GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Final Technical Results Report

2024

Identifying potassium (K) responsive soils and best practice application of K in the medium and high rainfall zones of the Southern Region

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REPORT SENSITIVITY

Does the report have any of the following sensitivities?

Intended for journal publication	YES ☐ NO ☒
Results are incomplete	YES ☐ NO ☒
Commercial/IP concerns	YES ☐ NO ☒
Embargo date	YES ☐ NO ☒ If Yes, Date: <Choose date>

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ABSTRACT

Despite high reserves of extractable potassium (K) relative to the industry critical threshold, K deficiencies in broad-acre crops growing on the heavier soils of south-eastern Australia are increasingly being reported.

This project conducted a series of field trials over two growing seasons across five sub-regions of South Australia and western Victoria to investigate these claims. Field trials were also conducted to assess the effectiveness of a range of application strategies for correcting K deficiency in wheat.

Crop responses to K were confirmed at 4 locations, or 30% of the total number of sites conducted. The largest increase occurred on the Yorke Peninsula of South Australia with wheat, a 2 t/ha increase in grain yield with added K.

The current industry threshold for the Colwell K soil test (largely based on sands) appears to be too low for the heavier soils of south-eastern Australia. However, current industry thresholds for plant testing appear to be valid for current crops in modern farming systems.

Banding K at seeding was more effective at alleviating K deficiency in wheat than broadcasting either before or after seeding. Early foliar application of K was not effective.

This study confirmed K deficiency is an emerging issue for the cropping industry in south-eastern Australia, suggests that it is likely to get worse, and that treating the problem where it is already occurring should increase productivity and profitability.

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EXECUTIVE SUMMARY

Detection of potassium (K) deficiency, and its correction, is becoming embedded in best practice crop management on many of the sands of Western Australia because these soils are inherently low in K. With many decades of extraction of K by crops and its transport off-farm in commodities, K deficiency in crops is becoming more common in that state. However, soil reserves of K are much higher in the generally heavier soils of south-eastern (se) Australia and it was believed that K deficiencies were unlikely on these soils. Despite these high reserves of K, deficiencies (suspected or confirmed) in crops are increasingly being reported on these soils.

The project reported here is a pilot study to investigate whether the claims of K deficiency in crops growing on heavy soils of south-eastern Australia have validity. The project also investigated the relevance of threshold values of soil and plant testing for current crops in modern farming systems on heavy soils and which application strategies of K fertilisers are most effective in those systems.

This project was contracted through the PIRSA-UoA Affiliate Agreement and the research delivered through SARDI. Dr Wilhelm (SARDI Farming Systems Leader) led the project and assembled a team which had experience with reports of K deficiency in broad-acre crops and/or an extensive network of farmers and advisers in the target sub-regions. This team consisted of:

Sam Trengove and co-workers (Trengove Consulting Pty Ltd)	Yorke Peninsula, SA
Ben Smith & Mick Faulkner (Agrilink Agricultural Consultants)	Mid North, SA
Amanda Pearce and co-workers (SARDI, Naracoorte)	Upper SE & SE, SA
Grace Evans (Southern Farming Systems)	SW, Vic.

Dr Sean Mason (Agronomy Solutions) provided wide experience in soil & plant testing as well as management of crop nutrition, awareness of reports of K deficiency and access to APAL soil and plant tests at reduced rates.

The experimental component of the project was divided into 2 parts. One part was to investigate existing reports of K deficiency so that an estimate could be determined of the extent and severity of K responses in crops across five sub-regions of the southern region nominated by GRDC: Yorke Peninsula, Mid North, Upper SE and SE of South Australia and SW of Victoria (strip trials). The second part was to assess the efficacy of a range of K application strategies in a current and intensive cropping system (application strategy trials). All trials were conducted on heavier soils, typical of the cropping zones in se Australia, and in locations where K deficiencies have been previously reported or claimed.

Every strip trial in 2022 was identical in design and consisted of 2 treatments replicated 4 times; an untreated control and a +K treatment. The +K treatment was muriate of potash (MOP) broadcast onto the soil surface at 75 kg K/ha pre-seeding + MOP broadcast onto the soil surface at 75 kg K/ha post-seeding (4-8 weeks after seeding). Responsive trials, and trials which were deemed still likely to respond, were monitored in 2023 as well to assess residual properties of K applied in 2022. Two application strategy trials consisted of ten treatments which varied in K fertiliser application timing, rate and placement.

Over the combined years of 2022 and 2023, a total of 19 trials were marked out and sampled for K fertility of the soil to depth using the industry standard soil test for crop-available K, Colwell-K, and for the response of crops to the addition of K to the soil early in the season.

A common feature with all the trials was that Colwell K levels in the top 10 cm were all well above the current industry threshold of 40-50 mg/kg of Colwell K, below which K deficiency is likely to occur in wheat and other broad-acre crops (Brennan and Bell 2013). Despite Colwell K levels being very high compared to the industry threshold, the addition of K increased grain yields of crops in 3 trial years at two sites (Maitland on the YP and Marrabel in the mid North of SA). Overall, of the 19 trials managed under this section of the project, crop responses to K (at some stage of their development) were confirmed at 4 sites or 30% of the total number of sites investigated.

Large responses in grain yield were recorded at Colwell K values double the current threshold, although no grain yield responses were recorded above 200 mg/kg of Colwell K. These results suggest that the current industry threshold for Colwell K (largely based on sands) is not appropriate, and too low, for these heavier soils of south-eastern Australia. However, it appears that the current thresholds for plant testing are valid for current crops in modern farming systems.

Investigations into application strategies for treating K deficiency in modern cropping systems revealed that banding K in the seeding operation was more effective at alleviating K deficiency in wheat than broadcasting either before or after seeding. Early foliar application of K was not effective. Rates of K required to alleviate K deficiency in these trials were much higher than those typically used in WA currently to manage K nutrition (Bell et al 2023).

While this pilot study did not include an extensive survey of the issue, it did find that K deficiency is present in cropping on heavier soils of south-eastern Australia. It also found that K deficiency can cause substantial losses in productivity in a range of crops when it occurs and that it may not yet be a widespread problem. However, it is reasonable to predict that its extent and severity will increase in the future. More attention to this disorder is warranted for cropping in south-eastern Australia, including more research into detecting and managing K deficiency in current farming systems.

