Drought and Soil Salinity Influence Response of Cereals to Potassium and Sulfur Fertilization

By Qifu Ma, Richard Bell, Craig Scanlan, Gavin Sarre, and Ross Brennan

Wheat required more K under drought than non-drought conditions, and the effectiveness of K fertilization was improved by early application.

In moderately saline, low K soil, K input improved growth and yield of barley—a response partially attributed to the plant's ability to tolerate the substitution of Na for K.

In sandy soils or acid lateritic soils containing kaolinitic clay with low CEC, considerable amounts of K can be lost by leaching (Sittiphanit et al., 2009). In Western Australia (WA), greater removal of K in hay, grain and straw than fertilizer K input has steadily increased the incidence of K deficiency on uniform deep sands and sandy duplex soils (sand over loam, clay or lateritic ironstone gravel) (Wong et al., 2000). In low K soils (less than 40 mg Colwell-K/kg), the reduction of wheat and barley growth is relatively greater in roots than shoots (Ma et al., 2011, 2013). The favoring of shoot growth at the expense of roots under K deficiency may, in turn, have a negative feedback on plant uptake of soil water and nutrients and thus make low K plants more vulnerable to drought and/or salinity.

The climate in the south-west WA is a Mediterranean type with short, mild, wet winters and long, hot, dry summers. In this environment, crops often experience intermittent drought during early growth and terminal drought after anthesis. Plant nutrients in the drying topsoil become less available at the root surface, particularly when stratified in the topsoil under no-till farming. In south-west WA, soil salinity and/or sodicity severely affects about 1 million ha of agricultural lands and is expected to expand because of rising saline groundwater due to the landscape water imbalance under annual pastures or crops (Clarke et al., 2002). In this study, we conducted field experiments to investigate the role of K nutrition in alleviating drought and salinity stresses in wheat and barley and compare K-use efficiency between KCl and K_2SO_4 sources. The effect of time of K application was also examined.

2011 Experiment - Wheat

Wheat was grown near Bolgart, Dowerin and Borden, in WA. A pre-sowing soil analysis showed that soil K at 0 to 30 cm depth was low and potentially deficient at all sites (**Table 1**). The experiments were sown in mid June, and each plot had an area of 2 m by 22 m and seven rows at 0.25-m row spacing. At sowing, 100 kg/ha of NPS fertilizer enriched with Cu-Zn-Mo was banded 5 cm below the seed. The fertilizer had 12.6 N, 17.7 P, 5.5 S, 0.25 Cu, 0.35 Zn, and 0.025 Mo (w/w%). At five weeks after sowing (WAS), 200 kg/ha of urea (46% N) was broadcast.

All experiments included two K sources (KCl, K_2SO_4), four K rates (0, 20, 40, and 80 kg K/ha), and four application times (0, 5, 10, or 15 WAS) by broadcast method. In addition, 80 kg K/ha using KCl without gypsum was also applied at 5 WAS to compare with the response of plants treated at the same rate of KCl plus gypsum. At anthesis, shoot dry weight was obtained by quadrat cuts and shoot K concentrations were determined by inductively coupled plasma atomic emission spectroscopy. At maturity, individual plots were machine harvested for grain yield.

Abbreviations and notes: K = potassium; S = sulfur; Cu = copper; Mo = molybdenum; Na = sodium; Zn = zinc; KCl = potassium chloride; K_2SO_4 = potassium sulfate; CEC = cation exchange capacity. P and K are expressed as elemental forms. 1 mg of Colwell K/kg is equivalent to 0.1 cmol exchangeable K/kg

Table 1. Pre-sowing soil potassium (Colwell-K) and sulfur (KCl-40 S) at three sites in the central and southern regions of the grain belt in Western Australia.

