the coming season). Examples of the types of correlations that can be obtained between exchangeable K and relative grain yields of wheat on a Ferrosol soil at Kingaroy are shown in Figure 4, with the depth increment (20cm) chosen to allow for fluctuations in K distributions across the different growing seasons and fertiliser placements in that study. Deriving such relationships requires a wide range of soil K availability and a significant proportion of plots that are consistently K deficient, which has proved challenging.



**Figure 4.** Relationship between exchangeable K in the top 20cm of the soil profile in a conventionally tilled Brown Ferrosol at Kingaroy and relative yield of wheat grown during 5 seasons. The dashed line represents 90% of the maximum yield ( $Y_{90}$ ) across those growing seasons, and  $Y_{max}$  for each crop season is also shown.

However, crops can extract K from other, less readily available (either positionally unavailable in clay lattices, or in sparingly soluble minerals) forms of K in the soil, or from soil layers deeper than the top 30 cm typically soil sampled. The extent to which this can occur will vary with soil type, the ability of crops to exploit deeper layers and the availability of stored water in those layers. An example of these effects is shown for a Brown Ferrosol (CEC ~10 cmol (+)/kg) with a neutral pH down the profile, with cropped plots paired with a series of adjacent uncropped

reference sites nearby. High water infiltration rates and a lack of constraints to root development have allowed roots to exploit K in deeper profile layers, and the long cropping history (>50 years) has allowed small annual removals to accumulate to larger totals over time. While ~60% of the K removed during the 50 years of cropping (~800 kg K/ha – Table 3) came from the top 30cm, and almost all the exchangeable K, the slow release pools in the 30–90cm layers have clearly been buffering removal from the top 30cm, and allowing the unfertilised plots to maintain yields of 60–70% of  $Y_{max}$  in most years and for most species, with cotton being a marked exception (Figure 3).

This buffering of the exchangeable K pool in the top 30 cm of the soil profile at this site is consistent with the fact that despite removal of ~400 kg K/ha in harvested grain/raw cotton over the 21 crop seasons that this experiment was conducted, exchangeable K in the top 30 cm of the profile remained effectively unchanged at  $133 \pm 8.5$  kg K/ha. While this buffering has reduced the impact of K rundown on productivity on this soil in the short term, it is clearly not sustainable.

**Table 3.** The quantity of K removed during cropping from different soil profile layers and from different pools of K measured using different extractants from a Brown Ferrosol at Kingaroy. Exchangeable K and Nitric K are commercially available soil tests that measure different proportions of the soil total K pool, with the additional K extracted by each method representing plant access to what have been considered relatively unavailable forms of soil K.

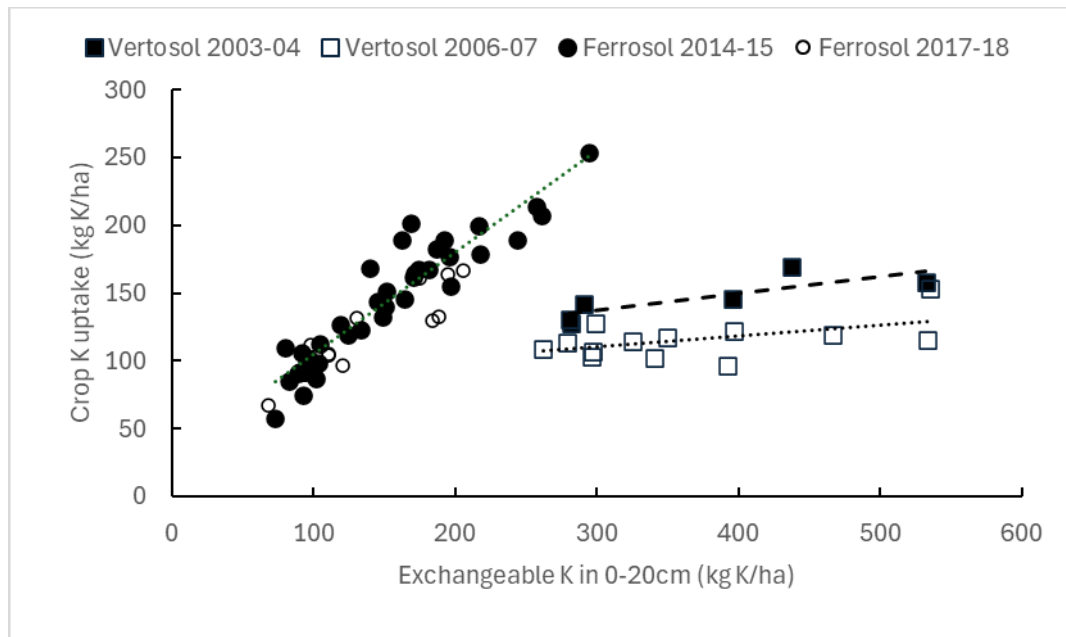
	K removed during cropping (kg K/ha)			
	Exchangeable K	Nitric K-Exch K	Total K – Nitric K	All K removed
0-30cm	294	99	98	491
30-60cm	30	20	158	207
60-90cm	6	18	87	111
Profile total	330	137	343	809