This project has identified several gaps in knowledge which currently make detection of the problem unreliable and its correction not fully effective or at minimised cost:

1. A more thorough assessment of how widespread and severe the problem is currently across the cropping zone of se Australia would scope the size of the issue more accurately.
2. The current thresholds for the Colwell K soil test are not appropriate for the heavier soils of se Australia. A high priority would be to develop robust thresholds for this region.

3. Broad-leaved crops behaved differently to wheat in this study. More knowledge about the relative sensitivities of crop types to K deficiency would be useful, especially with respect to thresholds for different crops in the Colwell K soil test.
4. Subsoil levels of Colwell K vary widely in the heavier soils of se Australia. Their impact on K deficiency and its management need to be defined.
5. Banding of muriate of potash was far more effective at correcting a severe K deficiency than broadcasting and foliar K was not effective but there are still large gaps in our knowledge on how to correct K deficiency cost-effectively in modern farming systems.
    a. Are sources of K other than MOP competitive in effectiveness and cost ?
    b. Will changing timing and sources of K improve the effectiveness of foliar applications. ?
    c. How much K can be applied with the seed on heavier soils without reducing emergence ? Does the type of seeder affect these rates ?
    d. What is the residual benefit of soil-applied K on heavy soils ?
    e. Do different crops respond the same to applications of K ?
6. On heavy soils, where K deficiencies may be exacerbated by slow cycling between pools and/or slow movement of K in soil solution, investigating the role of soil microbiology in K nutrition would be valuable.

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GRDC

BACKGROUND

Detection of potassium (K) deficiency, and its correction, is becoming embedded in best practice crop management on many of the sands of Western Australia because these soils are inherently low in K. With many decades of extraction of K by crops and its transport off-farm in commodities, K deficiency in crops is becoming more common in that state. However, soil reserves of K are much higher in the generally heavier soils of south-eastern (se) Australia and it was believed that K deficiencies were unlikely on these soils. Despite these high reserves of K, deficiencies (suspected or confirmed) in crops are increasingly being reported on these soils.

These reports have claimed either an improvement in crop performance following application of K fertiliser (with or without test strips) or are accounts of crops performing better on header rows or in areas of high stubble load. In some of these latter cases, soil and/or plant testing have shown higher K levels in the header rows or stubble dumps. Observations of similar patterns of crop performance in WA were some of the early triggers for more substantial studies into K nutrition and subsequent recognition of K deficiency being an emerging problem in WA cropping systems on sandy soils.

Part of the complacency around K deficiency in crops growing on heavier soils of south-eastern Australia is due to reserves of K in these soils usually being well above the critical thresholds currently in use for soil testing of broad-acre crops. However, the current critical levels for the Colwell K soil test are largely derived from data generated in Western Australia on sandy soils, and may be too low for heavier soils (ie underestimate the likelihood of K deficiency). There is also limited information on critical thresholds of K for crops other than wheat or canola.

Plant testing is a diagnostic tool for K deficiency in broad-acre crops but the critical levels were developed in farming systems well before the current intensive cropping systems based around minimum tillage and stubble retention. These critical levels may not be relevant for crops growing in modern systems and few criteria exist for break crops which are common now, eg lentils and faba beans.

The standard recommendation for treating K deficiency in broad-acre crops is to broadcast a K fertiliser (muriate of potash (MOP) is often the product of choice) prior to seeding. However, it is not known how effective this strategy is for cropping on heavier soils where no-till seeding, stubble retention and no grazing is a very common agronomic package. Other options available to growers are K-enriched high analysis fertilisers applied with the seeding operation, in-crop applications of K fertilisers or foliar products. These strategies have been rarely compared in current systems of southern Australia, and even more rarely on heavier soils.

The project reported here is a pilot study to investigate whether the claims of K deficiency in crops growing on heavy soils of south-eastern Australia have validity. The project also investigated the relevancy of threshold values of soil and plant testing for current crops in modern farming systems on heavy soils and which application strategies of K fertilisers are most effective in those systems.

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PROJECT OBJECTIVES

The primary goal of this pilot study was to establish whether the scattered reports of K deficiency in broad-acre crops growing on heavier soils of south-eastern Australia are indicating an emerging issue for the grains industry in these areas and hence an opportunity for growers to improve their productivity and profitability. If the issue were to be confirmed, then the project had secondary goals of:

1. investigating whether existing soil and plant testing thresholds were still relevant as diagnostic tools for crops in current farming systems,
2. assessing the efficacy of application strategies for treating K deficiency in current farming systems, and
3. ensuring that growers understand the value of soil and plant testing to diagnose K deficiency and at least 60 growers will be able to economically assess the best practice application to remediate K deficiencies and manage K levels long term to avoid future deficiency.

METHODOLOGY

This project was contracted through the PIRSA-UoA Affiliate Agreement and the research delivered through SARDI. Dr Wilhelm (SARDI Farming Systems Leader) led the project and assembled a team which had experience with reports of K deficiency in broad-acre crops and/or an extensive network of farmers and advisers in the target sub-regions. This team consisted of:

Sam Trengove and co-workers (Trengove Consulting Pty Ltd)	Yorke Peninsula, SA
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Grace Evans (Southern Farming Systems)	SW, Vic.

Dr Sean Mason (Agronomy Solutions) provided wide experience in soil & plant testing as well as management of crop nutrition, awareness of reports of K deficiency and access to APAL soil and plant tests at reduced rates.

The experimental component of the project was divided into 2 parts. One part was to investigate existing reports of K deficiency so that an estimate could be determined of the extent and severity of K responses in crops across five sub-regions of the southern region nominated by GRDC: Yorke Peninsula (YP), Mid North, Upper SE and SE of South Australia and SW of Victoria (strip trials). The second part was to assess the efficacy of a range of K application strategies in a current and intensive cropping system (application strategy trials).

Data from all trials were analysed with standard ANOVA models for randomised block designs. Individual treatments were deemed to be different if the treatment term in the ANOVA had a probability of less than, or equal to 5% and the treatments were separated by more than an LSD calculated at the 5% level.

Responsiveness of crops to K across five sub-regions.

Nine replicated strip trials were conducted in 2022 on a range of soil types across the YP (2 trials), Mid North (2), Upper SE (2), SE of SA (1) and SW of Vic (1) sub-regions of the southern region. An extra trial (over and above the eight required by the contract) was managed by the SE team (at Malinong) due to extra interest from a local farmer group (see LOCATION section for locations of all sites). Sandy sites were not chosen because diagnostic tools (soil and plant tests calibrated for those situations) for sandy soils and management strategies are already in place.

