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Full Length Research Paper

The effects of soil boron and calcium applications on boron and calcium uptake in Durum wheat (*Triticum durum* L.)

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Recently, boron (B^+) toxicity has received a great deal of attention as it decreases yield of crops significantly. In this study, we intestigated whether the application of different levels calcium (Ca^{2+}) could alleviate B^+ toxicity in Durum wheat induced by high levels of B^+ present in irrigation water. Durum wheat cv. Ege-88 was grown in soil culture with four levels of B^+ (0, 2.5, 5 and 10 mg kg^{-1} soil as HBO_3) and three levels of calcium (0, 100 and 200 mg kg^{-1} as CaOH). B^+ and Ca^{2+} applications increased shoots concentrations of these nutrients in a linear fashion, while increased Ca^{2+} application reduced B^+ concentrations in the shoots. According to the analysis results, increased B concentrations were decreased while Ca concentrations increased dry matter in shoot. These results suggest that liming has potential to alleviate B^+ toxicity and improve crop yield in Durum wheat.

Key words: Boron, boron toxicity, calcium, Durum wheat.

INTRODUCTION

The majority of recent studies have reported an antagonistic relationship between boron (B^+) and calcium (Ca^{2+}) or potassium (K^+) concentrations at plant-soil interface (Brady and Weil, 2008). Of soil properties, pH, texture, lime, moisture, temperature, organic matter and clay mineorology have the largest effects on plant available B in the soil (Goldberg, 1997). The author reported that lime (calcium carbonate, $CaCO_3$) was one of the most important factors affecting the adsoprtion of B^+. Marschner (1997) indicated that in soils with high pH, lime and clay content, plant available B^+ was reduced by the formation of $B(OH)_4$ and adsorption of anions. A recent study by Kizilgoz et al. (2004) found that there was a negative relationship between B^+ uptake by the plant and water soluble Ca^{2+} or total Ca^{2+} ($p < 0.01$).

In general Ca^{2+}/B^+ ratio is a good indicator of B^+ status of the plant (Blamey et al., 1979). In their study with different $CaCO_3$ applications (0, 4000 and 8000 kg ha^{-1} were applied to an acid soil; Tsadilas et al., 2005) demonstrated that the pH of the soil increased as $CaCO_3$ increased. As a result, both plant available B^+ and B^+ concentration in the tobacco plants were decreased significantly. Increasing Ca^{2+}/B^+ ratio resulted in B^+ deficiency. In a separate study with barley, it has been reported that Ca^{2+}/B^+ ratio greater than 697 resulted in B^+ deficiency (Gupta, 1972). While Ca^{2+}/B^+ ratio of 260 gave rise to adequate B^+ and Ca^{2+} nutrition, Ca^{2+}/B^+ ratio of 7-22 was associated with severe B^+ deficiency (Gupta, 1972).

In a hydroponic study with maize, Kanval et al. (2008) demonstrated that the application of both B^+ and Ca^{2+} increased shoot dry matter. In the same study, a negative relationship was found between the application of Ca^{2+} and B^+ concentration in the plant. Tariq and Mott (2006) reported that Ca^{2+}/B^+ ratio in the soil solution had a negative relationship with phosphorus (P^+), iron (Fe^{2+}), B^+ and molybdenum (Mo), while it had a positive relationship with nitrogen (N), K+, Ca^{2+}, magnesium (Mg^{2+}), sodium (Na^+), zinc (Zn^{2+}), manganese (Mn^{2+}) and copper (Cu^{2+}). Evans et al. (1994) showed that the application of $CaCO_3$ to acid soils increased shoot growth in alfa alfa, and there was a linear relationship between plant B^+ concentration and plant available B^+ concentration in the soil depending on Ca^{2+} addition.

Bread wheat and Durum wheat differ in their requirement of B^+ and their responses to B^+ fertilisation. Taban and Erdal (2000) investigated the effects of B^+

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Table 1. The physical and chemical properties of the soil used in the present study.

