Early growth of field peas under saline and boron toxic soils

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Abstract

Boron and salinity are both toxic to plant growth in high concentrations and frequently occur together. Field peas are one of the major break crops in Western Australia yet little is known about their tolerance to the combined influences of salinity and boron. A glasshouse study was conducted to determine the influence of salinity (0 and 6 dS/m) and boron (5 and 20 mg/kg) and the combined effects of both on the early growth of two field pea varieties 'kaspa', the predominant variety grown in south-east and Western Australia, and an older variety, 'parafield'. Levels were chosen as the upper levels for cereal production. Salinity was found to be the main inhibitor to plant growth in both 'Kaspa' and 'Parafield' reducing plant height, root length and the number of nodes on the main stem. No interaction was observed between the combined effects of salinity and boron toxic soils. 'Kaspa' was more tolerant of boron toxic soils than 'Parafield' with no significant difference between low and high boron soils. In 'Parafield' boron significantly reduced plant growth under low saline conditions. Results suggest that breeding for boron tolerance has had some success, but that there is an urgent need to develop cultivars with greater salinity tolerance and screening of accessions held in genebanks is required to determine if diversity for salinity tolerance exists.

Key Words

Field peas, salinity, boron, Western Australia, Kaspa, parafield,

Introduction

Australia currently produces 400,000 tons of field peas annually, which are primarily exported into Asia and the Middle East. 70% of these are kaspa-type due to their environmental adaptability, good seed quality and high yield potential 'Parafield', an older variety, still contributes up to 25% due to its resistance to bacterial blight (Pulse Australia 2009).

Saline toxic soils are common across southern Australia with currently 2 million ha of agriculture land affected by secondary salinity in Australia (McFarlane, George et al. 2004). Secondary salinity occurs as a result of clearance of the native vegetation, which leads to rising groundwater levels and mobilisation of salt stored deep in the soil profile. Increasing levels of salinity in the soil result in reduced yield potential and eventual vegetation mortality.

Boron is an essential micronutrient for plant growth, with boron deficiency occurring when boron levels are low. Boron toxicity is more common in Australia due to low rainfall and is hard to treat. About 15 per cent of agricultural soils in WA are at moderate to high risk of boron toxicity (Lacey and Davies 2009). In Western Australia high boron levels are frequently associated with high salinity. Levels of toxicity to both abiotic stresses vary seasonally depending on annual rainfall. However, in low rainfall environments and on clay soils boron is leached more slowly than salt (DAFWA 2005).

Independently, the effects of salinity and boron on plant growth and yield have been well investigated. However, there is little information on the interactive effects of boron and salinity, as the mechanism of boron uptake under saline conditions is not well understood (Grieve and Poss 2000; Wimmer and Goldbach 2012).

The aim of this study was therefore to investigate the interactive effect of salinity and boron on two varieties of field pea 'kaspa' and 'parafield'. It is hypothesised that the combined stress of boron and salinity on the early growth of field peas will be greater than either of the stresses independently, and that 'kaspa' will show a greater tolerance to boron than 'parafield'.

Materials and Methods

A glasshouse experiment was conducted at Curtin University, Bentley Campus, during the winter and spring of 2011 to determine the tolerance of field pea to the combined abiotic stresses of salinity and boron. Two varieties were sown on the 3rd August 2011; 'kaspa', a semi-dwarf, semi-leafless variety that is widely sown across Western Australia, and 'parafield', an older tall, conventional-leaved variety. The experiment was sown as a 6 block randomised design with two levels of salinity (0 and 6 dS/m NaCl), two levels of boron (5 and 20 mg/kg borax) and two varieties ('kaspa' and 'parafield') with five replicates. Pots were filled with 7 kg washed river sand and were fertilised with a basal nutrient mix of 325 mg/kg phosphorus and 25 ml of a nutrient solution (44.5 g potassium sulphate, 1.7 g copper sulphate, 1.8 g zinc sulphate and 0.4 g molybdenum dissolved in 1 L deionised water). Group F rhizobia was added to the pots as dry pellets prior to watering on 17th August 2011. Basal nutrient fertilisation was repeated on 31st August 2011. Plants were watered with the salinity/ boron solutions 2 times/ week, increasing to 3 times/ week as required. Pots were watered so that the solution just 'dripped' through the bottom of the pots to ensure that the soil did not dry out and the salt and boron solutions did not concentrate at the soil surface as a result of capillarity. Measurements were taken every 2 weeks and included; plant height, number of nodes on the main stem, stipule size and chlorophyll reading (using a Konica Minolta SPAD-502Plus Chlorophyll Meter), as well as a visual health description. The final readings were taken on the 28th September and included those listed above, plus root length and presence of rhizobial root nodules. Roots were removed and plants were dried in the oven at 65° C for 3 days before plant dry weights were taken. Data analysis was conducted using Genstat v.14.1 (VSN International). Variables were checked for normality before analysis of variance was conducted and were found to approximate normality.