The sites in each sub-region were chosen because they matched all or some of the following criteria (which are listed in order of importance) :

- Clear evidence of a crop response to the addition of a K fertiliser
- Previous plant testing had shown tissue levels in crops well below threshold
- Belief that crops were growing better after K fertilisers were used
- A soil type which was common for the district and without "high" levels of Colwell K in the top 0-10 cm (the notion of low was, and still is, quite vague on heavy soils).

Each trial site was chosen to be in a paddock which had not been previously treated with K and was an area which was uniform and consistent for soil type and that the soil type was one deemed to be responsive. The trial area was seeded and managed by the farmer in the same way as the rest of the paddock except K fertiliser was not to be used on the trial area if that were part of the paddock management package.

Every trial was identical in design and consisted of 2 treatments replicated 4 times ; an untreated control and a +K treatment. The +K treatment was muriate of potash (MOP) broadcast onto the soil surface at 75 kg K/ha pre-seeding + MOP broadcast onto the soil surface at 75 kg K/ha post-seeding (4-8 weeks after seeding). This approach avoided any inputs from the farmer or did not interfere with their seeding operations.

Trials consisted of 8 plots laid out in one bay, each plot running at right angles to the direction of seeding, with plots being at least 5 m wide and 10 m long. Wheat was the preferred crop to be seeded through the trials but we accepted any crop that the farmer was using.

Soil profiles were characterised pre-seeding at every site in stratified layers for type, texture, and the full soil test supplied by APAL

Crop performance was assessed at 4 stages during development:

- Establishment (to check if addition of K had reduced plant numbers)
- Crop biomass and whole shoot tissue levels of K at late tillering (Z30)
- Crop biomass and whole shoot tissue levels of K at flowering (Z60)
- Grain yield

Responsive trials, and trials which were deemed still likely to respond, were monitored in 2023 as well to assess residual properties of K applied in 2022. The original intention was to re-apply K to the +K plots in the second year of these trials but it was decided that assessing residual properties of a K application was more valuable than assessing crop response only. Crop choice in 2023 was set by the farmer's rotation at each site. Crop performance was monitored in the same way as in 2022.

The following trials were not monitored in both 2022 and 2023 but new trials were set up to replace those not monitored into a second year.

Malinong	no crop response in 2022 so a new trial was set up in 2023 at Coonalpyn where there was also a lot of farmer interest and several using K fertilisers
Hill River	poor crop establishment in 2022 so a new trial was set up in 2023 next to the 2022 site
Inverleigh	no crop response in 2022 and high reserves of soil K so a new trial was set up in 2023 at Wickliffe

The mid North group also set up an extra trial at Avon due to local interest in K and S nutrition. The project also supported the Elders representative at Naracoorte in the SE of SA to monitor crop performance at Bool Lagoon in 2023 following the application of K strips in a paddock of wheat. The project provided protocols and plant tests for flowering biomass samples.

Application strategies for K

One small plot trial at Maitland, YP in SA was undertaken in 2022 to investigate the effectiveness of a range of application strategies for correcting K deficiency in wheat. This location was chosen because the YP group had already undertaken a trial in 2021 where strong responses in wheat to K had been recorded. Treatments were replicated four times.

The original intent was to re-sow this trial in 2023 to assess residual benefits of the application strategies but instead, a new trial was set up nearby because crop responses in the 2022 trial were small and it was difficult to separate effectiveness of different application strategies. The contract also required a new application strategy trial to be set up in the SE of SA in 2023 but due to a paucity of K responses in SE trials, these resources were used to fund the extra strip trials mentioned in the previous section.

The application strategy trials consisted of ten treatments which varied in K fertiliser application timing, rate and placement (Table 1). The trials were sown to Scepter wheat on 24 May 2022 or Vixen wheat on 23 May 2023. Basal fertiliser applied across both trials was 100 kg/ha MAP plus Zn. All K fertiliser was applied as MOP except the foliar treatment which was liquid potassium citrate at tillering. Biomass at tillering and flowering as well as grain yield were assessed. Whole shoot levels of K were also measured at both sampling times.

Table 1. Potassium treatments for application strategy trials in 2022 and 2023.

Treatment name	**Timing**	**Rate*** **(kg K/ha)**
Control		0
Banded below seed	At seeding	12.5
Banded below seed	At seeding	25
Banded below seed	At seeding	50

Banded below seed	At seeding	75
Broadcast	Pre-seeding	75
Broadcast	Pre-seeding	150
Broadcast	PSPE	75
Broadcast	Pre-seeding + PSPE	75+75
Foliar	Stem elongation	1.4 (2022) 1.8 (2023)

* *Applied as muriate of potash except for foliar which was potassium citrate*

Communications and extension methodology.

Findings from the project were to be communicated to growers and advisers through visits to trial sites, publication of results in industry-relevant newsletters and events such as GRDC updates and farming systems group workshops.

Trial summaries were to be uploaded onto GRDC's Online Farm Trials (OFT) after approval from GRDC.

Since this project was a pilot study into the possibility of K deficiencies emerging as a new issue for cropping in south-eastern Australia, a high priority was to provide directions and identify gaps in knowledge to inform any future research into the area.

GRDC

LOCATION

Site	Latitude	Longitude	Nearest town
Yorke Peninsula, SA			
Arthurton	-34.258792°	137.755500°	
Maitland	-34.374274°	137.672369°	
Mid North, SA			
Avon	-34.284354°	138.335686°	
Hill River	-33.815203°	138.681869°	
Marrabel	-34.143137°	138.877775°	
Upper South-East, SA			
Coonalpyn	-35.696238°	139.856537°	
Keith	-36.098709°	140.354828°	
Malinong	-35.498153°	139.506390°	
Lower South-East, SA			
Bool Lagoon	-37.144728°	140.713615°	
Kalangadoo	-37.564022°	140.701581°	
Rendelsham	-37.549376°	140.225371°	
Western districts, Vic			
Inverleigh	-38.102670°	144.057658°	
Wickliffe	-37.690990°	142.724594°	

Research	Benefiting GRDC region	Benefitting GRDC agro-ecological zone	
Crop responses in the field Soil testing thresholds Plant testing thresholds	Southern Region Choose an item.	☐ Qld Central ☐ NSW NE/Qld SE ☐ NSW Vic Slopes ☒ Tas Grain ☒ SA Midnorth-Lower Yorke Eyre ☐ WA Northern ☐ WA Eastern ☐ WA Mallee	☐ NSW Central ☐ NSW NW/Qld SW ☒ Vic High Rainfall ☒ SA Vic Mallee ☒ SA Vic Bordertown-Wimmera ☐ WA Central ☐ WA Sandplain

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RESULTS

Responsiveness of crops to K across five sub-regions.