Sand (%)	Silt (%)	Clay (%)	pH	EC (dS m^{-1})	Cation exchange capacity (cmol kg^{-1})	$CaCO_3$ (%)	Organic Matter (%)	B (mg kg^{-1})
3.8	27.9	68.3	7.48	346	65.4	12.9	1.54	0.43

Table 2. The effects of soil B^+ and Ca^{2+} applications on shoot B^+ and Ca^{2+} concentrations in Durum wheat.

Soil application		Shoot concentration		Ca^{2+}/B^+(%)	Dry matter (%)
B^+ (mg kg^{-1})	Ca^{2+} (mg kg^{-1})	B^+ (ppm)	Ca^{2+}(%)		
0	0	7.2	0.32	444.4	11.3
0	100	5.9	0.68	1152.5	11.8
0	200	3.7	1.45	3918.9	12.6
2.5	0	35.4	0.25	70.6	10.7
2.5	100	25.5	0.53	207.8	11.2
2.5	200	11.8	0.94	796.6	11.8
5.0	0	51.7	0.20	38.7	9.8
5.0	100	34.2	0.36	105.2	10.2
5.0	200	15.4	0.64	415.6	10.9
10	0	82.6	0.14	16.9	8.3
10	100	63.3	0.26	41.0	9.0
10	200	34.6	0.41	118.5	9.9

fertilisation on bread and Durum wheat in a clay silty soil with 12% lime, pH of 7.9 and plant available B^+ concentration of 1.52 mg kg^{-1} soil. The authors reported that B^+ fertilisation increased dry matter of bread wheat, but decreased dry matter of Durum wheat. Kalayci et al. (1998) found that B^+ toxicity decreased root dry matter more than shoot dry matter.

The threshold for B^+ deficiency and toxicity is very narrow in wheat. Rehm et al. (2002) reported that B^+ deficiency reduced plant growth by 12 - 20%. B^+ toxicity also decreases crop yield and quality. For example, compared to the control treatment, the soil application of 25 mg kg^{-1} B^+ was shown to decrease yield by 5 - 34% in wheat (Alkan, 1998). The aim of this study was to determine the effects of soil B^+ and Ca^{2+} applications on the uptake of these two nutrients in Durum wheat.

MATERIALS AND METHODS

Plant material

A Durum wheat cultivar Ege-88 was used in this glasshouse study. Plants were grown in pots (4 kg capacity) filled with a soil determined based on detailed soil surveys conducted by Dinc et al. (1988). Different rates of Ca^{2+} [0, 100 and 200 mg kg^{-1} as $Ca(OH)_2$ and B^+ (0, 2.5, 5.0 and 10 mg kg^{-1} soil as HBO_3] were applied to this soil. Basal fertilisers were also applied to this soil to ensure the maximum uptake of B^+ by the plants (650 mg N as 26% NH_4NO_3, 300 mg P as KH_2PO_4 and 530 mg K as K_2SO_4 and KH_2PO_4 ; Hakerlerler et al., 1997). The physical and chemical properties of the soil used in the present study are given in Table 1.

Growing conditions

25 seedlings were sown in each pot. Seedlings were thinned to 15 once they established (5 cm tall). Plants were grown in a glasshouse and watered with de-ionised water. After six weeks of growth, shoots were harvested at 5 cm above the soil surface. Shoot samples were rinsed first in tap water then in de-ionised water. The samples were oven-dried at 70°C for determination of shoot dry matter. Dry shoot samples were ground, ashed 550°C and dissolved in 3.3% HCl (Cakmak et al., 1996). B^+ concentration in the ash was determined by azomethine-H method (Bingham, 1982).

Statistical analysis

The study was set up as randomized complete block design with four replications. The analysis of variance was conducted using statistical software Minitab 14. Significant differences were declared at 0.01 probability level.

