The role of 'boron tolerance' in improving adaptation of cereals to highly alkaline subsoils.

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Abstract

The impact of boron (B) tolerance and soil water supply on the growth and water use of barley was assessed under controlled environment conditions using near-isogenic lines of barley grown in large intact cores collected from Birchip (calcarosol) and Dooen (vertosol) in north western Victoria. . There was poor use of soil water by barley below 60 cm throughout the season in both soil types. This corresponded to a significant decrease in root density below 60 cm in both soil types, but this decrease was significantly more pronounced in the calcarosol. Root growth was significantly greater in the B tolerant line, especially in the subsoil. There were large effects of water stress, and to a lesser extent soil type, on above ground growth such as grain yield, harvest index, grain size and grain protein, but B tolerance had little effect. It appeared that some factor other than B may be over-riding the effect of B tolerance and that if grain yields and water use on these highly alkaline soils is to be improved, this factor needs to be identified and selected for in breeding programs.

Key Words

Soil boron, salinity, sodicity, tolerance, barley

Introduction

Low yields and poor water use by grain crops growing on highly alkaline soils in the Victorian Mallee region of southern Australia has been attributed to 'hostile' chemical and physical conditions in the subsoil. These subsoils are characterised by high levels of boron (B), sodicity and salinity. The low-input nature of these dryland farming systems means that breeding for tolerance is generally regarded as the best means of combating these toxicities. Significant variation in tolerance to B exists in cereals (1) and all cereal breeding programs targeting new improved varieties for these soils currently include boron tolerance as a key selection trait. However because of the simultaneous occurrence of a range of potential subsoil limitations in these soils, there is a poor understanding of the relationship between boron tolerance and improved yield and water use.

Methods

Large intact cores, 300 mm in diameter and 1000 mm long (2), which maintained the physical and chemical properties of these soils, were collected from two sites in NW Victoria: a calcarosol in the southern Mallee and a vertosol, collected from the Wimmera plains. General chemical/physical properties are listed in Table 1. Both soils were saline, sodic and had moderate concentrations of B likely to limit barley growth at depth.

A trial, comprising of a factorial combination of two soil types, ? boron tolerance and 2 soil water treatments on growth and water use of barley was established with the intact cores in a polyhouse. Prior to sowing (equivalent of 1.69 M plants ha^{-1}), a basal application of P (as KH_2PO_4), N (as NH_4NO_3), Cu (as $CuSO_4$) and Zn (as $ZnSO_4$) was added to the topsoil to ensure that nutrients were non limiting. To study the effect of B toxicity, near-isogenic lines of barley based on a double back cross of the parent VB9104 (B intolerant, B_i) and a B tolerant (B_t) line (VB9743/VB9104//VB9104 /3/VB9104) (3). Cores were maintained at field capacity until booting when two levels of soil water supply were established. For each soil type, half the cores were irrigated every 3 to 5 days by replacing the amount of water estimated to have been lost by evapo-transpiration ('non-limiting') whereas 1/3 of this amount of water was applied to the remaining cores ('drought').

Data collection

Plants were harvested at grain maturity by cutting below the tillering node prior to counting the number of tillers and spikes. Shoots were then separated into leaf, stems and spikes, dried at 70?C for 48 hrs before weighing. Grain was separated from the spikes using a stationary thrasher prior to weighing. Grain protein content was estimated using NIR. Root dry matter was determined by subsampling each intact core with 3 cores (42 mm diameter) after harvest, pooling the samples, removing root samples by elutriation and then drying at 70?C for 24 hrs. Random observations indicated that there was minimal preferential growth of roots along the walls of the PVC cores. Soil water was estimated using a Tekronics TDR with probes inserted at 10, 20, 40, 60 and 80 cm depth.

Table1 : Selected soil properties of (a) Calcarosol and (b) Vertosol

Depth (cm)	pH ($CaCl_2$)	E.C.$_{1:5}$ $CaCl_2$(dS/m^{-1})	B ($CaCl_2$)	ESP (%)
		(a) Calcarosol		
0 –10	8.1	0.27	1	1
10 – 20	8.2	0.23	1	3
20 – 40	8.6	0.36	4	8
40 – 60	9.1	0.66	14	19
60 – 80	9.3	0.74	17	24
80 -100	9.5	0.80	15	26
		(b) Vertosol		
0 –10	7.9	0.29	2	3
10 – 20	8.0	0.31	3	6
20 – 40	8.2	0.40	5	11
40 – 60	8.6	0.72	12	17
60 – 80	8.4	1.50	17	25

80 -100	8.7	1.50	23	29

Results

Imposing drought stress resulted in significantly ($P < 0.05$) reduced grain yield, harvest index and grain size but higher grain protein across both soil types and near-isogenic lines (Table 2). Soil type generally had little significant effect ($P > 0.05$) on the growth of barley except when drought was imposed. In this case a significantly greater negative impact on grain yield and harvest index in the calcarosol than the vertosol (Table 2). B tolerance had little impact on the growth of barley, with the exception of larger grain size in the B_T genotype.