Over the combined years of 2022 and 2023, a total of 19 trials were marked out and sampled for K fertility of the soil to depth using the industry standard soil test for crop-available K, Colwell-K, and for the response of crops to the addition of K to the soil early in the season. These trials were conducted within the five sub-regions nominated by GRDC and the total exceeds the number required by GRDC of 16 (see tables 2 and 3). All trials were conducted on heavier soils, typical of the cropping zones in south-eastern Australia, and in locations where K deficiencies have been previously reported or claimed.

While wheat was the preferred crop for these trials, because it is the major crop for south-eastern Australia and is also a crop for which we have the most information about thresholds for plant and soil testing, other crops are also present in the data set. Wheat was present in 11 of the 19 trials while lentils, beans, canola, and barley were the other crops monitored.

A common feature with all the trials was that Colwell K levels in the top 10 cm were all well above the current industry threshold of 40-50 mg/kg of Colwell K, below which K deficiency is likely to occur in wheat and other broad-acre crops (Brennan and Bell 2013). However, this threshold was largely developed on sandy soils of Western Australia. Colwell K levels deeper in the soil profiles of our sites could be higher or lower than those in the topsoil (see tables 2 and 3). Despite Colwell K levels being very high compared to the industry threshold, the addition of K increased grain yields of crops in 3 trial years at two sites (Maitland on the YP and Marrabel in the mid North of SA). Biomass increases (either early or late) occurred in 6 trial years over 4 sites. In addition to these crop responses which were statistically significant, there were also another 8 trial years, at a further 5 sites, in which the addition of K increased crop performance (biomass or grain yield) by 15% or more. While these increases may have been due to natural variability at the sites, the small scope of these trials meant that only large crop responses could be confirmed by statistics, and smaller (but still important) increases could only be observed as trends. In summary, of the 19 trials managed under this section of the project, crop responses to K (at some stage of their development) were confirmed at 4 sites (Maitland on YP, Marrabel in mid North, Coonalpyn in the upper SE and Kalangadoo in the SE) or 30% of the total number of sites. Surprisingly, few responses to K were recorded in the south-east of SA or the western districts of Victoria, despite many reports coming from these areas of the value of K fertilisers to crop productivity.

Table 2. K reserves in the soil, crop performance and K nutrition in trials conducted in 5 sub-regions of the southern region in 2022. Values in the body of the table are measurements taken without added K and the values in brackets are the % response to added K for that measurement. If the value in brackets is in italics, the % response is not statistically significant.

Location	**Soil Type**	**Crop**	**Colwell K in 0-10 cm, mg/kg**	**Colwell K in subsoil, mg/kg**	**Est, plants per sq m**	**Early shoot DM, kg/ha**	**Early shoot K, %**	**Late shoot DM, kg/ha**	**Late shoot K, %**	**Grain yield, t/ha**
York Peninsula										
Arthurton	Calcarosol	Lentils	200	43	Not taken	0.93 *(-8%)*	2.2 (32%)	3.0 *(15%)*	1.9 (32%)	3.8 *(16%)*
Maitland	Calcarosol	Wheat	98	32		0.72 (74%)	2.4 (63%)	6.7 (41%)	0.9 (71%)	5.4 (37%)
Mid North										
Avon	Calcarosol	conducted in 2023 only								
Hill River	Sodosol	Beans	130	170	27 *(11%)*	0.37 *(9%)*	1.3 (85%)	4.6 *(20%)*	1.7 (50%)	10.2 *(9%)*
Marrabel	Sodosol	Beans	270	130	26 *(0%)*	0.49 *(2%)*	3.6 *(9%)*	5.3 *(4%)*	3.5 *(7%)*	3.7 (45%)
Upper South-East										
Coonalpyn	Calcarosol	conducted in 2023 only								
Keith	Calcarosol	Wheat	350	220	149 *(0%)*	1.90 *(4%)*	3.4 *(-1%)*	8.1 *(-11%)*	Not taken	6.3 *(-1%)*
Malinong	Calcarosol	Wheat	130	-	202 *(2%)*	0.97 (2%)	4.0 (7%)	4.8 *(8%)*	1.9 *(7%)*	4.1 *(-4%)*
South-East										
Bool Lagoon	Vertosol	conducted in 2023 only								
Kalangadoo	Calcarosol	Wheat	99	260	119 *(0%)*	0.65 *(5%)*	3.7 *(8%)*	3.8 (18%)	2.7 *(7%)*	5.9 *(5%)*
Rendelsham	Calcarosol	Wheat	110	31	144 *(-2%)*	0.73 *(16%)*	6.0 *(7%)*	9.8 *(2%)*	2.8 *(17%)*	7.8 *(2%)*
Western Districts										
Inverleigh	Sodosol	Wheat	297	178	Not taken	2.2 *(8%)*	Not taken	12.5 *(10%)*	1.7 *(-4%)*	5.8 *(0%)*
Wickliffe	Sodosol	conducted in 2023 only								

Table 3. K reserves in the soil, crop performance and K nutrition in trials conducted in 5 sub-regions of the southern region in 2023. Values in the body of the table are measurements taken without added K and the values in brackets are the % response to added K for that measurement. If the value in brackets is in italics, the % response is not statistically significant. For Colwell K, values in bold are from soil samples taken prior to seeding in 2023, the rest were values obtained in the previous year.

