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Boron uptake and toxicity in wheat in relation to zinc supply

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Abstract

Zinc deficiency may enhance B absorption and transport to such an extent that B may possibly accumulate to toxic levels in plant tops. Therefore, a screen house experiment was conducted to investigate the effect of B levels (0, 2.5, 5.0, 7.5 and 10 mg B kg^{-1} soil) as influenced by Zn levels (0, 10 and 20 mg Zn kg^{-1} soil) on DM yield of wheat tops and tissue concentration and uptake of B, Zn, Cu, Mn, Fe, Ca, Mg, K and P. Application of B decreased the dry matter yield of wheat significantly at all levels of Zn. Conversely, increasing levels of Zn increased the wheat yield significantly. The application of B increased the tissue concentration and uptake of B by wheat plants more in the absence than in the presence of Zn application. Consequently, concentration of B in wheat plants decreased with increasing levels of Zn application to the soil. This decrease in tissue B concentration was not only due to increased growth of wheat plants. Zinc application appears to have created a protective mechanism in the root cell environment against excessive uptake of B, as evidenced by the reduction of B uptake in Zn treated plants. The uptake of Mn, Mg and P decreased while the uptake of Cu, Fe, and K by wheat plants increased with Zn application. Whereas, the uptake of all nutrients (Cu, Fe, Mn, Ca, Mg, K and P) decreased significantly with the application of B. However, this depressive effect of B on nutrient uptake was less marked in the presence of applied Zn.

Introduction

In general, B contents of dicotyledonous plants are several orders of magnitude higher than those of monocotyledonous plants [3]. Therefore, cereal crops often show symptoms of boron toxicity when grown in alkaline soils of semi-arid regions containing inherently high levels of soluble B [2, 3]. Although the boron becomes less available to plants with increasing soil pH [4] but use of irrigation water containing B may results in toxic levels of B in soils [9, 16]. The availability of Zn to plants decreases in high pH soils [12]. Therefore it is possible that high levels of B and low levels of available Zn for cereals may occur simultaneously.

Recent study on P X Zn interaction has found, under conditions of low Zn, accumulation of P in bean tops with increasing P supply [17]. Phosphorus can possibly accumulate to toxic levels in leaves under conditions of low Zn supply [14, 15]. In a solution culture study [5], it was reported that B toxicity was more severe and appeared first in Zn deficient barley plants compared to those of supplied with adequate Zn. This screen house study was conducted to determine the nature of B × Zn interaction in wheat plants.

Materials and methods

A screen house experiment was conducted in polyethylene-lined earthen pots filled with 4 kg of Zn deficient loamy sand (*Typic Torripsamments*). Some characteristics of the soil are as follows, pH (1 : 2) 8.1, E.C. 0.28 ds m^{-1}, organic carbon [7] 0.05%, CEC [7] 3.4 cmol(p^+) kg^{-1} and DTPA-extractable [13] Zn 0.32 mg kg^{-1}. Treatments consisted of five levels of B as boric acid (0, 2.5, 5, 7.5 and 10 mg B kg^{-1} soil) and three levels of Zn as $ZnSO_4.7H_2O$ (0, 10 and 20 mg Zn kg^{-1} soil). All treatments were replicated four times in a completely randomized factorial design. A basal dose of 100, 50, 63, 10, 5 and 5 mg kg^{-1} soil of N, P, K, Fe, Cu and Mn, respectively was added to the soil in solution form and mixed thoroughly with soil before sowing. The soil pots were wetted to field capacity with deionized water and incubated for 48 h before seeding. Six seeds of wheat (*Triticum aestiuum* L.) were sown in each pot and thinned to four plants after germination. The pots were watered daily to field capacity. The aboveground plant material was harvested at FEEKES 10 (Sheath of the last leaf extended with the ear swollen but not yet visible) growth stage and washed with deionized/distilled water.

The plant material was oven dried at 60°C for 72 h and weighed. Dried plant material was ground to <425 μm in a wiley mill and digested in an acid mixture of H_2SO_4 and $HClO_4$ (5 : 1) for the analysis of all nutrients except boron. Boron was analysed by dry ashing plant samples at 550°C for 4 h, extracting the ash with HCl and using Azomethine-H method [8]. Zinc, Cu, Fe and Mn in plant digest were determined by atomic absorption spectrophotometry [6] and K by flamephotometry [6]. Phosphorus was determined on spectrophotometer using Koenig and Johnson method [10] and Ca and Mg by EDTA Titrimetry [11]. All data were analysed by a two-way analysis of variance. Least significant difference was used to compare the main treatment and interaction effects at $P < 0.05$.

