Effects of potassium (K) supply on plant growth, potassium uptake and grain yield in wheat grown in grey sand

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Key Messages
• Shoot and root dry weights reached a plateau at 75 mg/kg of potassium (K) at most growth stages. Reduced shoot growth was best explained by reduced tiller numbers and rate of development.
• An increase in leaf numbers and functions (for example, net photosynthesis, stomatal conductance) to applied potassium mainly occurred at the same level of available potassium where an increase in top biomass occurred.
• Luxury potassium supply (135 mg/kg) greatly increased shoot potassium percentage compared with adequate potassium supply (75 mg/kg). However, both potassium treatments had similar seed potassium and nitrogen (N) percentages and harvest index. Seeds were not properly filled under severe potassium deficiency and had decreased seed size (13–18 mg) at moderate potassium deficiency, compared with 30 mg at adequate potassium supply.
• Unlike nitrogen and phosphorus (P) deficiencies that decrease shoot:root ratio, with potassium deficiency shoot:root ratio increased. The greater effect of potassium deficiency on roots may make low-potassium plants more vulnerable to drought.
• Further potassium trials including soil water deficit at late growth stage will be undertaken during 2011 to examine the interaction of soil potassium supply and drought on crop potassium uptake, growth and grain yields.

Background and Aims
In south-western Western Australia, the incidence of potassium (K) deficiency in wheat has increased steadily, with two-thirds of the arable lands prone to potassium depletion through continued removal in hay or grain and straw. Leaching of potassium especially in sandy soils, where the total potassium pool is small, is also a significant contributor to poor K-use efficiency in farming systems. Adequate K supply is required for obtaining high crop yield and quality and enhancing the efficiency of other nutrients and the ability of plants to tolerate stresses from soil moisture, salinity, temperature, disease and pests.

In this study wheat was grown in grey sand in a glasshouse and treated with six levels of soil potassium supply to assess plant responses during the growing season in terms of plant growth, potassium uptake and yield components.

Method

Growth conditions
The experiment was carried out in a naturally-lit glasshouse at Murdoch University, WA. Wheat (Triticum aestivum L. Cv Wyalkatchem) was grown in bottom-sealed plastic pots (diameter 25 cm, depth 25 cm) containing grey sand. Surface soils (20 cm depth) from a non-fertilised field at Muchea, about 40 km north of Perth, were collected and sieved (2 mm). The Muchea sand had background nutrient levels (mg/kg) of 1 nitrate nitrogen (NO3), 1 ammonium nitrate (NH4), 2 Colwell P, 15 Colwell K and 2 potassium chloride (KCl), 13 g organic carbon (OC)/kg, 0.01 dS/m EC and pH 5.4 (CaCl2).

Eight kilograms of air-dried soils were weighed into each pot and mixed with basal nutrients at the following rates (mg/kg): 103 (NH4)2HPO4, 237 Ca(NO3)2·4H2O, 80 MgSO4·7H2O, 18 FeSO4·7H2O, 14 MnSO4·H2O, 9 ZnSO4·7H2O, 8.3 CuSO4·5H2O, 0.33 H3BO3, 0.33 Na2MoO4·2H2O, and 0.3 CoSO4·7H2O. Seeds were sown at eight per pot on July 9, 2010, and 14 days later seedlings were thinned to four uniform plants, equivalent to about 100 plants/m2. During the experiment the pots were watered daily to field capacity with de-ionised water. Plants were treated with 80 mg/kg of ammonium nitrate soil in solution every fortnight.
Soil potassium treatments
Six levels of potassium fertiliser were applied using potassium sulphate (K₂SO₄): nil, 7.5, 15, 30, 60, 120 mg/kg of potassium to supplement 15 mg available potassium per kilogram in the soil, making a total of 15, 22.5, 30, 45, 75, 135 mg/kg of potassium available to plants. Supplementary ammonium sulphate [(NH₄)₂SO₄] was also added to the pots in the low-to-median potassium treatments to balance sulphur (S) supply with the high potassium treatment. Plants in all potassium treatments were harvested six times through the growing season and replicated three times, totalling 108 pots.

Measurements
The number of main stem leaves was recorded weekly from 21 days after seeding (DAS), and the tiller numbers also recorded starting one week later. At heading, the rates of net photosynthesis and stomatal conductance were determined on the flag leaves using a LCpro+ advanced photosynthesis system (ADC BioScientific Ltd, UK) at ambient relative humidity of 50%–60%, reference carbon dioxide (CO₂) of 380 ppm, leaf temperature of 20°C and photosynthetic active radiation of 1500 μmol/m²/s.

Plants were harvested at 28, 49, 63, 77 and 91 DAS for growth measurements. Final harvest for yield components was made at day 117. Shoots were cut off at the soil surface, and roots were collected. Shoots and roots were dried in a forced-draught oven at 60°C for 48 h and weighed. About 1 g of ground shoot material was digested in nitric acid using a Milestone microwave, and potassium concentrations were determined by inductively coupled plasma atomic emission spectroscopy. Seed total nitrogen was determined using a Leco FP-428 nitrogen analyser.

Statistical analysis
All results were subjected to one-way analysis of variance to assess the effects of soil potassium supply. The treatment differences were separated by Fisher-protected lsd test and accepted at $P \leq 0.05$. To ensure the normality and homogeneity of variances, results were log-transformed where necessary. The statistics were conducted by GenStat 9 (Laws Agricultural Trust, Rothamsted, UK).

