FINAL REPORT

UMU00042

MPCN II -13 Managing Potassium Nutrition to Alleviate Crop Stress

PROJECT DETAILS

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Summary

At low soil-test potassium (K) levels, this project found K supply increased wheat yields at one site with a long, mid-season dry spell, but not at two sites with regular rainfall over the season. On a moderately saline and low K soil, K supply reduced sodium (Na) uptake, but had relatively small effect on grain yields, indicating possible partial K substitution by Na. Under severe frosts in 2012, K supply increased viable tillers, seeds per spikelet and grain yields, despite adequate soil K levels (> 80mg/K/kg). In 2013 and 2014, however, few and mild frost events occurred from booting to grain fill and frost induced sterility (FIS) was too low to draw any firm conclusion about the effects of K treatments.

Conclusions

Unlike soils in many other regions, soils of south west Australia generally contain negligible reserves of non-exchangeable K, which can act as a buffer for soil K stocks and minimise the onset of K deficiency. Many growers in the western grains region are applying 15-25kgKCl/ha, which barely supplies enough K to replace removal in 2t grain/ha. With grain yields of 3-5t/ha, fertiliser rates should be 30-50kgKCl/ha to replace losses in grain. This project found K deficiency suppressed tiller development and lowered shoot dry weight, leaf photosynthesis and transpiration efficiency in wheat (Ma et al. 2013). Low-K plants also had lower root-to-shoot ratios than adequate-K plants. K fertiliser enhanced grain yields by increasing ear numbers, single seed weight and harvest index. The poor adaptation of root growth to soil K deficiency may impair the plant's ability for water and nutrient acquisition, especially in water-limited environments. Field experiments have demonstrated that soil K supply increased wheat yields at the trial site with a long mid-season dry spell, but had no effect at two sites with regular rainfall over the season (Ma et al. 2015). In another field experiment with drought, K-efficient wheat variety Carnamah showed less response to K supply than the K-inefficient varieties, Wyalkatchem⌽ and Bonnie Rock⌽: in the latter K-inefficient varieties, grain yield responded to 40kgK/ha - with further yield increases at 120kgK/ha. In the relatively wet years of 2013 and 2014, however, the increase in grain yield by K supply was similar between the supply of 40 or 120kgK/ha. The project also found a negative yield effect using rainout shelters (in mid to late September) only under nil K supply. These findings suggest a positive role of K nutrition in plant adaptation to soil water deficits.

Although there is good evidence that high K levels in tissue protect it from damage during frost events (Romheld and Kirkby 2010), the potential for protection of crops against frost damage by increased K supply has not been explored for crops in the western region, where up to 50% of soils are low in K. In this study, an experiment at Tincurrin in 2012 found K supply increased viable tillers, seeds per spikelet and grain yields under severe frosts, despite apparently adequate soil K levels (> 80mgK/kg). In 2013 and 2014, however, regular rainfall occurred at the growth stages from booting to grain fill and frost events were few and mild at the critical stages across the sites. FIS in 2014 was 8% in the control and 6% with soil K supply and foliar spray of K, copper (Cu) and boron (B). The treatments increased the concentrations of top-leaf K from 13 to 18mg/g, as well as increasing Cu and B, with an increase in grain yields of 0.3-0.4t/ha. The overall levels of FIS in 2013 and 2014 were too low to draw any firm conclusions about the protective role of K, or other nutrients, against frost damage. More work is needed to test the capacity for increased K supply to alleviate abiotic stress in a year with less rainfall and/or more severe frosts.

Recommendations

Frost and K

In 2013 and 2014, FIS was too low to draw any firm conclusions about the effect of K treatments. More work using a different approach (multiple sowing dates and two varieties) is underway (in Project UMU00045 under the GRDC's National Frost Initiative (NFI)) to test the role of K nutrition on frost. Other nutrients may play a protective role against frost damage (e.g. molybdenum (Mb), B, Cu, manganese (Mn), zinc (Zn)) and the role of these nutrients is also being examined in 2015. Another approach would be to carry out glasshouse experiments in a location that always experiences frost. At critical stages of crop development, glasshouse-grown plants with a range of nutrient levels could be exposed to short episodes of frost.

Drought and K
Results from this project are indicative of a beneficial role of K in decreasing drought stress in wheat - but the results are not definitive. In successive seasons (2013 and 2014), rainout shelters decreased soil water levels significantly when applied before and after anthesis. But the mid to late spring rainfall ensured soil water was not limiting. An alternative approach to this research would be to work at a lower rainfall site with low K and irrigation water available. With the irrigated treatment as the control, either seasonal drought or rainout shelters could be used to test the effect of K on water stress.