Location	Soil Type	Crop	Colwell K in 0-10 cm, mg/kg	Colwell K in subsoil, mg/kg	Est, plants per sq m	Early shoot DM, kg/ha	Early shoot K, %	Late shoot DM, kg/ha	Late shoot K, %	Grain yield, t/ha
York Peninsula										
Arthurton	Calcarosol	Wheat	200	43	Not taken	0.73 *(13%)*	Not taken	6.4 *(5%)*	1.0 *(20%)*	4.6 *(-1%)*
Maitland	Calcarosol	Lentils	98	32		0.86 (73%)	0.77 (91%)	2.3 (100%)	0.5 (76%)	1.9 (29%)
Mid North										
Avon	Calcarosol	Wheat	**98**	**470**	Not taken	0.40 *(17%)*	3.5 *(-16%)*	2.5 *(2%)*	1.6 *(-1%)*	2.2 *(21%)*
Hill River	Sodosol	Wheat	**150**	**530**		1.72 *(6%)*	2.7 (42%)	6.1 *(13%)*	1.4 *(4%)*	3.6 *(3%)*
Marrabel	Sodosol	Canola	**303**	130		1.19 *(13%)*	5.2 *(2%)*	8.1 *(-5%)*	3.7 *(-7%)*	Not taken
Upper South-East										
Coonalpyn	Calcarosol	Canola	**280**	**130**	52 *(-6%)*	Not taken		0.6 (22%)	3.3 *(11%)*	2.8 *(0%)*
Keith	Calcarosol	Not conducted in 2023								
Malinong	Calcarosol	Not conducted in 2023								
South-East										
Bool Lagoon	Vertosol	Wheat	**150**	**160**	Not taken			1.1 *(-6%)*	2.8 *(-11%)*	Not taken
Kalangadoo	Calcarosol	Wheat	99	260	168 (-1%)	0.83 (31%)	3.5 *(-2%)*	7.4 *(10%)*	1.72 *(-3%)*	Not taken
Rendelsham	Calcarosol	Canola	110	31	15 (20%)	2.77 *(-5%)*	3.9 *(14%)*	Too difficult to sample		4.7 *(-2%)*
Western Districts										
Inverleigh	Sodosol	Not conducted in 2023								
Wickliffe	Sodosol	Barley	**243**	**190**	186 (-2%)	2.28 *(-1%)*	3.4 *(9%)*	5.3 *(14%)*	Not taken	2.8 *(16%)*

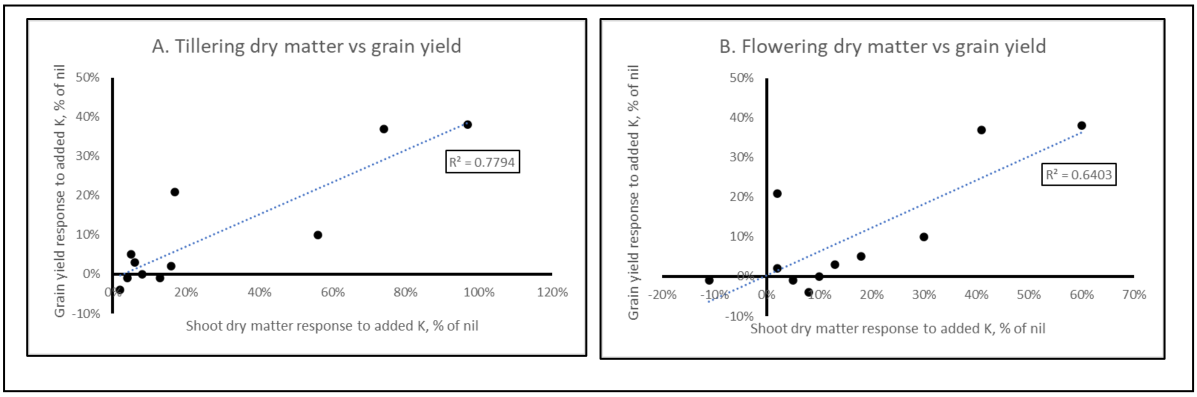
Responses to K were confirmed in 4 of the 5 crops present in the trials (wheat, canola, lentils and beans). However, the largest and most visual responses (in terms of percentage increases) were recorded with wheat and lentils at Maitland on YP. In 2022, wheat grain yields increased by nearly 2 t/ha with the addition of K and in the following year, lentil grain yields increased by more than 0.5 t/ha. Despite these large increases in dry matter during the season and in grain yield, characteristic symptoms were difficult to identify. Crops lacked vigour without added K but there was little evidence of other symptoms which were unique to K deficiency (see photo 1).

Photo 1. Early response in wheat to added K at Maitland in 2022.

Although not all trials were managed for both of the growing seasons of the project and only Maitland produced large crop responses in both years, there were two examples of the application of K providing crop benefits in the year after application; Maitland and Kalangadoo.

YP trial managers had observed that when wheat showed early signs of K deficiency (reduced crop vigour and poorer colour) then generally grain yield losses were also likely to occur. Comparison of dry matter responses in wheat in this data set support those observations. Figure 1 shows that the relationships between responses in dry matter to the addition of K and responses in grain yield at maturity are quite clear (R^2 of 0.78 for shoot dry matter at tillering and grain yield, R^2 of 0.64 for flowering dry matter and grain yield).

Figure 1. Relationships between responses to K in shoot dry matter and responses in grain yield. Data is only for wheat trials but includes data from the results section which follows, “Application strategies for K”. Dotted lines are linear regression derived lines of best fit. A - Shoot dry matter at tillering vs grain yield . B – Flowering dry matter vs grain yield.



