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ORIGINAL PAPER

EFFECT OF PHOSPHORUS ON THE ALLEVIATION OF BORON TOXICITY IN THE TOMATO PLANT*

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Abstract

Boron plays an important role in plant nutrition and plant growth. Boron in low concentrations is essential for plants but produces a toxic effect if present in high amounts. Boron toxicity is particularly common in arid and semi-arid climates and in areas where thermal water resources are used. High boron levels in soils can cause toxicity in plants and prevent plant growth. Negative effects of toxicity can be reduced by some plant nutrition treatments. The aim of this study was to investigate the effects of plant nutrition treatments on the alleviation of B toxicity, and the effects of increasing P doses on tomato plant at toxic levels of B were observed in greenhouse conditions. The study was conducted under greenhouse conditions in the autumn growing period, in Antalya-Turkey, and using 4 different levels of B (0, 5, 10 and 20 mg kg^{-1} with H_3BO_3) and 3 levels of P (25, 50, 100 mg kg^{-1} with mono ammonium phosphate). Tomato plants (*Lycopersicon esculentum* Mill., cv. 'Tayfun F1') were cultivated in plastic pots (6 kg pot^{-1} soil) for a period of 10 weeks to determine some growth parameters and the nutrient content. As a result of the research, it was determined that the growth of tomato plant was negatively affected by B toxicity and boron toxicity symptoms occurred in the plants. B and P applications increased the plant nutrient content, and P2 (50 mg kg^{-1} P) treatment decreased the B content in the plant. Increased P treatments caused an increase in nutrient content, thereby ensuring plant development and the negative effects of toxicity were reduced owing to the effect of dilution.

Keywords: boric acid, phosphorus, plant nutrition, tomato.

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INTRODUCTION

Plants need nutrients to grow and nutrients can be supplied to plants by fertilization. Macronutrients have an important place in the nutrition of plants, and micronutrient elements have many physiological functions that affect the plant growth. Although 800 million people worldwide are undernourished in terms of energy and protein requirements, about 2 billion people are exposed to insufficient levels of micro-elements (B, Zn, Fe, Se etc.) and vitamin deficiency; this group is known as the hidden hungry (Çakmak 2002). The World Health Organization reported that a healthy adult could take 1-13 mg of boron through nutrition (WHO 1998). The main source of boron in food are vegetable crops, such as legumes, fruits and vegetables. Boron is an essential element for brain functions and mental performance. Boron element is involved in the regulation of calcium, vitamin D and some body minerals; it has also been found to protect the bone structure by preventing the reduction of Ca and Mg (Demirtas 2010). Boron (B) is a necessary micronutrient for nutrition of plants, where it improves some growth parameters, such as the plant growth, metabolic processes, cell functions, etc. (El-Hamdaoui et al. 2003). Boron is transported with the xylem in plants by transpiration. The element boron is absorbed from the soil by plants as non-ionized boric acid (Shelp et al. 1992, Dordas, Brown 2000). The amount of boron needed by plants is quite low and any amount above or below this critical level has a negative impact on the development of the plant (Hu et al. 1996, Hua et al. 2020).

Boron is mostly present within normal limits in soil, especially in arid and semi-arid climates, but boron deficiency can be seen in sandy or acid-reactive soils. Boron concentrations in arid and calcareous alkaline or organic soils can be toxic to plants (Kacar 2019). Water-soluble boron content of soil is classified as: very low (<0.25 mg kg^{-1}), low (0.25-0.5 mg kg^{-1}), medium (0.51-1.0 mg kg^{-1}), high (1.1-2.0 mg kg^{-1}) and very high (>2.0 mg kg^{-1}) – Choi et al. (2015). Boron absorbed by plant organs is carried to the plant's upper parts by transpiration, where it can accumulate (Kacar, Katkat 1999). Although low concentrations of boron are necessary, high concentrations have a toxic effect on plants (Ozgul 1974). Erdal et al. (2014) emphasized that genetic factors can be an important defence mechanism against the negative effects of boron toxicity. High levels of boron in soils are known to have negative effects on the growth of plants (Khan et al. 1999). Aydin et al. (2005) reported that B and P treatments improved the maize growth while the phosphorus content decreased under boron toxicity conditions. Gunes, Alpaslan (2000) found that increasing P concentrations reduced boron concentrations in maize genotypes under conditions of boron toxicity. The methods used for the alleviation of boron toxicity in plants consist of the application of some nutrient elements, plant growth regulators (PGRs), plant growth promoting microbes (PGPMs), lime, organic matter or leaching the soil with water, etc. (Hua et al. 2020). This study aimed to determine the effects of increasing phosphorus doses on the macro- and micronutrient content of tomato plants under boron toxicity conditions.