Subsoil K
In general, from the field experiments, the prediction of K fertiliser response was improved by sampling to 30cm depth, rather than 10cm depth. Recommendations for soil K testing need to progressively move towards 0-30cm sampling depth. In the duplex soils, sub-soil K levels are very variable. In general, subsoils of deep sands and deep sandy duplex profiles sampled from the Albany and Esperance sandplains, around the Stirling range and the south-east ancient drainage, have extractable K levels near the critical values. Those in the eastern Darling range, south-west ancient drainage and northern and southern rejuvenated drainages are mostly at deficient levels. In the grey deep sandy duplex soil group (representing 1.5 million hectares of WA) and deep sands (2.4 million ha of WA), low soil K coincides with moderate Na levels and Na alleviation of K deficiency is most likely. By contrast, the grey shallow sandy duplex soils generally had high sub-soil Na levels. In these profiles, adequate K may play a role in decreasing the harmful effects on plants of excessive soil Na.

Rate and timing of K application
Applying 40kgKCl/ha was generally effective to increase grain yields in wheat and barley on low-K soils. In some cases, under drought stress, K inefficient varieties of wheat responded to higher K rates. Many growers are applying 15-25kgKCl/ha, which barely supplies enough K to replace removal in 2t of grain/ha. When crops are yielding 3-5t/ha, fertiliser rates should be 30-50kgKCl/ha to replace removal of K in grain. To increase crop resilience to stress, and to compensate for K leaching, higher K rates may be required. The occurrence of K uptake mostly during the vegetative growth and substantial K redistribution at the reproductive stage in cereals suggests the benefit of early K fertilisation. Early K fertilisation (at sowing or five weeks after sowing) should also avert losses in tiller numbers, which is a major effect of K deficiency in cereals (Ma et al. 2011).

Outcomes

Economic Outcomes
Depending on crop species grown, currently 7-50% of soils in the western region are deficient in K (Weaver and Wong, 2011). The expansion of areas causing K deficiency in crops is attributed to continual depletion of soil K reserves in harvested products and inadequate replacement of fertiliser K. Depletion is exacerbated by rising grain yields and leaching of K. Soil K availability may also be limited by the stratification of K near the soil surface under minimum tillage systems and by extended dry spells in the growing season.

In three years, nine out of 11 field experiments were conducted at K-deficient sites (30-40mgK/kg at 0-30cm). Applying 20kgK/ha increased grain yields by 0.4-0.5t/ha under drought, but not at non-stressed sites. Under drought, yields increased further with increasing K supply to 120kg/ha in K inefficient varieties. In the relatively wet seasons of 2013 and 2014, applying 40kgK/ha increased grain yields by 0.5-0.6t/ha but higher K supply had no significant effect. Under severe frost events, K supply increased viable tillers, seeds per spikelet and grain yields, even at an apparently adequate-K site.

The findings suggest high K plants may have greater resilience to abiotic stresses and that adequate K supply will reduce risks of crop losses from drought or frost. Given predictions of increased frost risks and greater climate variability, K fertiliser may be a tool for decreasing the risk of crop losses. However, from anecdotal information, most growers are barely replacing K removal in grain with the rates of K applied and there is no obvious strategy to boost soil K levels.

This project also found with moderate salinity, there is a possibility of partial K substitution by Na on low-K soils (i.e. Na may reduce plant demand for K). From the research completed in Project UMU00035, it was identified that the deep sandy duplex soil profiles with low soil K and exchangeable Na levels between 0.1 and 0.4cmol/kg as the most likely soils on which Na substitution of K is able to alleviate K deficiency. The management of K fertilisation on saline and sodic soils needs to consider not only soil K status and crop requirements, but also soil Na status and genotypic variation in the uptake and use of K and Na.

Environmental Outcomes
In K-deficient soils, the reduction in plant growth is greater in roots than shoots of wheat and barley (Ma et al. 2013). The favouring of shoot growth at the expense of roots may render the low-K plants more vulnerable to drought and salinity. Alleviation of K deficiency by K supply increases the root/shoot ratio and will lead to greater nutrient use efficiency, which should in turn reduce losses of N and P by leaching off the farms.