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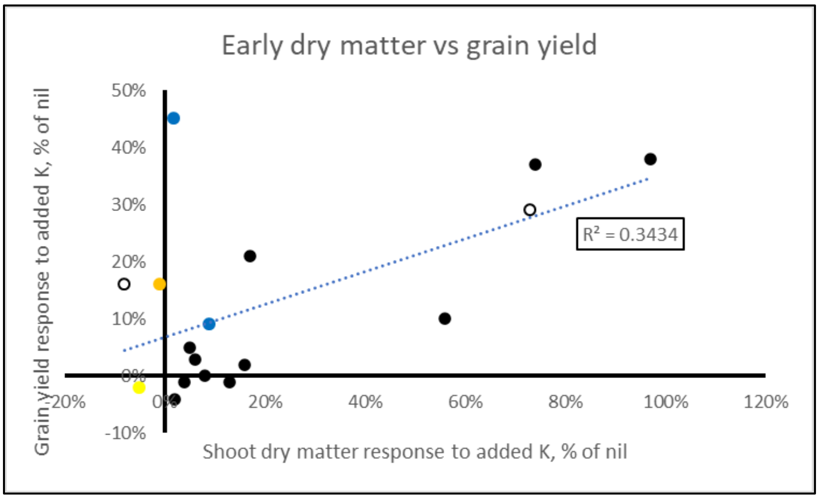
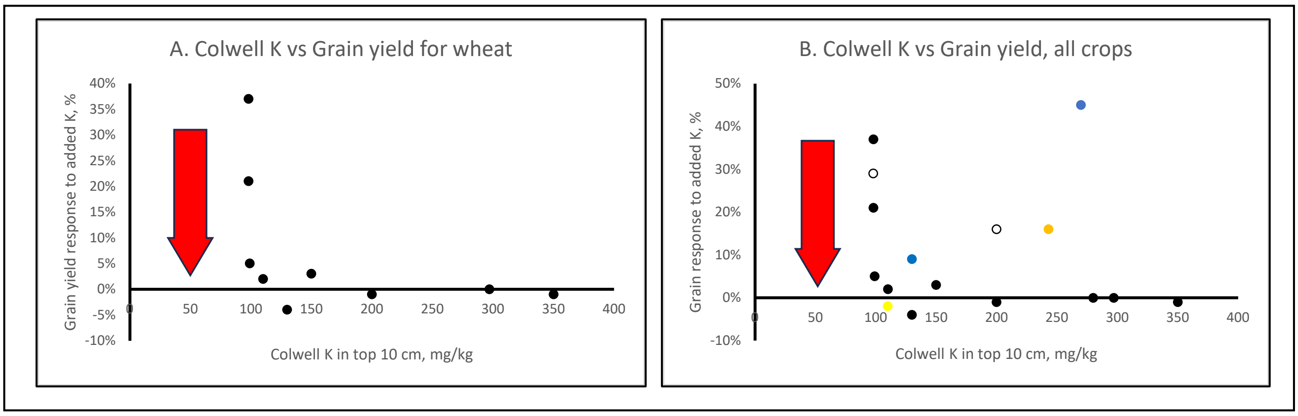
This suggests that if K deficiency in wheat is detected early in the growing season, corrective treatments are likely to improve grain yield. Equally, if there is no sign of K deficiency early in the growing season, grain yield is unlikely to be at risk. However, if break crops are included in these comparisons (canola, beans, lentils) the relationships between shoot responses to K and responses in grain yield are far less clear (see figure 2 for the relationship between K responses in early dry matter and responses to K in grain yield). Perhaps the effects of K deficiency on early growth of broad-leafed crops and the consequent impacts on grain yield are different to wheat.

Figure 2. Relationship between responses to K in early shoot dry matter and responses in grain yield. Data is for all crops and includes data from the results section which follows, "Application strategies for K". Dotted line is a linear regression derived line of best fit. Black circles - wheat; blue – beans, mustard – barley, yellow – canola, hollow – lentils.



While this data set is too small to develop a calibration curve for crop performance against Colwell K, from which a threshold value could be estimated, it can be used to compare crop responses against the current industry threshold of 40-50 mg Colwell K/kg in the top 10 cm of soil (Brennan and Bell 2013). Figure 3A shows this relationship for the wheat trials, including data from the following results section. All sites were chosen on previous reports or claims that K deficiency had occurred at the location, or in the area. Sites were not chosen based on their Colwell K values but this was assessed for all trials prior to seeding. All sites had Colwell K values in the top 10 cm of soil well above the current industry threshold but large responses in grain yield still occurred at Colwell K values double the current threshold, although no grain yield responses were recorded above 200 mg/kg of Colwell K. These results suggest that the current industry threshold for Colwell K (largely based on sands) is not appropriate, and too low, for these heavier soils of south-eastern Australia. This relationship is less clear when all crops were plotted against topsoil Colwell K values prior to seeding (figure 3B), another suggestion that break crops are behaving differently to wheat in response to added K and soil reserves of K.

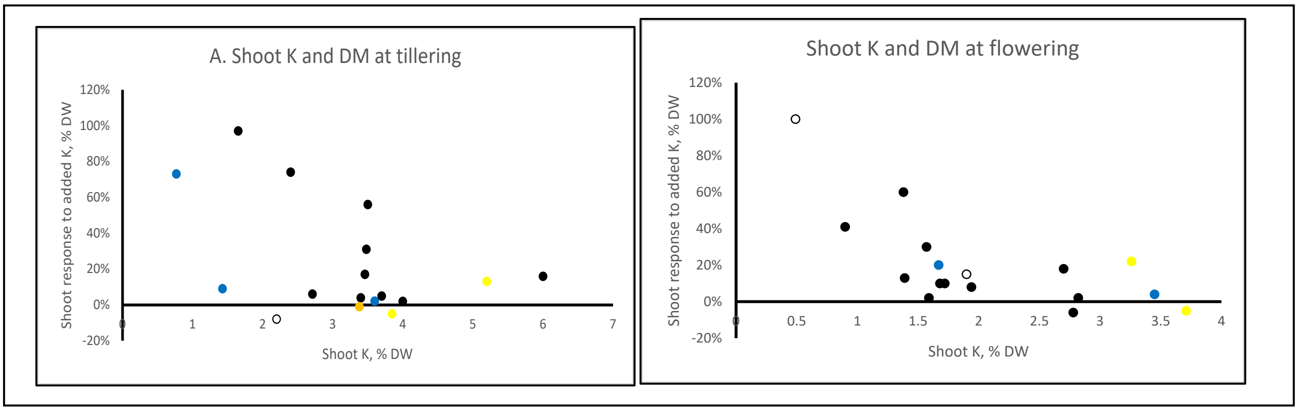
Figure 3. Relationships between grain yield responses to K and Colwell K in the top 10 cm of the soil profile prior to seeding. A Wheat only . B – All crops. Black circles - wheat; blue –



beans, mustard – barley, yellow – canola, hollow – lentils.

Using a similar approach, the relationship between whole shoot concentrations of K and dry matter response at the time of sampling (tillering and flowering) were compared (see figure 4). The current industry thresholds for whole shoot K are 3-4% at tillering and 1.5-2% for crops at flowering (Reuter, Edwards and Wilhelm 1997). In the data set here, little or no dry matter responses were recorded at tissue concentrations of K above the industry thresholds at those respective growth stages, which suggests that the current thresholds are valid for current crops in modern farming systems.

Figure 4. Relationships between dry matter responses to K and whole shoot concentrations of K at the time of sampling. A Tillering. B – Flowering. Black circles - wheat; blue – beans, mustard – barley, yellow – canola, hollow – lentils.



Application strategies for K

Soil reserves of K were high compared to the current industry threshold of 50 mg Colwell K/kg in the top 10 cm. Topsoil Colwell K at the 2022 site was 175 mg/kg and was 138 mg/kg at the 2023 site. Colwell K levels decrease with depth in this soil type which has a loam topsoil transitioning to a clay loam or sandy loam below 10 cm.