### Effects of CEC on K availability and crop K uptake

While K acquisition by a crop in a given season is most closely related to exchangeable/Colwell extractable K in the layers where there is moist soil and a high density of active roots, the amount of K that those crops can acquire will be influenced by the concentration of K in the soil solution, and the speed with which K removed from the soil solution by plant uptake can be replaced by K released from the exchange sites. Examples of this have been reported in Bell *et al.*, (2009) with a subset of that data shown here (Figure 5). Increases in soil K from high rates of fertiliser addition have resulted in a similar range of available K in both soil types. However, while this range in soil K has produced increases in crop K accumulation of 60–100 kg K/ha in the low CEC Ferrosol, only an additional 20–30 kg K/ha uptake was observed in the high CEC Vertosol and maximum K uptake was much higher from the Ferrosol, despite lower exchangeable K. Yields in crops with >150 kg K/ha were not responsive to additional K uptake, but luxury K accumulation in the Ferrosol far exceeded that in crops with similar yield potentials grown on the Vertosol.

These results suggest that on soils that behave like the Ferrosol, relatively small increases in soil exchangeable K can achieve quite substantial increases in crop K uptake, while on soils that behave like the Vertosol, large increases in soil exchangeable K would be needed to achieve the same increase in K uptake. The soil property that has a large impact on these characteristics is

called the K buffer capacity ( $K_{BC}$ ), which essentially reflects the equilibrium that is established between K held on the exchange complex and K in the soil solution. Research conducted in project UNE00022 by Chris Guppy and Phil Moody showed that soil CEC was a strong determinant of  $K_{BC}$  for a wide range of grain growing soils in Qld and northern NSW, and this relationship is likely to be a major driver of the differences in luxury K accumulation shown between the Ferrosol (CEC 10 cmol (+)/kg) and the Vertosol (CEC 62 cmol(+)/kg) for the same K rates and application methods (i.e. fertiliser K applied to the soil and mixed through varying soil volumes with tillage).



**Figure 5** Accumulation of K in sorghum above ground biomass in response to increasing exchangeable K in the top 20cm of the soil profile of a Brown Ferrosol (CEC ~10 cmol(+)/kg) and a Black Vertosol (CEC 62 cmol(+)/kg). Maximum yields in all crop seasons shown here ranged from 6-7 t/ha. Data derived from Bell *et al.*, 2009

This effect is likely to impact the critical soil test concentration indicative of fertiliser K responsiveness in different soils and cropping systems, with a single critical value for exchangeable K (such as derived on CEC 10 Ferrosols at Kingaroy) not likely to apply to all the diverse soils of the Northern grains region. Guppy and Moody speculated that CEC will be a major determinant of this critical soil test K concentration, and that this value may be related to exchangeable K somewhere near 2% of the total CEC (i.e. 2% K saturation), but considerable research is required to confirm either of these hypotheses.

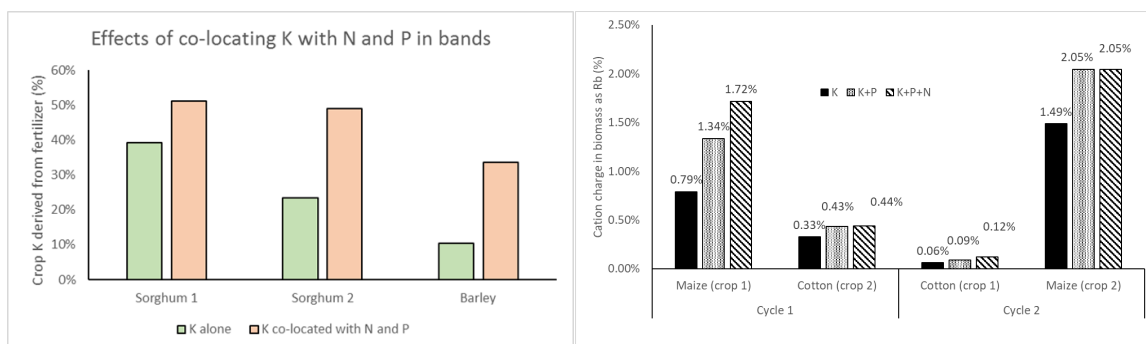
### Effectiveness of different K application strategies