Soil depth	Dowerin (central)		Bolgart (central)		Borden (southern)	
	K	S	K	S	K	S
	----------	----------	---------- mg/kg	----------	----------	----------
0 – 10 cm	31	14.6	40	6.7	23	6.1
10 – 20 cm	29	1.8	30	4.6	23	3.5
20 – 30 cm	28	2.2	37	3.0	30	4.4
30 – 40 cm	37	3.0	45	4.0	–	–
40 – 60 cm	34	4.1	59	4.3	–	–
60 – 80 cm	33	7.2	59	3.3	–	–

2012 Experiment - Barley

Barley was grown at Beverley, WA. A pre-sowing soil analysis showed 20 mg Colwell-K/kg in the 0 to 40 cm profile, 10 mg S/kg in the top 10 cm soil and 6 mg S/kg at the lower depths. The soil was marginally saline. The experiment was sown in early June with similar rate of basal fertilizers to the 2011 experiments. At 2 WAS, KCl and K_2SO_4 were broadcast at 0, 20, 40, and 120 kg K/ha. At anthesis, photosynthetic gas exchange of the flag leaves was measured and concentrations of K and Na of the uppermost three leaves were determined. At maturity, grain yields were measured from quadrat cuts.

Results

In the 2011 season, there was a dry spell of <30 mm total rainfall from stem elongation to grain development at Dowerin, compared to regular rainfall at Bolgart and Borden with monthly averages of 54 and 41 mm over the growing period, respectively. The difference in rainfall among the sites affected crop response to soil K treatments. While little K response was observed at Bolgart and Borden, applying 20, 40 and 80 kg K/ha as either K_2SO_4 or KCl with gypsum at 0 or 5 WAS at Dowerin increased grain yield (**Figure 1**). Later broadcast application reduced the K effectiveness. The supply of 80 kg K/ha as KCl without gypsum at 5 WAS had lower shoot K and S contents, and decreased dry weight and grain yield than the same K rate using K_2SO_4 (**Table 2**).