Applying K to soil at Maitland in 2022 improved crop growth throughout the season (Table 2) but banding K at seeding was more effective than broadcasting. Biomass increased with K banded at seeding for all rates from 12.5 to 75 kg K/ha. However, broadcasting K pre-seeding or in combination with PSPE did not improve biomass compared to the control, except at the highest rate of K, 150 kg K/ha. Shoot K at tillering only increased with 50 and 75 kg K/ha banded at seeding, not with broadcast K (table 2).

Later in the season (GS60) crop biomass was similar for all K strategies (Table 2). Shoot K ranged from 1.6 – 2.0% with minor differences between the treatments.

Wheat grain yield across the trial averaged 7.22 t/ha. There were only two treatments which improved grain yield compared to the control, the high rates of K (50 and 75 kg K/ha) banded at seeding. These two treatments also showed increased biomass, shoot K and K uptake early in the season which translated to a grain yield response of approximately 0.5 t/ha (or 9%). All other K treatments were not different to the control. This indicates broadcasting and foliar application of K were not effective K application strategies. This is consistent with previous field trials in SA which have shown banding K below the seed was more productive than topdressing or pre-spreading (Wilhelm and White 2004).

In 2023 a new trial site was established with the same grower at Maitland to evaluate the same K fertiliser strategies. Similar to the previous season, 50 and 75 kg K/ha banded at seeding increased biomass, shoot K and grain yield (Table 3). However, at this site and season there were also several other K strategies which performed well. Later in the season biomass and grain yield were also high in the 25 kg K/ha banded at seeding and the 150 kg K/ha broadcast split timing (pre-seeding + PSPE). The only treatment which did not improve grain yield compared to the control was the foliar application. The largest grain yield increase was 1.4 t/ha (or 39%) with the highest rate of banded K.

The larger crop response with added K in 2023 was likely related to the lower starting Colwell K (138 mg K/kg in 0-10 cm) compared to the previous trial site (175 mg K/kg).

Table 4. Wheat biomass, shoot K and grain yield for Maitland K application strategy trial in 2022.

Treatment	Timing	Rate kg K/ha	Biomass kg/ha	Shoot K %	Biomass kg/ha	Shoot K %	Grain yield t/ha
			First node		Flowering		
Control		0	514 e	3.0 c	6691	1.7 bc	7.03 cd
Banded below seed	At seeding	12.5	778 bc	2.8 c	7785	1.7 bc	7.32 abc
		25	814 ab	3.6 bc	7650	1.7 bc	7.21 bcd
		50	821 ab	5.1 a	7654	1.8 bc	7.42 ab
		75	965 a	4.3 ab	7975	1.7 bc	7.61 a
Broadcast	Pre-seeding	75	616 cde	2.9 c	7066	1.6 c	7.02 d
		150	725 bcd	3.6 bc	7648	1.9 ab	7.22 bcd
	PSPE	75	520 e	3.2 bc	6552	1.9 ab	7.26 bcd
	Pre-seeding + PSPE	75+75	590 de	3.8 bc	6787	2.0 a	7.06 cd
Foliar	First node*	1.4	704 bcd	2.5 c	6862	1.6 c	7.03 cd
		Pr(>F)	0.002	0.011	0.551	0.009	0.02
		LSD 0.05	180	1.3	ns	0.240	0.299

**Note foliar application of K was only applied after biomass and shoot K assessment at first node.*

Table 5. Wheat biomass, shoot K and grain yield for Maitland K application strategy trial in 2023.

Treatment	Timing	Rate kg K/ha	Biomass kg/ha	Shoot K %	Biomass kg/ha	Shoot K %	Grain yield t/ha
			First node		Flowering		
Control		0	334 cd	1.7 ab	3830 de	1.4 bcd	3.59 e
Banded below seed	At seeding	12.5	555 a	2.0 abc	4450 bcd	1.1 e	4.24 bcd
		25	550 ab	2.3 bc	5330 ab	1.3 cde	4.58 abc
		50	658 a	3.2 d	6110 a	1.5 abc	4.63 ab
		75	587 a	3.5 d	5960 a	1.5 bcd	4.96 a
Broadcast	Pre-seeding	75	279 d	1.5 a	4250 cd	1.4 bcd	4.31 bcd
		150	367 cd	1.9 abc	4130 cd	1.2 de	4.17 cd
	PSPE	75	415 c	1.9 abc	4920 bcd	1.6 ab	4.08 d
	Pre-seeding + PSPE	75+75	421 bc	2.4 c	5220 ab	1.8 a	4.60 abc
Foliar	First node	1.4	245 d	1.3 a	3210 e	1.1 e	3.30 e
		Pr(>F)	<0.001	<0.001	<0.001	<0.001	<0.001
		LSD 0.05	134	0.4	0.92	0.3	0.45

**Note foliar application of K was only applied after biomass and shoot K assessment at first node.*

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Communications and extension methodology.

A wide range of activities were undertaken by team members during the conduct of this project. These activities raised awareness about the project and the possibility of K deficiency being a new issue for cropping in south-eastern Australia. Collectively, these activities informed many farmers and advisers across south-eastern Australia and the team is confident that the contracted target of at least 60 growers being able to economically assess the best practice application to remediate K deficiencies and manage K levels long term to avoid future deficiency has been met and surpassed.

A summary of the interim findings from the project was presented to advisers and researchers at the GRDC Grains Research Update in Adelaide, 2023 by Dr Wilhelm, and a paper lodged on the GRDC website as part of the Update programme (Wilhelm et al 2023). This activity probably had the widest coverage into the cropping industry with more than 70 advisers and researchers present in the audience.

A video and audio podcast were produced with support from GRDC communications using the Maitland applications strategy trial, in spring 2022, as background to highlight the risks of K deficiency and how to detect it reliably (Trengove and Wilhelm, 2023).

Several updates on trial activities in the western districts of Vic were published in the e-newsletter of Southern Farming Systems. Interim findings of the project were also presented to the HyperYielding Cropping Innovators Groups in March 2023 at Hatherleigh and Coonawarra (a total of 33 growers and advisers). The possibility of K deficiency in cropping on the YP was presented to approx. 30 growers and advisers at Arthurton on YP in autumn of 2023. This meeting was organised by Nutrien Ag. Dr Wilhelm discussed K deficiency to a group of young famers (5 present) in the upper SE of SA in spring of 2022. A trial was subsequently placed in their district in 2023, at Coonalpyn. Dr Wilhelm also contributed results and experiences with K deficiency in south-eastern Australia to the organiser of technical updates for the national team of Nutrien Ag advisers. This material was incorporated into 3 webinars (delivered by researchers from QLD, NSW and WA) presented to that national team over late 2023 and early 2024 (approx. 30 advisers present for each webinar).