Research conducted in the northern stored water crop systems has mainly focussed on applying K into the strongly depleted subsoils, which has primarily necessitated banded applications. There have been a couple of attempts to look at other application strategies (e.g. applying the same rates of K and either mixing through the top 10cm (broadcast and offset discs), banding at 20–25 cm (deep bands) or using a reversible plough and secondary tillage to mix the K through as much of the top 30 cm as possible) on both a Vertosol and a Ferrosol. These studies were relatively inconclusive in terms of generating differences in grain yield responses, with the primary conclusion being that K rate was more important than application

method, but research conducted in southern cropping systems (Tregove *et al.*, 2026) clearly shows drilled K is more effective than K broadcast onto the soil surface without incorporation.

The excessive disturbance of soil structure resulting from deep ploughing in clay soils and the greater exposure of applied K to soil with high buffer capacity for K suggests that mixing K through large soil volumes to maximize root exposure to K enriched soil will become increasingly ineffective as CEC increases. Creating zones of high K enrichment (bands) in areas of high root density and available moisture are likely to become an increasingly effective application strategy as CEC increases. While this strategy will limit access to the applied K because of the limited soil volume enriched, this potentially negative effect may counter the propensity for luxury K accumulation from such applications and prolong the residual benefit from deep placed bands. Luxury K uptake, combined with the low KHI in the dominant grain crops, would result in the rapid redistribution of K from deeper layers into the topsoils in crop residues, increasing the frequency with which deep placement needed to occur to overcome low subsoil K.

Field experiments with deep banding in project UQ00063 showed that deep K bands could be an effective way of improving crop K access, although in most locations the primary constraint at each site was P, with crop K responses not evident until the P deficiency was overcome. Those studies also showed that crop K uptake typically increased when either K or P were applied, with the P effect presumably due to production of a more vigorous root system that could extract more K from the soil profile. Determining the efficiency of additional K uptake in producing grain yields was difficult under these multi-nutrient limitations, and further work is clearly required. Glasshouse studies have shown that placing P within the K band, or close to it, enhances uptake of K due to root proliferation caused by the concentrated P source (Bell *et al.*, 2018), although this has been difficult to demonstrate clearly in field studies when soils are low in both P and K. There are also some concerns that the placement of high rates of banded K with P in widely spaced (and therefore concentrated) bands can reduce the recovery of applied P and/or limit the size of the P response (Meyer *et al.*, 2020). This effect is caused by high concentrations of ammonium ( $\text{NH}_4\text{-N}$ ) and K in and around the P band, which can result in precipitation of soluble P as sparingly soluble taranakite and Ca-phosphate minerals. This effect has only been observed in one field study where K rates were very high (200 kg K/ha), with moderate K rates and narrower band spacings ( $\leq 50\text{--}60\text{cm}$ ) reducing the risk by reducing the in-band concentrations. Examples of the benefits of co-location of K with P or N and P are shown in Figure 6.



**Figure 6.** The impact of co-locating K with N and P in fertiliser bands on (left) the recovery of applied fertiliser K by crops in the field or (right) recovery of rubidium (Rb, a tracer for K acquisition in plants) applied in a K band by plants grown in soil lysimeters in the glasshouse. In these studies, K was applied as KCl, Rb as RbCl and N and P were applied as MAP.

Finally, there is considerable interest in foliar K applications as an alternate way of addressing K infertility. There are reports of consistent successes in some situations, with yield responses typically in the range of 5–15%, but an equal number of reports show no response in other regions or crops. Cotton and chickpeas have been reported as the most consistent responders to K, and foliar K in particular, in these on-farm trials with few responses in wheat or sorghum. The variability in responses between regions, the low rates of K that can be applied (~10 kg K/ha) and the large amounts of crop K uptake that appear to be needed to overcome large K limitations create considerable uncertainty about the nature of such responses, and whether they are in fact overcoming a K deficit or doing something else.