There was a trend for poorer use of soil water by the barley below 60 cm throughout the season in both soil types (data not presented). In the calcarosol, there was little difference in soil water content at any one soil depth regardless of B tolerance or whether irrigation was applied. In the vertosol under irrigated conditions soil water content at grain maturity tended to be lower in the B_t cores than in cores sown to the B_I line. However, when drought stress was imposed, B tolerance had no apparent impact on the amount of water remaining in the vertosol at crop maturity.

The amount of root biomass recovered from the soil reflected the pattern of water use, with highest root densities found in the topsoil (0 – 10 cm) followed by the middle soil layers (Figure 1). Root density was significantly decreased below 50 cm depth with this decrease significantly ($P < 0.05$) more pronounced in the calacarosol. There was significantly greater ($P < 0.001$) root biomass in the vertosol than the calcarosol, especially in lower parts of the soil profile. Cores with B_t barley had a significantly greater ($P < 0.05$) amount of roots across all depths than those with the B_I genotype.

Discussion

Boron toxicity is regarded as a major constraint to crop production on the highly alkaline soils of southern Australia (4) and all cereal breeding programs targeting this region currently include B tolerance as a desirable trait (R Eastwood, pers. comm.). In our study near-isogenic lines were used to assess the impact of B tolerance on the growth and water use of barley. Although these lines are approximately 87% isogenic (D Moody, pers comm.), they are comparable in phenology and disease resistance and provide a powerful tool when assessing the impact of subsoil limitations such as B. There are always inherent limitations when growing plants in any container. However the use of very large intact cores (> 110 kg soil) that maintain soil chemical and physical conditions throughout the profile helped minimise these effects and allowed us to simultaneously compare different soil types under semi-controlled conditions.

Table 2: Impact of soil type, irrigation and tolerance to boron on the growth of barley

Soil type	Genotype	Irrigation	Grain yield (g/m^2)	Above ground biomass (g/m^2)	Harvest index	Grain weight (mg)	Grain Protein (%)
Calcarosol	B_T	Irrigated	1021	1852	0.53	54.9	9.6
		Drought	739	1684	0.45	45.7	11.5
	mean B_T		880	1768	0.49	50.3	10.6

	B_I	Irrigated	1027	1768	0.61	54.6	9.8
		Drought	669	1813	0.36	41.2	13.3
	Mean B_I		848	1791	0.49	47.9	11.6
	Mean irri.		1024	1810	0.57	54.8	9.7
	Mean drought		704	1749	0.41	43.5	12.4
Vertosol	B_T	Irrigated	977	1927	0.51	55.3	8.2
		Drought	878	1798	0.45	57.6	9.2
	Mean B_T		928	1863	0.48	56.5	8.7
	B_I	Irrigated	932	1927	0.51	52.7	7.5
		Drought	808	1766	0.49	54.4	9.5
	Mean B_I		870	1847	0.50	53.6	8.5
	Mean irri.		955	1927	0.51	54.0	7.9
	Mean drought		843	1782	0.47	56.0	9.4
lsd (P=0.05)			*115*	*335*	*0.08*	*4.3*	*0.9*
	S		n.s.	n.s.	n.s.	***	***
	V		n.s.	n.s.	n.s.	*	n.s.
	I		***	n.s.	***	***	***
	S*G		n.s.	n.s.	n.s.	n.s.	**

G*I	**	n.s.	*	***	**
V*I	n.s.	n.s.	n.s.	n.s.	**
S*V*I	n.s.	n.s.	***	n.s.	n.s.