Results

A summary of the results taken during the course of the glasshouse trial are presented in Table 1, where it can be seen that large differences were recorded in most variables between cultivars and between salinity treatments. Rhizobial root nodules were recorded on 100% of plants in the low salinity, low boron treatment and the low salinity, high boron treatment, on 20% of plants in the high salinity, low boron treatment and on 60% of plants in the high salinity, high boron treatment. Analysis of variance found that significant differences were present between salinity treatments ($P<0.05$) for number of nodes (21-09-2011 and 31-08-2011), plant weight, stipule size (21-08-2011) and chlorophyll score, and for boron treatments ($P<0.05$) for plant height (17-08-2011) and stipule size (17-08-2011). The toxic effects of high boron levels are apparent in the early growth of field peas, but the effect of salinity increases as the trial continues. There were no significant interactions between salinity and boron following analysis of variance. Tolerances to salinity and to boron were found to differ significantly between cultivars following analysis of variance in plant height (21-08-2011) and root length.

Table 1. Summary of variables scored on 'kaspa' (K) and 'parafield' (P) cultivars of field pea at different salinity and boron treatments, showing mean and standard error of the mean (s.e.m in brackets after value). For variables that were scored at a number of dates over time only the final reading measurements are shown. LSLB = 0 dS/m ECe, 5 mg/kg boron, LSHB = 0 dS/m ECe, 20 mg/kg boron, HSLB = 6 dS/m ECe, 5 mg/kg boron and HSHB = 6 dS/m ECe, 20 mg/kg boron.

Treatment	No. Nodes (21-09-11)	Plant ht (mm) (21/09/11)	Stipule width (mm) (21-09-11)	Chlorophyll	Plant dry wt (g)	Root length (mm)
K-HSHB	6.06 (0.403)	150 (9.3)	20.5 (1.09)	12.7 (1.33)	0.22 (0.147)	168 (21.8)
K-HSLB	5.28 (0.228)	132 (5.5)	20.8 (2.43)	13.0 (1.31)	0.28 (0.245)	166 (20.9)
K-LSHB	10.70 (0.689)	283 (19.8)	27.7 (1.41)	20.2 (1.31)	1.10 (0.041)	277 (10.2)
K-LSLB	11.24 (0.599)	284 (16.9)	26.4 (1.04)	20.3 (0.97)	1.19 (0.021)	267 (12.2)
P-HSHB	6.68 (0.523)	194 (14.8)	19.6 (1.58)	17.7 (1.43)	0.48 (0.493)	173 (19.6)
P-HSLB	7.19 (0.737)	197 (31.0)	17.6 (1.58)	16.7 (1.16)	0.33 (0.499)	228 (20.5)
P-LSHB	9.92 (0.814)	364 (45.4)	26.9 (2.56)	17.8 (1.31)	2.03 (0.150)	234 (17.0)
P-LSLB	11.68 (0.869)	508 (52.8)	25.9 (2.18)	19.5 (1.53)	2.32 (0.078)	266 (8.2)

Repeated measures analysis of variance for plant height, stipule size and number of nodes over time found significant differences ($P<0.05$) between cultivars, salinity, time and the associated interactions. The interaction between boron and cultivar was found to show significant differences ($P<0.05$) and is due to the increased tolerance of boron in 'kaspa' which means that the interactive effect of boron and salt has little or no effect on plant growth compared to the high salinity treatment alone. Also in 'kaspa' the low salinity, high boron, treatment shows little difference from the low salinity, low boron treatment, whereas in 'parafield' there is a significant difference ($P<0.05$) between high and low boron treatments when salt is excluded. This can clearly be seen in Figure 1, particularly at the last measurement.