Social Outcomes
No specific social benefits identified

Achievements/Benefits

Glasshouse experiments
This project has advanced understanding of the dynamic uptake and use of K over the growth cycle and the critical role of K in root growth in wheat (Ma et al. 2013) - and the effects of K supply on wheat, barley and canola under drought and salinity conditions.
In a K response pot experiment, decreased shoot growth in wheat by K deficiency was best explained by reduced tiller numbers and rate of tiller development. Adequate K supply enhanced grain yields by increasing ear numbers, single grain weight and harvest index. Shoot K uptake was completed by about anthesis on a sandy soil and thereafter K retranslocation supplied K to grains.

Unlike N and P deficiency that increase root/shoot ratio, K deficiency decreased root/shoot ratio, which may impair the plant's ability for nutrient uptake - especially under drought. In a column experiment, soil K supply was 40, 100 and 160mgK/kg, representing deficient, adequate and luxury levels, respectively. A drying cycle of four weeks was applied at three stages: seedling to tillering, elongation to booting or anthesis to early seed fill. Soil drying lowered shoot growth, especially at low K supply. The reduction of root/shoot ratio by low K was more significant under drought.

Leaf photosynthesis was suppressed by low K and soil drying and increased by adequate and luxury K supply, but at a similar scale. There was visual evidence of alleviated drought effect (wilted appearance of leaves) in luxury K plants compared with adequate K plants. Low K caused a decrease in ear numbers and late drying reduced single grain weight. Yield components in the adequate and luxury K plants were largely the same under drought.

In a separate experiment, wheat plants with 40, 100 and 160mg K/kg were treated with 0, 50, 100 and 200mgNa/kg. The luxury K plants had higher shoot K concentration than the adequate K plants, but the two treatments had similar shoot Na concentration, shoot dry weight and yield components across the Na levels. The findings indicate that adequate K plays a vital role in plant adaptation to drought and salinity, but higher than adequate K may not provide extra protection from the two stresses. It was also found that 50mgNa/kg soil increased shoot K concentration, shoot and root dry weight and grain yields of low K plants in wheat and 100mgNa/kg eliminated K deficiency symptoms and increased plant growth and yield in barley and canola at low K supply, indicating at least partial K substitution by Na.

Under no-till farming systems, nutrient stratification in the dry topsoil impairs nutrient uptake by plants and deep placement is likely to increase the availability of soil nutrients. In a column experiment, fertiliser K was banded at 0-10cm or 30-40cm depth, or uniformly mixed as the control. Plant responses were compared between wheat genotypes differing in K use efficiency. Wheat variety Wyalkatchem showed greater response in growth to K banding than the variety Gutha (K-inefficient). Root proliferation was not evident at the banding layers, but Wyalkatchem wheat had higher root/shoot ratio and shoot K concentration than Gutha wheat. A genotype with higher root/shoot ratio is likely to be more resistant to drought stress than one with a smaller root system, which was tested in separate experiments with transient drought and recovery treatments. Wyalkatchem is K-efficient, especially in root growth under well-watered conditions, but with similar K-use efficiency to Gutha under soil drying. It was found that foliar K had little effect on shoot growth, but increased root growth by 50% in both varieties, indicating the role of K in supplying photosynthates from leaves to meet the demand of root growth.

Field experiments

Soil K supply and drought

A series of field experiments were conducted to determine the effects of K nutrition on alleviation of drought stress in wheat. At a low rainfall and low K (30mgK/kg) site near Meckering in 2012, a trial examined wheat varieties Bonnie Rock$^{\phi}$, Wyalkatchem and Carnamah with nil, 40 and 120kgK/ha supply and two sowing dates that altered the exposure to drought stress. The order of K efficiency was Bonnie Rock < Wyalkatchem < Carnamah.The season had a long dry spell from July to October, with total rainfall of 75mm. The first sowing in mid-June showed good yield response to 40kgK/ha, with further yield increases at 120kgK/ha in Bonnie Rock and Wyalkatchem, but not in Carnamah. However, there were no effects of K rate and genotype for the second sowing in mid-July due to dry sowing, poor seedling establishment and low yield potential.

Field experiments with four K rates (nil, 20, 40 and 80kgK/ha) and four application times (zero, five, 10 and 15 weeks after sowing) were also conducted in the central and southern grainbelt. The trial found the lack of plant response to K supply at the sites of Bolgart (36mgK/kg at 0-30cm) and Borden (25mgK/kg at 0-30cm), compared with significant gain in K uptake, dry matter and grain yield at Dowerin (29mgK/kg at 0-30cm), was not explained by differences in soil K levels (Ma et al. 2015). In contrast to regular rainfall over the season at Bolgart and Borden, there was a dry spell of less than 30 mm total rainfall from mid-August to mid-October at Dowerin.