S = soil; V = genotype; I = irrigation; B_T = B tolerant; B_I = B intolerant; n.s. = not significant ($P > 0.05$); * significant ($P < 0.05$); ** ($P < 0.01$); *** ($P< 0.001$)

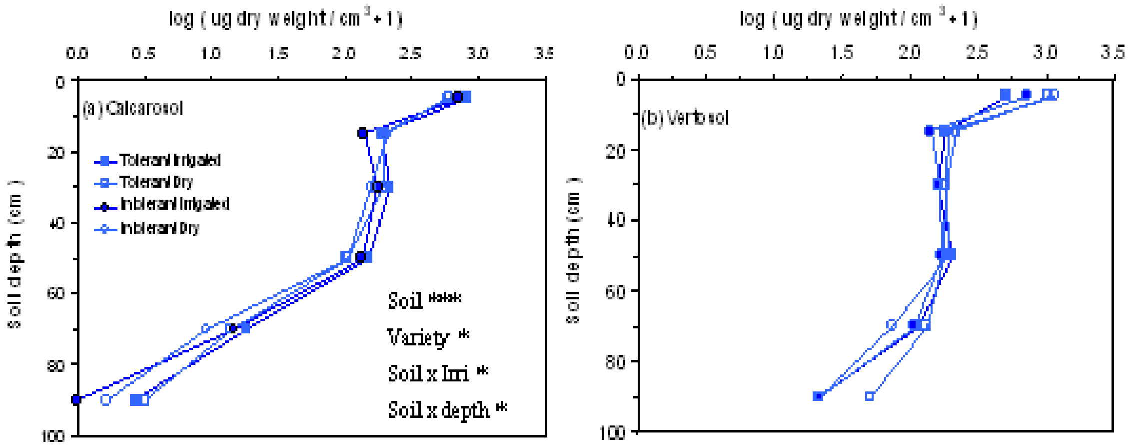

Figure 1: Effect of B tolerance and irrigation on the root biomass for (a) Calcarosol and (b) Vertosol

Despite the perceived importance of B toxicity throughout southern Australia, we found that B tolerance had minimal beneficial impact on the selected growth parameters reported although there was some evidence that B tolerance improved root growth and possibly water use in the subsoil. There are several possible explanations for this finding. Firstly, soil B levels may have been below a critical threshold. There are inherent limitations using soil testing to assess critical levels of B (1). However concentrations of $CaCl_2$ extractable B in the subsoil of 17 mg kg^{-1} in the calcarosol and up to 23 mg kg^{-1} in the vertosol were recorded. Clearly visible signs of B toxicity also appeared on the leaves of all treatments at late tillering. Secondly, some factors other than B toxicity was limiting growth. There was no obvious sign of foliar disease during the trial and sites used to collect the cores were selected so as to minimise the potential for root disease. A recent survey (Nuttall, pers comm.) in NW Victoria has found that potentially phyto-toxic concentrations of B, salinity and sodicity in the subsoil normally occur concurrently. Although the calcarosol was general non saline (< 0.8 dS m^{-1}) in the subsoil, salinity levels reached 1.5 dS m^{-1} below 60 cm depth in the vertosol and both soils were highly sodic (%ESP > 15) below 50 cm depth (Table 1). This finding lends support to another study (5) involving a wide ranging field survey in the southern Mallee of Victoria that suggests that primary salinity and sodicity rather than B toxicity were having greatest impact on the grain yield of wheat. Finally, the technique used to select for tolerance to soil B toxicity in barley (assessing rate of root growth of young seedlings in a non soil based hydroponic system) may not adequately reflect the mechanism required by barley crops to tolerate high levels of sub soil B under field conditions.

Other research (6) and anecdotal evidence from the field indicates that symptoms of B toxicity are most common during periods of drought stress. Although the water stress treatment used in this study had a marked negative effect on the growth of barley (especially grain yield), there was no interaction between water stress and B tolerance. This is surprising as the B tolerant line had significantly greater mass of roots than the intolerant line, especially in the subsoil. This greater mass of roots in the subsoil would presumably enhance the ability to tolerate water stress (7) by permitting greater access to reserves of subsoil water. One possible explanation of this inconsistency is that although there were likely to have been roots already present in the subsoil at the timing of water stress (booting), their capacity to fully function was impaired. If the effect of salinity did over-ride that of subsoil B, effective increases in the EC of the soil solution as soil water content decreased may have had a proportionally greater negative impact on root growth than drought stress.

We conclude that for the two soil types studied, B tolerance provided minimal benefit to the growth of barley and that some other factor, probably either salinity or sodicity, was having an overriding affect. These other factors need to be considered in current selection strategies utilised by plant breeders if the productivity of crops growing on these soils is to be improved in the future.

Acknowledgements

We would like to thank David Moody (VIDA) for supplying the barley germplasm and David Smith (Birchip) for allowing us to collect intact cores from his property. This research was funded by the Victorian Government's 'Science and Technology Initiative'.

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