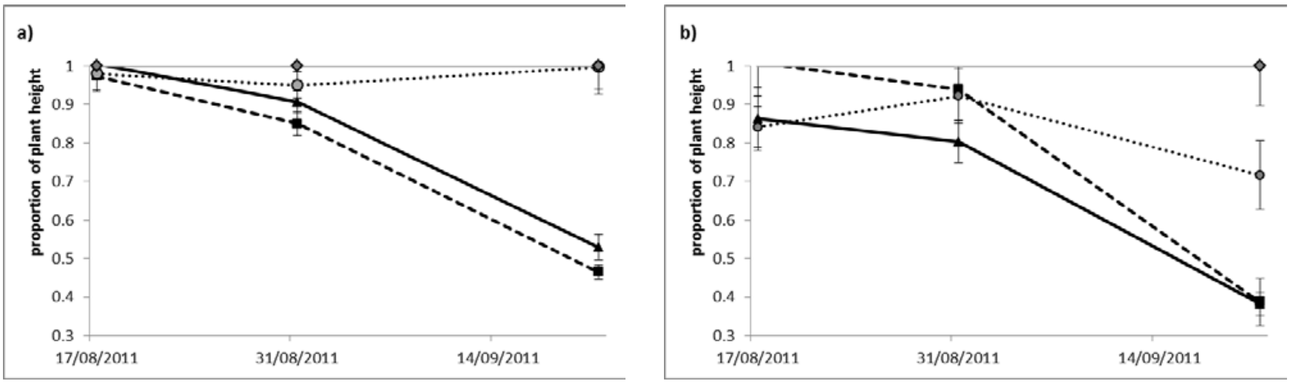

Figure 1. Plant height during early growth of a) ‘kaspa’ and b) ‘parafield’ shown as a proportion of the height of the low salinity/ low boron treatment. Salinity/ boron treatments were; 0 dS/m ECe, 5 mg/kg boron, 0 dS/m ECe, 20 mg/kg boron, 6 dS/m ECe, 5 mg/kg boron and 6 dS/m ECe, 20 mg/kg boron.

Plant dry weight shows a marked decrease in both high salinity treatments and in both varieties compared to the low salinity treatments (Figure 2a). A number of variables, including plant weight and root length show an increase in weight or length at the low salinity, high boron treatment, compared to the low salinity, low boron treatment in ‘kaspa’, whereas in ‘parafield’ there is no significant difference between the two treatments (Figure 2a and 2b).

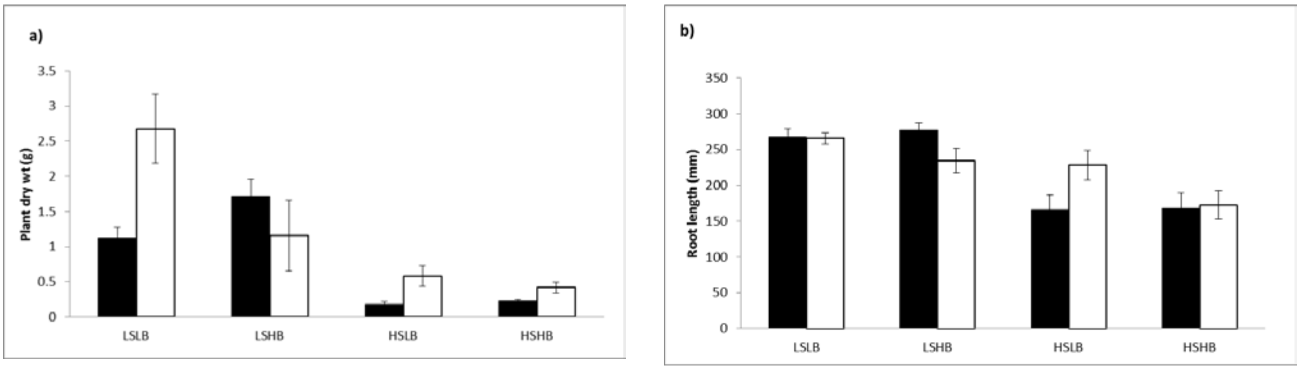

Figure 2. Plant dry weight (a) and root length (b) of 'Kaspa' (black bars) and 'Parafield' (white bars) field pea varieties after 9 weeks growth under saline and boron treatments. Salinity/ boron treatments were; LSLB - 0 dS/m salinity, 5 mg/kg boron, LSHB - 0 dS/m salinity, 20 mg/kg boron, HSLB - 6 dS/m salinity, 5 mg/kg boron and HSHB - 6 dS/m salinity, 20 mg/kg boron.