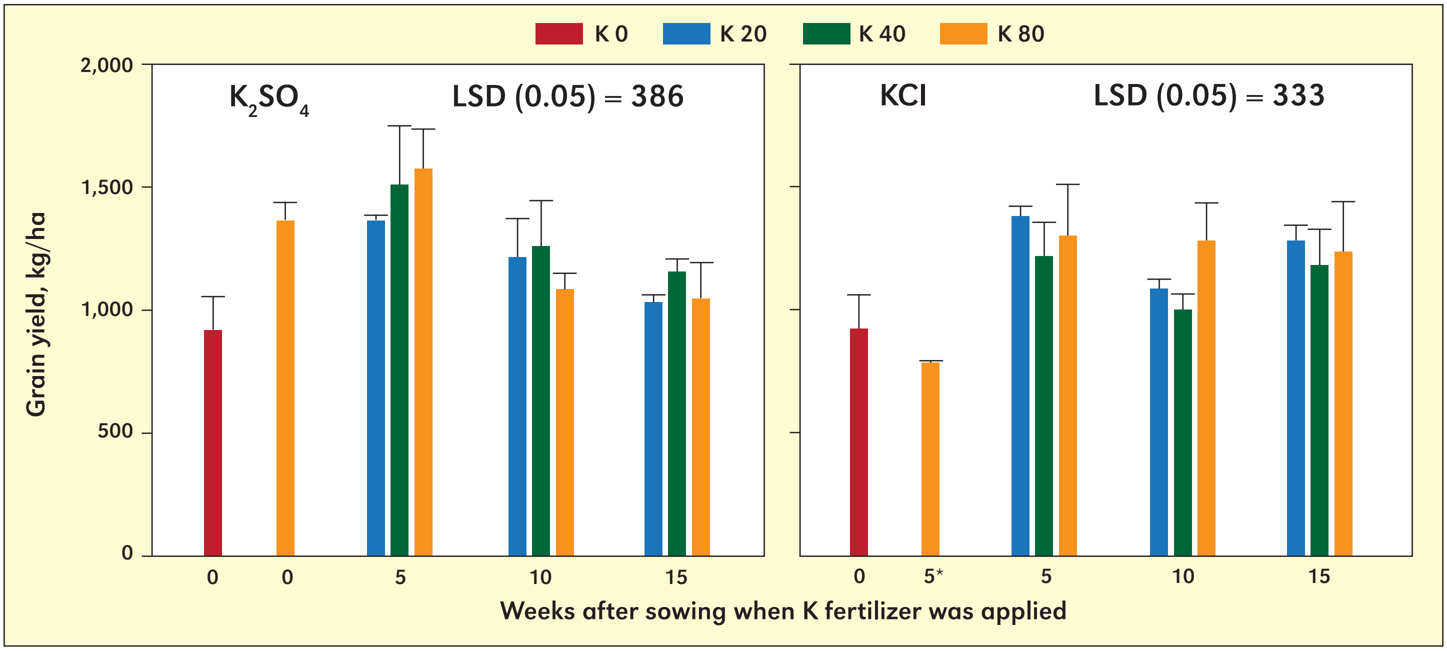

Figure 1. Grain yield of wheat in response to K source, rate and application time at Dowerin in 2011. Capped lines are standard errors. Except for 5* denoting 80 kg K/ha as KCl without gypsum at 5 weeks after sowing, all other K treatments received 100 kg of gypsum/ha.

At the saline site in 2012, 120 kg K/ha as KCl and both 40 and 120 kg K/ha as K_2SO4 increased K concentration, but decreased Na concentration of the uppermost three leaves at anthesis in barley (**Figure 2**). Applying K also improved leaf photosynthesis (**Figure 3**). At maturity, plants with 20 or 40 kg K/ha as K_2SO_4 generally had higher shoot K concentration and lower shoot Na concentration than plants from treatments with the same K rates as KCl. Grain yield was significantly increased by applying KCl and K_2SO_4 compared with zero K input, but the difference between the rates of 20, 40 and 120 kg K/ha was mostly not significant (**Figure 4**).

Table 2. Effects of 80 kg K/ha as K_2SO_4 or as KCl without gypsum on shoot growth, K and S contents at anthesis, and grain yield of wheat in the central and southern grain belts of Western Australia.

	--- Dowerin ---		--- Bolgart ---		--- Borden ---	
Response parameters	K_2SO_4	KCl	K_2SO_4	KCl	K_2SO_4	KCl
Shoot dry wt., kg/ha	2,295 a	1,054 b	4,284	4,249	6,816	6,153
Shoot K, kg/ha	19.5 a	7.8 b	66.4	65.0	77.2	54.7
Shoot S, kg/ha	4.9 a	2.4 b	7.1	6.7	13.3	11.4
Grain yield, kg/ha	1,365 a	792 b	1,776	1,848	2,673	2,684

Comparisons are within site. For each parameter, different letters indicate significant effect ($p \leq 0.05$) of K sources.

Conclusions

At three sites with similarly low soil K, fertilizer K application only increased shoot K, dry matter and grain yield at Dowerin where there was a long dry spell from the mid to late season, but had no effect at Bolgart and Bolden where there was regular rainfall through the season. Under drought, root growth and K uptake would be impaired, especially on low K soil where root growth is reduced at a greater extent than shoot growth (Ma et al., 2011, 2013). Increasing soil exchangeable K by fertilizer application would render more K available to plants for essential physiological functions (e.g., photosynthesis and turgor maintenance) and for better root growth. In this study, the positive response in wheat to soil K supply at the drought-affected site, but not at the non-stressed sites suggests more K is required for optimal growth and yield under limiting soil water supply.

Applying K fertilizers at sowing or 5 WAS was much more effective for dry matter and grain yield than later application. The majority of K uptake in wheat occurs in the vegetative phase and maximal K accumulation is reached at anthesis (Ma et al., 2013). Early K application would allow time for surface-applied K to move into the root zone and match the pattern of K uptake and growth demand, particularly during tillering which can be depressed by low K. Adequate plant K status would also promote translocation of photoassimilates to support root growth during the long dry spell and therefore enhance drought resistance.