The effectiveness of K application time followed the order of 0, 5, > 10 and > 15 weeks after sowing. Findings from this project suggest that more K may be required for optimal growth and grain yields in wheat under drought, than non water-stressed conditions, with increased effectiveness by early K supply.

In the 2013 season, an experiment with nil, 40 and 120kgK/ha supply and rainout sheltering during two separate periods (6 Aug to 10 Sep and 11 to 26 Sep) was conducted at a low K site (35-40mgK/kg) in Wickepin. Compared to a dry June with 10.8mm, the rest of the season had regular rainfall (i.e. 48.8mm in May, 48.2mm in July, 45.6mm in August, 53.6mm in September and 22.6mm in October). Rainout shelters kept out 63mm by early sheltering and 49.6mm by late sheltering.

Soil K supply or foliar K spray increased grain yields by 0.4-0.5t/ha. There was a negative yield effect by late sheltering, but only under nil K supply, indicating a degree of drought stress due to marginal K.

In the 2014 season, rainout shelters were applied again during the rain events for four weeks, either before or after ear emergence, to induce soil drought. Rains fell regularly during the season, except in June (e.g. 61mm in May, 17mm in June, 65mm in July, 45mm in August, 33mm in September and 36mm in October). Both early and late sheltering kept out 40mm, but the rainfall before and after sheltering minimised the temporary drying effect and no significant difference in yield was found.

Taken together, the field experiments support the hypothesis that increased fertiliser K increased tolerance to drought. But under the seasonal conditions of 2013-14, it was not possible to draw firm conclusions and advice for growers. Recommendations for alternative approaches to define the relationship between K supply and drought are provided below.

Soil K supply and frost damage
A series of field experiments were conducted to determine the effects of K on alleviation of frost damage in wheat. A field trial of K supply and frost damage was conducted on two farms in Tincurrin in 2012. At Z13-Z14 wheat growth stage, three K rates (nil, 40 and 120kgK/ha) as muriate of potash were top-dressed. At booting, the uppermost two to three leaves were sampled for measuring K concentration. At anthesis, ears were tagged for assessing FIS. Between mid-September and early October, the trial sites experienced five episodes of sub-zero chill stress.

Although soil K at both sites was greater than 80mg/kg in the top 10cm of soil, there was evidence at one site that K supply provided some protection from frost damage, as the number of grains per spikelet and grain yield were increased compared with the nil-K control. The responsive site was located at lower valley level and had a profile of shallow sandy loam over gravel, which likely made the plants more sensitive to frost damage.

In the 2013 season, the role of K nutrition in alleviating frost damage was tested with nil, 40 and 120kgK/ha at sowing and foliar sprays of nil, 4% sulphate of potash (SOP) or 4% SOP + 0.5% boric acid + 1% copper sulphate at ear emergence at two low-K sites (35-40mgK/kg) in Wickepin. The 2013 season in the trial area experienced relatively wet and mild growing conditions. Frost events (<2ºC, which is known to cause frost damage in flowering crops) from early September to mid-October were few and only moderate (0.2-0.5ºC on 6 September, 0.6-0.7ºC on 27 September, 0.4-0.6ºC on 1 October, 0.3-0.6ºC on 12-13 October) at both sites, causing no obvious frost damage during anthesis and grain filling. The lack of severe frosts prevented any firm conclusions being drawn about K effects on frost damage.

In 2014, two experiments (1) soil and foliar K supply; 2) soil K and trace elements B, Cu, Zn, Mn and Mo) were conducted at Wickepin and repeated at Corrigin. Both sites are located in lowlands with a south-west aspect and are prone to frost events.

Pre-sowing soil analysis showed the Wickepin site had a Colwell K of 25-30mg/kg at 0-30cm and was deficient in micronutrients (Cu, Zn, B of 0.15-0.20mg/kg) below 10cm. At the Corrigin site, the soil K was 60mg/kg at 0-10cm and 40mg/kg at 10-30cm, but soil micronutrients were mostly above the critical values. Frost events were few and mild at both sites in 2014.