While the project did not organise visits to field trials which were not showing clear responses to K, several visits to the Maitland trials were hosted in the spring of 2022. During these visits, issues of detecting K deficiency reliably were discussed as well as options for correcting the deficiency. A total of 33 farmers and advisers participated in these visits.

The project team has been in contact with Federation University with the aim of uploading project results and findings onto the Online Farms Trial Database (OFTD). A file summarising the project trials with interim data has been lodged with them. However, updating results and outcomes has stalled as Federation University negotiated a new contract for ongoing management of the database. Lodgement of the final technical report onto the OFTD will occur once it is accepted by GRDC.

DISCUSSION OF RESULTS

This pilot study into K deficiency in crops growing on heavier soils of south-eastern Australia has confirmed that prior reports of the productivity of crops in these areas improving with additions of K fertilisers are indicating an emerging issue for the cropping industry in this region. Thirty percent of the trials conducted in this project recorded a response in biomass or grain yield to added K which proves that K deficiency does exist in this region but also suggests that it is not yet widespread. Only 5 out of a total of 21 trials recorded grain yield increases and 4 of these were at one location on the YP. Responses in biomass, either early in the season or at flowering, were more common and more widespread. Responses to K were recorded in a range of crop types, although wheat was the most common crop grown in the trials. A similar situation is emerging in cropping on the heavier soils of WA (Bell et 2023).

Current pricing of muriate of potash (the most common fertiliser used for correcting K deficiency in broad-acre crops) is approximately $750/tonne. If 100 kg/ha of MOP were necessary to correct a severe problem (as suggested by trials reported here), then a grain yield increase in wheat (at $350/t) of less than 0. 25 t/ha would cover the cost of the application in that year, ignoring any carry-over benefits of that application (which were recorded in trials reported here). The largest grain yield increase recorded in this project was 2 t/ha of wheat, which suggests that treating severe K deficiencies is likely to be very profitable in south-eastern Australia.

Investigations into application strategies for treating K deficiency in modern cropping systems revealed that banding K in the seeding operation was more effective at alleviating K deficiency in wheat than broadcasting either before or after seeding. Early foliar application of K was not effective. Similar results were recorded in a study conducted in SA about 20 years ago (Wilhelm and White 2004). Rates of K required to alleviate K deficiency in these trials were much higher than those typically used in WA currently to manage K nutrition (Bell et al 2023).

Soil and plant testing are robust tools for detecting a wide range of nutritional disorders. This project investigated the validity of current threshold values for both Colwell K (the industry standard soil test for cropping in southern Australia) and K analysis of whole shoots as diagnostic tools. While the dataset generated by this project was quite small, it suggested that the current threshold for Colwell K is too low for the heavier soils of south-eastern Australia. This has meant that the extent and severity of K deficiencies in cropping in this region has been under-estimated by commercial soil testing. Comparison of shoot K concentrations and dry matter responses at the time of sampling suggest that current thresholds for plant testing are valid for crops in modern farming systems. Until the Colwell K soil test is re-calibrated for heavier soils of southern Australia, plant testing is a more reliable tool for detecting K deficiency in crops. Visual diagnosis of K deficiency in field crops was not reliable, even where large responses to added K were recorded.

While wheat was the most common crop in the trials reported here, and hence it was easiest to establish patterns with this crop in terms of the value of current thresholds for soil and plant testing, broad-leaved crops (canola, beans or lentils) appeared to behave differently to wheat for soil testing. Responses to added K in these break crops sometimes occurred at Colwell K values much higher than where responses in wheat were likely but this may have been due to different crops being grown in different locations and in different years.

CONCLUSION and IMPLICATIONS

While this pilot study did not include an extensive survey of the issue (so we can not be certain about the true extent of K deficiency), it did find that K deficiency is present in cropping on heavier soils of south-eastern Australia. It also found that K deficiency can cause substantial losses in productivity in a range of crops when it occurs and that it may not yet be a widespread problem. However, it is reasonable to predict that its extent and severity will increase in the future because K is exported from farms in commodities and without additions of K, soil reserves of K can only decline with time (Ma et al 2022). More attention to this disorder is warranted for cropping in south-eastern Australia, including more research into detecting and managing K deficiency in current farming systems.

This project has identified several gaps in knowledge which currently make detection of the problem unreliable and its correction not fully effective or at minimised cost. These gaps and opportunities are:

7. The extent and severity of K deficiency in crops growing on heavier soils of south-eastern Australia is uncertain but likely to be increasing. A more thorough assessment of how widespread and severe the problem is currently across the cropping zone of se Australia would scope the size of the issue more accurately. A range of soil types were present in the trials reported here but not frequently enough to establish whether K deficiency was more likely on some than others. Identifying which soil types are more prone to the problem would help management of K deficiency.
8. The current thresholds for the Colwell K soil test are not appropriate for the heavier soils of se Australia. A high priority would be to develop robust thresholds for this region. These studies could include assessments of other soil testing approaches which might be more suitable for cropping heavier soils in this region.
9. Broad-leaved crops behaved differently to wheat in this study. More knowledge about the relative sensitivities of crop types to K deficiency would be useful, especially with respect to thresholds for different crops in the Colwell K soil test.
10. Subsoil levels of Colwell K vary widely in the heavier soils of se Australia. Their impact on K deficiency and its management need to be defined. This information needs to be incorporated into interpretations of soil testing for K reserves.
11. Banding of MOP was far more effective at correcting a severe K deficiency than broadcasting and foliar K was not effective but there are still large gaps in our knowledge on how to correct K deficiency cost-effectively in modern farming systems.
    a. Are sources of K other than MOP competitive in effectiveness and cost ?
    b. Will changing timing and sources of K improve the effectiveness of foliar applications. ?
    c. How much K can be applied with the seed on heavier soils without reducing emergence ? Does the type of seeder affect these rates ?
    d. What is the residual benefit of soil-applied K ?
    e. Do different crops respond the same to applications of K ?

12. On heavy soils, where K deficiencies may be exacerbated by slow cycling between pools and/or slow movement of K in soil solution, investigating the role of soil microbiology in K nutrition would be valuable.
13. The relationship between in-season growth and grain yield was less clear for break crops than it was for wheat. Better understanding of the impact of K deficiency early in the season on the grain yield of break crops would be useful.

GLOSSARY AND ACRONYMS

se	south-eastern
MOP	muriate of potash
YP	Yorke Peninsula of SA

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