Results
Main-stem leaf numbers increased with increase in soil potassium levels of 15, 22.5 and 30 mg/kg (see Figure 1). Further increase in soil potassium (45, 75 and 135 mg/kg of potassium), however, did not enhance leaf production. By comparison, tiller development was more responsive to soil potassium supply, and the difference in tiller numbers between the low and high potassium treatments increased with time (see Figure 1). At heading, tillers per plant were 0, 4, 6, 10, 14 and 16 at 15, 22.5, 30, 45, 75 and 135 mg/kg- soil potassium, respectively.

At 28 DAS, shoot dry weight increased with increasing potassium supply up to 75 mg/kg with no further increase at 135 mg/kg of potassium, while root dry weight reached a plateau at 45 mg/kg of potassium (see Figure 2).

As the growing season continued, both shoot and root dry weights maximised at 75 mg/kg of potassium at 49, 63, 77, and 91 DAS (see Figures 2 and 3). At heading (63 DAS), plants supplied with 75 or 135 mg/kg of potassium had a shoot:root ratio of around 2.3, which was doubled for plants with 22.5 or 30 mg/kg of potassium, indicating a greater effect of potassium deficiency on root growth.

At heading, leaf net photosynthesis and stomatal conductance of flag leaves also reached a plateau at 45 mg/kg of potassium (see Figure 3). Two weeks later the leaf gas exchanges decreased and achieved lower rates at 45 than at 75 or 135 mg/kg of potassium.

Shoot potassium concentrations at heading were 1.2%–1.8% (not significantly different) for the plants supplied with 15, 22.5, 30, 45 and 75 mg/kg of potassium but increased to 3.2% in plants with 135 mg/kg of potassium (see Figure 3). Shoot potassium contents were 434 mg/pot at 75 mg/kg of potassium and 761 mg/pot at 135 mg/kg of potassium, despite similar shoot dry weights. At maturity, straw potassium concentration was 0.3% at 75 mg/kg of potassium and 1.0% at 135 mg/kg of potassium (see Figure 4), but plants of the two treatments had similar seed potassium concentrations (0.5%–0.6%) and seed nitrogen concentrations (3.2%).

Plant height at maturity maximised at 75 mg/kg of potassium, whereas total above-ground dry weight was the highest at 135 mg/kg of potassium (see Table 1). Ear numbers increased with each successive increment of
potassium between 15, 22.5, 30 and 45 mg/kg, without further significant increase at 75 mg/kg of potassium. Plants supplied with 135 mg/kg also showed a non-significant increase in ear numbers compared with plants with 75 mg/kg of potassium, despite many more ears than those with 45 mg/kg. Seed size was increased from 5 mg at 15 and 22.5 mg/kg of potassium to 30 mg at 75 and 135 mg/kg (see Table 1). Seed yield was poor at 15, 22.5 and 30 mg/kg of potassium and greatly increased at 45 mg/kg, then more than doubled at 75 mg/kg and increased again at 135 mg/kg. Harvest index increased with soil potassium supply, and reached 0.46 at 75 and 135 mg/kg of potassium.

Figure 1. The emergence of main-stem leaves and tillers per plants in Wyalkatchem wheat as a function of days after seeding and potassium supply in grey sand. Each value is the mean (average) of 12 plants.
Figure 2. Shoot and root dry weights over the growth stages of Wyalkatchem wheat as a function of potassium supply in grey sand. Values are means of three replicates.
Figure 3. Net photosynthesis and stomatal conductance in flag leaves, shoot dry weight and potassium percentage of Wyalkatchem wheat as a function of potassium supply in grey sand at heading. Values are means (±s.e.) of three replicates.

Figure 4. Straw and seed potassium percentage at maturity of Wyalkatchem wheat as a function of potassium supply in grey sand. Values are means (±s.e.) of three replicates.
Table 1. Yield components of wheat (Cv Wyalkatchem) in response to potassium supply in grey sand. Values are means of three replicates.

<table>
<thead>
<tr>
<th>Soil potassium supply (mg/kg)</th>
<th>Plant height (cm)</th>
<th>Ears/pot</th>
<th>Seed size (mg/seed)</th>
<th>Seed weight (g/pot)</th>
<th>Plant top weight (g/pot)</th>
<th>Harvest index</th>
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<tr>
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Discussion

Soil potassium supply had greater effect on tiller than leaf development or function (stomatal conductance and net photosynthesis). While main-stem leaf numbers reached a plateau at 30 mg/kg of potassium, tillers continued to increase with increasing soil potassium, but did not differ at 75 and 135 mg/kg. Shoot and root dry weights also maximised at 75 mg/kg at most growth stages. At luxury potassium supply (135 mg/kg), plants had much greater potassium accumulation in shoots with no increase in biomass, but similar seed potassium and nitrogen concentrations compared with plants treated with 75 mg/kg. Potassium deficiency increased the shoot:root ratio of plants.

Seed size and harvest index were the same between plants supplied with 75 and 135 mg/kg of potassium, but seed yield increased at 135 mg/kg due to a general increase in ear numbers. Further study is warranted to evaluate interactive effects of soil potassium supply and terminal drought on yield components and grain quality.

Key Words

Wheat, soil potassium supply, plant growth, shoot:root ratio, potassium uptake, yield components, harvest index.

Acknowledgments

This project was funded by the Grains Research and Development Corporation (GRDC). Mr Reg Lunt collected Muchea sandy soil.

Project No.: GRDC UMU00035

Paper reviewed by: Bill Bowden