Results and discussion

Yield

Dry matter (DM) yield of wheat decreased significantly with the increasing levels of applied B at all levels of Zn (Table 1). The maximum reduction in mean DM yield occured at 10 mg kg^{-1} B level and amounted to 38% compared to control. In contrast, increasing levels of Zn increased the DM yield significantly. The increase in DM yield was largest for the first

Table 1. Effect of B and Zn application on the dry matter yield and microelement concentration of wheat

Treatment, mg kg^{-1}		Dry matter yield (g pot^{-1})	Microelement concentration, mg kg^{-1}				
B	Zn		B	Zn	Cu	Fe	Mn
0	0	5.84	35	6.7	30.2	260	160
	10	8.77	23	40.0	24.5	193	101
	20	9.01	20	55.5	24.8	137	87
2.5	0	5.47	132	5.9	27.4	266	148
	10	7.79	60	39.1	21.3	198	90
	20	8.15	48	51.8	21.2	190	76
5.0	0	4.91	215	6.7	27.7	272	141
	10	7.15	135	38.9	20.2	203	83
	20	7.55	114	48.8	19.7	194	69
7.5	0	4.23	334	7.1	28.2	279	139
	10	6.17	202	38.5	21.2	208	81
	20	6.90	172	49.3	20.3	198	67
10.0	0	3.37	465	8.6	31.8	286	140
	10	5.23	252	40.0	24.4	214	83
	20	6.03	209	49.9	23.0	203	69
LSD ($P < 0.05$)							
	B	0.19	7.8	1.6	0.9	8.7	4.1
	Zn	0.15	6.0	1.2	0.7	6.7	3.2
	B × Zn	0.33	13.5	2.7	NS	NS	NS

addition of applied Zn, however, further increase in DM due to the application of 20 mg Zn kg^{-1} was small but significant. A significant B × Zn interaction at $P < 0.05$ on DM yield was obtained and the applied Zn increased the yield at all levels of applied B. The effect of Zn in increasing DM yield varied depending upon B level. For example, the effect of 20 mg Zn kg^{-1} over 10 mg Zn kg^{-1} in increasing DM yield was greatest (0.80 g pot^{-1}) at 10 mg B kg^{-1}, least (0.36 g pot^{-1}) at 2.5 mg B kg^{-1} and non-significant (0.14 g pot^{-1}) at 0 mg B kg^{-1} soil treatment. This marked effect of Zn on DM in the presence of applied B supports the recent finding of Graham et al. [5] which suggested that Zn has a protective role against toxic effect of B concentration in the root environment.

Microelement concentration and uptake

Application of B to the soil resulted in a significant increase in the B concentration and uptake (Tables 1 and 2). The increase in concentration and uptake of B by wheat plants was greater in the absence than in the presence of applied Zn. There was a significant interaction between B and Zn on the concentration and uptake of B in wheat plants (Tables 1 and 2). When no B was applied, increasing Zn levels decreased but not significantly the B concentration and uptake of B by wheat plants. However, when B was applied, increasing Zn levels significantly decreased the concentration and uptake of B. The decrease in tissue B concentration was not only due to growth response (dilution effect) to applied Zn, since the decrease in B concentration was accompanied by decrease in total B uptake. Thus, these results imply that application of Zn provided a protective mechanism in the root cell environment against the excessive uptake of B as previously reported [5].

Application of B resulted in significant decrease in the uptake of B by wheat plants (Table 2) but there was an increase in the concentration of Zn with the application of B from 2.5 mg kg^{-1} treatment onward, where no Zn had been applied (Table 1). This could be due to the decrease in DM yield at higher levels of applied B. The effect of B in depressing Zn uptake was more marked at 10 or 20 mg Zn kg^{-1} than at 0 mg Zn kg^{-1} treatment (B × Zn interaction significant at $P < 0.05$). Zinc concentration and uptake of Zn by wheat plant tissue increased

Table 2. Effect of B and Zn application on the microelement uptake of wheat

Treatment, mg kg^{-1}		Microelement uptake				
B	Zn	μg pot^{-1}		mg pot^{-1}		
		Zn	Cu	B	Fe	Mn
0	0	39.1	176.4	0.20	1.52	0.93
	10	350.8	214.9	0.20	1.69	0.89
	20	500.1	223.4	0.18	1.68	0.78
2.5	0	32.3	149.9	0.72	1.45	0.81
	10	304.6	165.9	0.47	1.54	0.70
	20	422.2	172.8	0.39	1.55	0.62
5.0	0	32.9	131.1	1.06	1.34	0.69
	10	278.1	144.4	0.97	1.45	0.61
	20	368.4	148.7	0.86	1.46	0.52
7.5	0	30.0	119.3	1.41	1.18	0.59
	10	237.5	130.8	1.25	1.28	0.52
	20	340.2	140.1	1.19	1.37	0.46
10.0	0	28.9	107.2	1.57	0.96	0.47
	10	209.2	127.6	1.32	1.12	0.43
	20	300.9	138.7	1.26	1.22	0.42
L.S.D. ($P < 0.05$)						
	B	5.7	6.2	0.03	0.05	0.03
	Zn	4.4	4.8	0.02	0.04	0.02
	B × Zn	9.9	10.7	0.05	NS	0.05

several folds with the application of 10 or 20 mg Zn kg^{-1} soil compared to the treatment where no Zn had been applied. This effect of Zn was marked at each level of B.