RESULTS AND DISCUSSION

Shoot B^+ and Ca^{2+} concentrations as a result of soil applications of B^+ and Ca^{2+} and the relationship between shoot B^+ and Ca^{2+} concentrations are given in Table 2 and Figures 1, 2 and 3. It is clear that increasing soil application of B^+ increase shoot B^+ concentrations. For example, when no B^+ was applied to the soil, shoot B^+ concentration was 7.2 mg kg^{-1} DW. At 10 mg B^+ kg^{-1} soil, shoot B^+ concentration reached 82.6 mg kg^{-1} DW. In contrast, increasing soil Ca^{2+} supply decreased shoot B^+

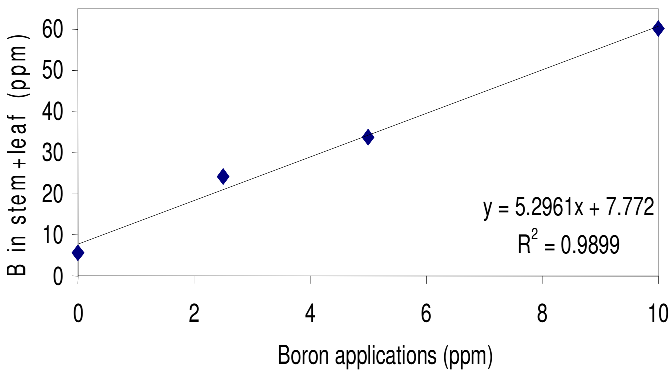

Figure 1. The relationship between soil B^+ applications and shoot B^+ concentrations.

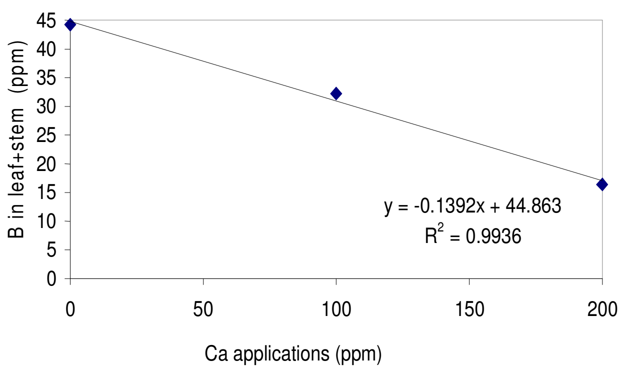

Figure 2. The relationship between soil Ca^{2+} applications and shoot B^+ concentrations.

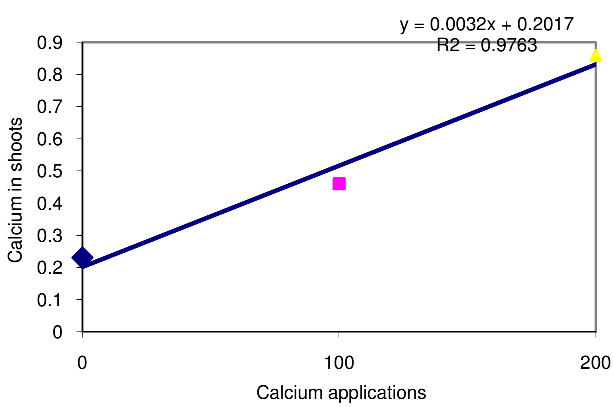

Figure 3. The relationship between soil Ca^{2+} applications and shoot Ca^{2+}concentrations.

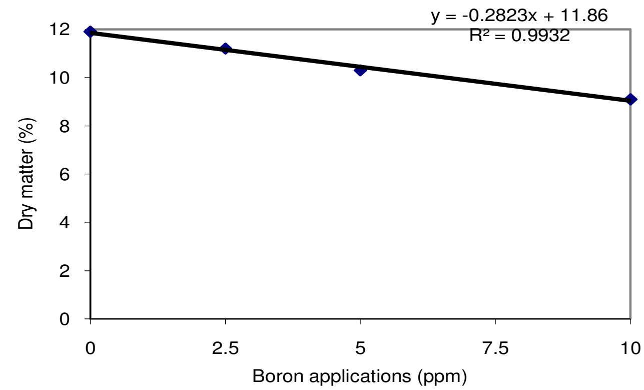

Figure 4. The relationship between boron application and dry matter content of shoot.