Discussion

The hypothesis that ‘the combined stress of boron and salinity on the early growth of field peas’ was accepted for the older variety ‘parafield’, but was rejected for the newer variety ‘kaspa’. ‘Parafield’ showed a similar reduction in plant growth under high boron and under high salinity treatments, but growth was significantly less under the combined stresses. A similar response to high levels of boron and salinity have also been recorded in wheat (Grieve and Poss 2000). ‘Kaspa’ however, has been bred to contain some tolerance to boron and this was apparent in its response to the low salinity, high boron treatment where plant height was comparable, and plant weight and root length were greater than the low salinity, low boron control. A study by Wimmer and Goldbach (2012), also on wheat, found that varieties that were more salt tolerant showed a reduced impact of boron under high saline conditions. It is suggested that a similar response may be present in varieties tolerant of boron, that the impact of salt is reduced under high boron conditions, thus reducing the interactive effect of the two stresses. It is also suggested that in ‘kaspa’ the impact of boron is reduced and that higher levels may actually be required than the low boron treatment in this study to achieve maximum yield potential. In saline conditions, Wimmer and Goldbach (2012) report variable rates of boron uptake under low boron supply and suggest that this is due to a) variation in salt tolerance of different wheat varieties, and b) variation in low levels of boron concentration chosen as control treatments. Yermiyahu et al. (2008) also suggest that there are differing responses to the combined effects of salinity and boron with some species, or varieties within species, showing an antagonistic response, where the effect of boron and salinity is less than either of the stresses independently, whereas other species show a synergistic response where the effect of combined salinity and boron is greater than either of the stresses applied independently. Their work also found that different variables respond differently to the combined stresses. For example, in bell peppers root growth showed an antagonistic response (Yermiyahu, Ben-Gal et al. 2008). Further work is on-going to determine the responses in field peas to salinity and boron across a wider range of levels and in a number of different varieties.

The results from this study show that the impact of the two abiotic stresses increases over time. In both plant height and stipule size, a negative response to the high salinity treatment is not apparent until the 2nd measurement taken four weeks after the commencement of the experiment. This supports the results of (Yermiyahu, Ben-Gal et al. 2008) who found a similar response in bell peppers. However, the significant effect of high boron levels at the first measurement after two weeks was surprising as boron does not move as easily through the soil as sodium chloride (Nable, Banuelos et al. 1997) and so it was expected that the impact of high salinity levels would be recorded before those of high boron. However, the uptake of boron at high concentrations is generally considered to be a passive process, rather than requiring a plant physiological response (Nable, Banuelos et al. 1997) and this may explain the rapid response of boron toxicity compared to those of toxic saline conditions.

A further complication on the interaction of boron and salt in field peas is the impact of these abiotic stresses on nodule formation and health. Boron is required for nodule formation. However, high salinity levels reduce the availability of boron and thus nodulation formation (El-Hamdaoui, Redondo-Nieto et al. 2003). This is particularly evident in ‘kaspa’ under the high salinity, low boron treatment where only 20% of plants had nodule development, and compares to both varieties under the low boron, low salinity treatment which had a 100% nodule development. In contrast boron has been shown to prevent nitrogenase activity from declining under high saline environments, when added with calcium (Bolanos, Martin et al. 2006), which reduces the decline in nodule formation in high saline, high boron conditions. This supports the results found in this study where 60 % of plants grown under high salinity, high boron treatment had root nodules.

Conclusion

Field peas are severely restricted in their plant growth under saline conditions. ‘Kaspa’, the more boron-tolerant variety showed a reduced effect of boron toxicity at the high level used in this study, with boron potentially reducing the impact of salinity toxicity. ‘Parafield’, by contrast, suffered from boron toxic affects at 20 mg/kg and showed an interactive effect of the combined abiotic stresses. Formation of root nodule bacteria was also affected by boron and salinity, although the combination of high boron and high salinity treatments appear to reduce the impact of salinity. It is suggested that as boron toxic soils are also commonly affected by saline conditions in Western Australia there is a need to breed for varieties of field pea and associated root nodule bacteria that exhibit some tolerance to saline conditions combined with tolerance to boron. As current varieties of field pea do not contain any tolerance to salinity it is suggested that screening of material held in genebanks is required to determine if diversity for salinity tolerance exists.

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