On the K deficient and moderately saline soil, K fertilizer application improved leaf photosynthesis, plant growth and grain yield in barley, but the differences among the treatments of 20, 40 and 120 kg K/ha were relatively small and showed at least partial substitution of K by Na. The findings suggest that K fertilizer management needs to consider not only soil K status and crop requirement, but also soil Na status and genotypic variation in the uptake and use of K and Na. In this regard, since barley takes up Na into leaves, it may respond more to Na substitution of K than wheat, which excludes Na (Ma et al., 2011; Krishnasamy et al., 2014).

The fertilizer K_2SO_4 performed better than KCl at both the drought-affected and saline sites. Under drought, the treatment supplying 80 kg K/ha as KCl without gypsum lowered shoot S and K contents at anthesis, compared with the same rate of K using K_2SO_4 and other K treatments that received

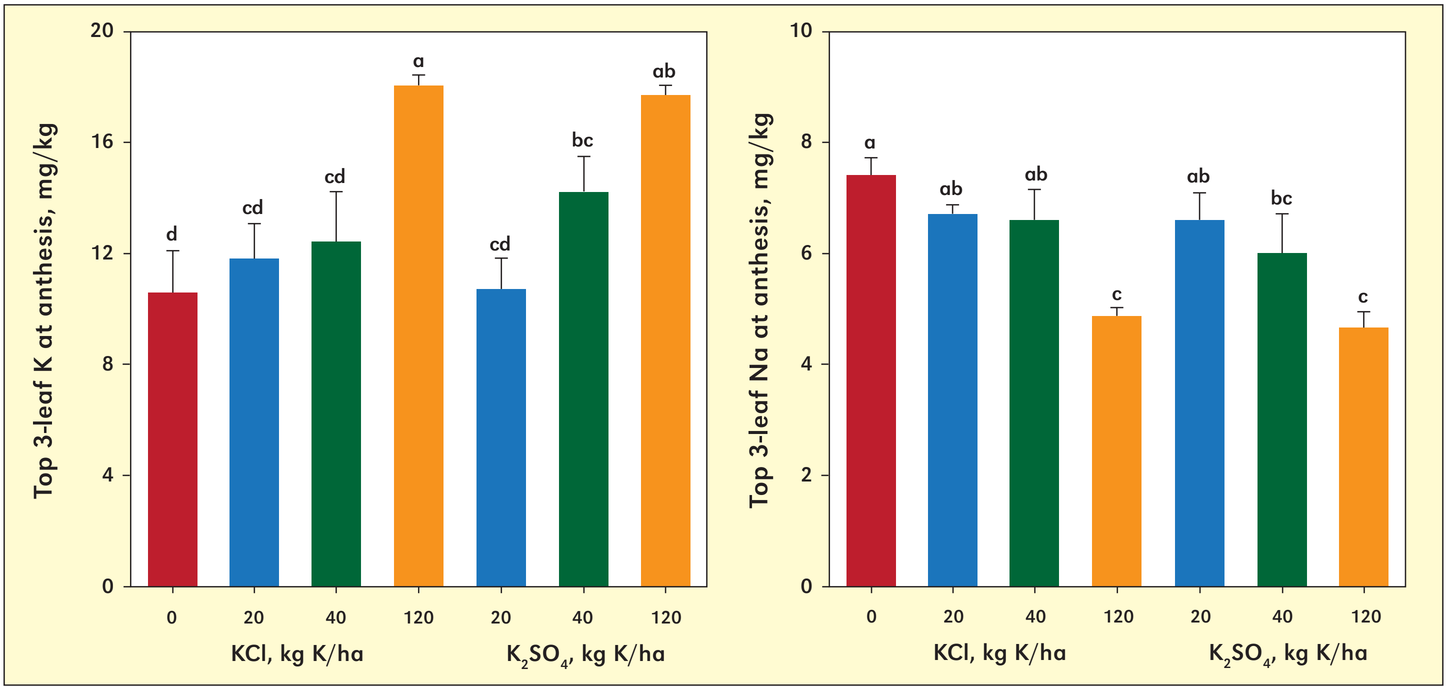