### **What don't we know (but will address in project UOQ2503-008RTX)**

While this review has shown that we do know a significant amount about crop K requirements and use, and even about K soil testing methods and sampling depths, there are some clear knowledge gaps that this project will attempt to address.

#### **(i) What are critical soil K concentrations indicative of K responsiveness?**

This is a critical research area, but one that will be difficult to address without a prolonged research effort. Key factors that will need to be accounted for include –

- a. The fluctuating contributions of topsoil (0–10cm) and subsoil (10–30cm) profile layers to crop K supply in highly variable seasonal rainfall environments. An important consideration from this work will be whether highly K-enriched surface soils are able to compensate for K depleted subsoils, and what soil and environmental conditions would allow this to occur. This research will require access to a wide variety of naturally occurring stratified K profiles in farmers' fields, as the propensity for luxury crop K uptake and the (often) low rates of K removal in harvested grain make establishing long term sites with contrasting soil K concentrations and distributions difficult to sustain over time.
- b. How much does increasing CEC influence the critical soil test K concentration that determines the need for fertiliser K application.

#### **(ii) What are the most effective K application strategies in different soils and climates**

This research area requires a combination of laboratory and field experimentation under contrasting environmental conditions and in different soil types with a focus on the following questions –

- a. What are the trade-offs between mixing K through large soil volumes versus concentrating K in bands in the most K-depleted parts of the soil profile? How do these trade-offs change with soil properties (e.g. CEC)?
- b. Should K be applied regularly in small amounts, to supply 1–2 crops, or can larger amounts of K be banked in the soil profile and exploited over extended periods?
- c. Do low rates of foliar K overcome K deficits in plants, or do they do something else? What factors increase the chance of success of foliar K applications?
- d. What is the fate of fertiliser K applied in contrasting soil types, and how long do residual benefits persist?

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## References

Bell MJ, Moody PW, Harch GR, Compton BW and Want PS (2009) Fate of potassium fertilisers applied to clay soils under rainfed grain cropping in southeast Queensland, Australia. *Aust J Soil Res.* 47, 60-73.

Bell MJ, Moody PW, Lester D, Want P (2018) Using Rb relative abundance to determine root activity in K fertilizer bands. *Proc., ISRR 10<sup>th</sup> Symposium 'Exposing the hidden half', Ma'ale HaHamisha, Israel.*

Brennan RF, Bell MJ (2013) Soil potassium—crop response calibration relationships and criteria for field crops grown in Australia. *Crop & Pasture Science.* 64, 514–522.

Edis R, Norton RM, Dassanayake K (2012) Soil nutrient budgets of Australian natural resource regions. In: Burkitt LL, Sparrow LA (eds) *Proceedings of the 5<sup>th</sup> joint Australian and New Zealand soil science conference: Soil solutions for diverse landscapes.* Australian Society of Soil Science, Hobart, p11.

Grundon NJ, Leslie JK, Best EK, Wall W, Glasby JM and Mackenzie J (1985) Technical Report Q085020: Nutrient screening of Queensland cereal soils. Technical Report Q085020. Queensland Department of Primary Industries. Brisbane, Qld, Queensland Department of Primary Industries: 161.

Meyer G, Bell MJ, Doolette CL, Brunetti G, Zhang Y, Lombi E, Kopittke PM (2020) Plant-available phosphorus in highly concentrated fertilizer bands: Effects of soil type, phosphorus form, and co-applied potassium. *Journal of Agricultural and Food Chemistry* 68, 7571–7580.  
<https://dx.doi.org/10.1021/acs.jafc.0c01287>

Pluske W (1998) Potassium in the wheat-belt. Department of Agriculture and Food, Western Australia Crop Updates 1998- Cereals.

Scanlan C (2015) Potassium. In “Wheat. Western Region – Grownotes”. GRDC. Pp. 18-21.

Trengove S, Wilhelm N, Sherriff S, Bruce J, Noack S, Bell M (2026). Identifying potassium responsive soils and best practice management where deficiencies occur. GRDC Update Adelaide, February 2026.

White PJ, Bell MJ, Djalovic I, Hinsinger P, Rengel Z (2021) Potassium Use Efficiency of Plants. Chapter 5, p. 119-145. In: T.S. Murrell, R. Mikkelsen, G Sulewski, Norton R, Thompson ML (Eds.). 'Improving Potassium Recommendations for Agricultural Crops'. Springer Publishing ISBN 978-3-030-59196-0

Wilhelm N, White J (2004) Potassium Responses Observed in South Australian Cereals. *Better Crops.* 88/1.

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