FIS varied from 6 to 8%, with no clear evidence of the effects by soil and foliar K, Cu and B supply. Top leaves had marginal K concentrations (13mgK/g) at nil K supply and increased to 15-18mgK/g at 40 and 120kgK/kg, but leaf Mg concentration was lowered at 120kg K/ha. Foliar spray also increased leaf Cu and B concentrations. The K and micronutrient treatments increased grain yields by 0.3-0.4t/ha, compared with the control that yielded 3.5t/ha.

Based on the learning from 2013 and 2014 seasons, under Project UMU00045 (in the NFI), an alternative approach was used comprising multiple sowings (every two weeks from 15 April) and two varieties (different in frost susceptibility) to maximise the chance of damaging frosts at flowering stage.

Soil K supply and salinity
In 2012, barley variety Hindmarsh⍉ was grown on a moderately saline (saturation extract EC approx. 4 dS/m) and low K (20mgK/kg) field in the central grainbelt and treated with 0, 20, 40 and 120kgK/ha as KCl or K_2SO_4. Applying K increased K uptake but decreased Na uptake, especially at 120kgK/ha. Shoot growth and grain yield increased significantly with KCl or K_2SO_4 supply, but the difference between the rates of 20, 40 and 120kgK/ha was relatively small, indicating partial K substitution by Na under low K conditions.

At the same rate of K supply, K_2SO_4 was generally more effective in promoting crop growth and yield than KCl. The finding suggests K-fertiliser management on moderately saline soils may need to account for both K and Na uptake and use by the crops and K_2SO_4 (sulphate of potash) may be preferable on such soils because it minimises the salt load compared to KCl fertiliser.

Other research

K balance and cycling through residues
As use of K fertiliser spreads, there is a need to develop a more detailed understanding of K balance and K cycling in order to develop cost effective K fertiliser strategies. While generalised data are available on K removal in grain, paddock-scale data are needed by growers in order to estimate yearly removal of K. Paddock-scale information on K removal in grainis the primary input, together with the soil test K for deciding on fertiliser K rates required.

There is very little experimental data on K leaching rates in the western grains region. Edwards et al. (1993) reported on a long term experiment at Badgingarra, in which K leaching loss was only significant in one year out of five when heavy rainfall occurred soon after application of a high K fertiliser rate. Leaching losses also varied from negligible under lupins due to K recycling from the subsoil to significant under shallow-rooted annual pastures. However, there should be caution about extrapolating from a single study at Badgingarra on a deep sand. Quantifying the leaching of K in terms of how much occurs, the variation among soil profile types and seasonal conditions is an essential requirement for constructing the K balance and for estimating the residual value of K applied.

Increasing K rates at sowing

Costs of K fertiliser application can be reduced if it is applied at sowing. K fertiliser is most valuable if applied at sowing or up to five weeks later. Further studies are needed into the most cost effective methods for supplying higher rates of K at sowing without causing crop damage.

K use efficiency among varieties

The K use efficiency varies among wheat varieties. The practical significance of this was evident in one field experiment in 2012 when the K-efficient variety showed no response to K, while the two inefficient varieties responded up to 120kgK/ha. K efficient varieties will not avert the need for K fertiliser on low K soils, but may increase the efficiency of use and achieve greater resilience to drought and frost stresses. The last assessment of K use efficiency among wheat varieties did not include many of the popular current varieties. Hence screening of current varieties would be useful to provide updated advice to growers about varieties that might be better suited to low K soils.

Na replacement of K

Findings suggest that low-to-moderate Na can be beneficial to crop production on low-K soils and a partial substitution of K by Na may mean less K demand by crops. In the grey deep sandy duplex soil group (covering 1.5Mha of WA) and deep sands (2.4Mha of WA), low soil K coincides with moderate Na levels. Therefore, more research is warranted to determine where both soil K and Na levels need to be tested in order to predict the likely response to K fertiliser in the main grain crops in the region.

Interlayer K

The prevailing view is that plant available K in soils of the western region is in the exchangeable form, with little significant contribution from non-exchangeable K. However, illite is a significant clay mineral in some soils and its role in K supply to crops needs to be better defined. It is recommended that a range of soils containing illite clay minerals be collected so that the role of non-exchangeable K in crop nutrition can be assessed.

Further development of K-Agricultural Production Simulator (APSIM) for K fertiliser scenario analysis

The present K-module for APSIM (Scanlan et al. 2015a,b) needs to be upgraded, with capacity for simulation of the effects of drought and soil Na levels.

Additional information

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