Figure 2. Effect of KCl and K_2SO_4 fertilization on K and Na concentrations in the uppermost three leaves at anthesis of barley grown in moderately-saline soil. Within a graph, means (+std. err.) with the same letter are not significantly different at $p = 0.05$.

supplementary S from gypsum. At the saline site, the soil had a moderate level of S (10 mg/kg) in the top 10 cm but was S deficient at the lower depths, and applying K_2SO_4 would have increased soil available S and K levels.

In the rainfed environment of WA, cereal crops responded to K fertilizer on low K soils, but the response varied with soil salinity and available S levels and soil water stress. BC

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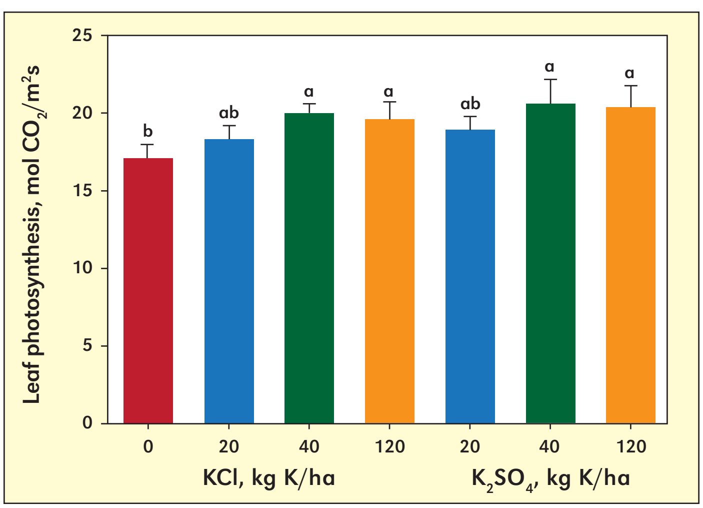

Figure 3. Effect of KCl and K_2SO_4 fertilization on leaf photosynthesis at anthesis of barley grown in moderately-saline soil. Means (+std. err., n=9) with the same letter are not significantly different at $p = 0.05$.

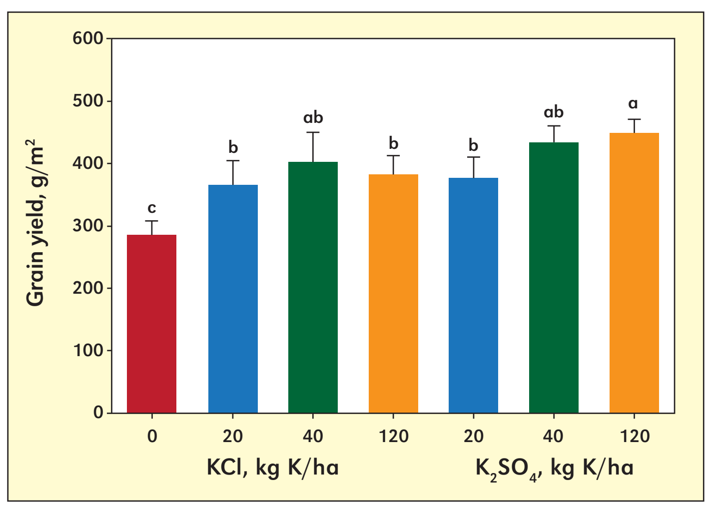

Figure 4. Effect of KCl and K_2SO_4 fertilization on grain yield of barley grown on a moderately-saline soil. Means (+std. err., n=3) with the same letter are not significantly different at $p = 0.05$.