The concentration of Cu in wheat plants decreased with the applied B upto 5 mg kg^{-1} levels and then increased with the further application of B to soil. However, tissue concentration of Mn in wheat plants decreased significantly with the increasing levels of applied B to the soil (Table 1). On the contrary, tissue Fe concentration increased with the application of B which may be due to a concentrating effect of B because of reduced plant growth. Copper, Fe and Mn uptake in wheat plants decreased significantly with the increasing levels of B application (Table 2). The decrease in micro-element uptake could be due to the toxic effects of B on root cells resulting in impaired nutrient absorption processes.

The tissue concentration of Cu, Fe and Mn significantly decreased with the application of Zn. The uptake of Cu and Fe by wheat plants increased while the uptake of Mn by wheat plants decreased markedly with the application of Zn (Table 2). Thus, the decrease in Cu and Fe concentration was due to dilution effect but decrease in Mn uptake with the application of Zn indicated that Zn had a antagonistic effect at the root surface on the absorption of Mn from the soil. Zinc treatment has also been found to decrease Mn uptake to a much greater extent than other nutrient elements [5].

A significant interaction of B × Zn observed on Cu and Fe uptake indicated that the increase in Cu and Fe uptake was more in the absence than in the presence of applied B. On the other hand, combined application of both B and Zn together resulted in a greater magnitude of decrease in the Mn uptake compared to where B and Zn were applied separately.

Macroelement concentration and uptake

Tables 3 and 4 show the effect of B and Zn application on the concentration and uptake of Ca, Mg, K and P in wheat plants. The tissue concentration of P and Mg increased while concentration of Ca and K decreased with the increasing supply of B in soil. Application of Zn decreased the concentration of Mg, K and P but only P concentration was affected significantly. Calcium concentration in wheat plants increased with the application of Zn at lower levels of applied B. However, at 7.5 and 10 mg kg^{-1} B levels, Ca concentration decreased with the increasing levels of applied Zn. The uptake of P and Mg by wheat plants decreased while the

Table 3. Effect of B and Zn application on macroelement concentration of wheat

Treatment, mg kg^{-1}		Macroelement concentration, %			
B	Zn	Ca	Mg	K	P
0	0	0.88	0.26	3.85	0.63
	10	0.90	0.16	3.46	0.41
	20	0.97	0.14	3.31	0.38
2.5	0	0.82	0.28	3.63	0.66
	10	0.82	0.17	3.25	0.42
	20	0.87	0.15	3.12	0.39
5.0	0	0.79	0.29	3.50	0.70
	10	0.77	0.17	3.14	0.43
	20	0.80	0.15	3.01	0.40
7.5	0	0.78	0.30	3.46	0.75
	10	0.74	0.18	3.10	0.46
	20	0.75	0.15	2.99	0.41
10.0	0	0.79	0.31	3.50	0.81
	10	0.73	0.18	3.16	0.50
	20	0.72	0.15	3.06	0.42
L.S.D. ($P < 0.05$)					
	B	0.03	NS	NS	0.02
	Zn	0.02	NS	NS	0.02
	B × Zn	0.05	NS	NS	0.04

Table 4. Effect of B and Zn application on the macroelement uptake of wheat

Treatment, mg kg^{-1}		Macroelement uptake, mg pot^{-1}			
B	Zn	Ca	Mg	K	P
0	0	51.4	15.2	224.8	36.8
	10	78.9	14.0	303.4	36.0
	20	87.4	12.6	298.4	34.2
2.5	0	44.9	15.3	198.6	36.1
	10	63.9	13.2	253.2	32.7
	20	70.9	12.2	254.3	31.8
5.0	0	38.8	14.2	171.8	34.4
	10	55.1	12.2	224.5	30.8
	20	60.4	11.3	227.3	30.2
7.5	0	33.0	12.7	146.4	31.7
	10	45.7	11.1	191.3	28.4
	20	51.8	10.4	206.3	28.3
10.0	0	26.2	10.5	117.9	27.3
	10	38.2	9.4	165.3	26.2
	20	43.4	9.1	184.5	25.3
L.S.D. ($P < 0.05$)					
	B	2.1	0.5	8.4	1.2
	Zn	1.7	0.4	6.5	0.9
	B × Zn	3.7	NS	14.5	NS

uptake of Ca and K by wheat plants increased with the increasing levels of applied Zn. On the contrary, increasing the supply of B to wheat plants significantly decreased the uptake of all the four macronutrient by wheat plants. Interactive effect of B and Zn was significant at P 0.05 only on the uptake of Ca and K. The highest uptake of Ca and K by wheat plants occurred at 20 mg kg^{-1} of applied Zn in the absence of applied B while lowest uptake occurred where 10 mg kg^{-1} B had been applied to the soil. The antagonistic relationship between the application of B and the uptake of macronutrients (Ca, Mg, K and P) has also been observed in other studies [1, 4, 18].

In conclusion, the results of this work support the concept that Zn performs a protective role at or in root cell membranes against toxic effects of boron [5]. Application of Zn lowered tissue B concentration of wheat plants by promoting plant growth and by curtailing the excess uptake of B. In general, high levels of applied B had an antagonistic effect on the uptake of macro and micro elements.

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