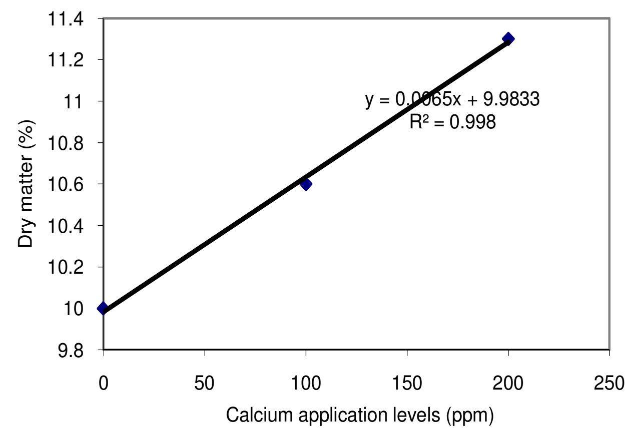

Figure 5. The relationship between calcium application and dry matter content of shoot.

concentration significantly. When soil Ca^{2+} supply was increased from nill to 200 mg Ca^{2+} kg^{-1} soil, shoot B^+ concentrations declined from 7.2 to 3.7 mg kg^{-1} DW. Increasing Ca^{2+} supply from 100 - 200 mg kg^{-1} soil reduced shoot B^+ concentration by 37.3%. These results are in agreement with previous studies (Sotiropoulos et al., 1999; Turan et al., 2009).

The trend was similar for other B^+ and Ca^{2+} rates. For example, at 2.5 mg B^+ kg^{-1} soil, plants supplied with 100 mg Ca^{2+} kg $soil^{-1}$ had 116% higher B^+ concentration compared to those supplied with 200 mg Ca^{2+} kg^{-1} soil. At 5.0 mg B^+ kg^{-1} soil, shoot B^+ concentration of plants supplied with 100 mg Ca^{2+} kg^{-1} soil was 122.1% higher than those supplied with 200 mg Ca^{2+} kg^{-1} soil. At the highest soil B^+ supply, compared to 200 mg Ca^{2+} kg^{-1} soil, shoot B^+ concentrations in plants supplied with no external Ca^{2+} were increased by 138.7. It is clear from Figures 2 and 3 that soil Ca^{2+} application reduced shoot B^+ concentration , while it increased shoot Ca^{2+} concentration. When Ca^{2+} supply was increased from nill to 200 mg kg^{-1} soil, shoot Ca^{2+} concentration was increased from 0.32 to 1.45%, 0.94, 0.64 and 0.41% at 0, 2.5, 5.0 and 10 mg B^+ kg^{-1} soil, respectively. According to the analysis results, increased B concentrations were decreased while Ca concentrations increased dry matter in shoot (Figures 4 and 5). These results are in agreement with previous studies (Havlin et al., 2005; Tsadilas, 2005; Kanvall et al., 2008; Brady and Weil, 2008).

Obtained Ca/B ratio confirms above mentioned results while Ca/B ratio >697) causes boron deficiency, 7-22 ratio result in boron toxicity (Gupta, 1972). In this current study, 4th application showed boron deficiency and 10th application caused boron toxicity.

Conclusıon

In conclusion, soil B^+ application increased shoot B^+ concentration while soil Ca^{2+} application decreased shoot B^+ concentration. The responses were linear in both cases (Figures 1 and 2). Similar to B^+, soil Ca^{2+} application increased shoot Ca^{2+} concentration. Liming has potential to alleviate B^+ toxicity and improve crop yield.

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