MATERIAL AND METHODS

The study was carried out in a spring-roofed plastic greenhouse (36°54′ 00.25 north latitude, 30°38′ 49.07 east longitude, altitude 37 m) in the Research and Application Site of the Agricultural Faculty of Akdeniz University, Antalya in Turkey. The experiment was laid out in a randomized plot design, with four replications. The soil was analysed and the results are shown at Table 1. Tomato seedlings (*Lycopersicon esculentum* Mill., cv. 'Tayfun F1') were grown in pots (6 kg pot^{-1} soil) and the experiment was planned for 10 weeks. Boron was added at doses of B0 – 0 mg kg^{-1}, B1 – 5 mg kg^{-1}, B2 – 10 mg kg^{-1} and B3 – 20 mg kg^{-1} as H_3BO_3, phosphorus was added at doses of P1 – 25 mg kg^{-1}, P2 – 50 mg kg^{-1} and P3 – 100 mg kg^{-1} to soil, and the basic fertilization were applied using ammonium nitrate, potassium nitrate and mono ammonium phosphate. Irrigation was adjusted according to 70% of the field capacity of the soil, the air temperature in the greenhouse varied between 16-26°C, and the relative humidity was maintained between 60-65% during the experimental period. All necessary plant cultivation and protection treatments were uniformly followed for all the treatments during the entire period of experimentation.

Table 1

Some physical and chemical parameters of soil in experiment

Parameters	Value	Parameters	Value
Texture (%)	clay (44.16)	Ca (mg kg^{-1})	2581
Organic matter (%)	4.34	Mg (mg kg^{-1})	441.4
$CaCO_3$ (%)	30.25	Fe (mg kg^{-1})	3.31
pH (1:2.5; soil/water)	7.46	Zn (mg kg^{-1})	0.284
EC (1:2.5; soil/water)(dS m^{-1})	0.803	Mn (mg kg^{-1})	35.2
Total N (%)	0.245	Cu (mg kg^{-1})	0.59
P (mg kg^{-1})	156	B (mg kg^{-1})	0.001
K (mg kg^{-1})	430		

Plant analysis

The tomato plants were harvested and prepared for analysis. The plant samples were rinsed with distilled water and dried in an air-forced oven at 65°C to constant weight. Plant samples were subjected to wet combustion with $HNO_3/HClO_4$ (4:1) acid mixture and the amounts of macro- and micro-elements (K, Ca, Mg, Fe, Zn, Mn, Cu) were determined by using inductively coupled plasma (Perkin Elmer Optima DV7000-ICP OES). Kjeldahl nitrogen (N) was determined by Kjeldahl digestion according to Bremner (1965). Phosphorus (P) was measured by spectrophotometry (Kacar, Kovanci 1982). Boron in plant samples was determined using the azomethine-H reagent method (Wolf 1974).

Statistical analysis

All data obtained from the study were subjected to analysis of variance. The Duncan's Multiple Range Test was used to determine the significance of differences between treatments, using SPSS software to determine the importance of the effects of the treatments (p<0.05).

RESULTS AND DISCUSSIONS

The increasing doses of phosphorus affected the nutrient content of tomato plants under boron toxicity conditions. Although the negative effects of boron toxicity were mostly observed in the early growth stages, the adverse impact of toxicity decreased with phosphorus treatments. Tomato plants showed pronounced B toxicity symptoms when grown in soil with excess B. Boron toxicity symptoms were leaf burn, chlorosis (yellow-green interveinal) and necrotic patches in tips of older leaves, same as noted by Brown, Shelp (1997).

The effects of increasing levels of B and P on the boron content of tomato plants are shown in Table 2. Increasing the dose of boron caused an increase

Table 2

Change of boron contents (g kg^{-1}) of plants with B and P treatments

Specification	P1	P2	P3	Mean
B0	0.082	0.060	0.054	0.065*D*
B1	0.268	0.227	0.291	0.262*C*
B2	0.488	0.451	0.733	0.557*B*
B3	1.138	0.903	1.110	1.050*A*
Mean	0.494(*BA*)	0.410(*B*)	0.547(*A*)	-
B	109.03***			
P	3.77*			
B×P interaction	1.46 ns			

* p<0.05, *** p<0.001, ns – not significant

The values followed by uppercase letters indicate a difference between the increasing levels of boron. The values followed by uppercase letters in parentheses indicate a difference between the increasing phosphorus levels.

in boron accumulation in plants, and B toxicity in plants reached critical levels with the lowest B dose but P2 – 50 mg kg^{-1} P dose reduced the amount of boron in tomato plants compared to the other doses. The 50 mg kg^{-1} P dose can be considered as a critical dose and effects of boron toxicity continued to be visible above the 50 mg kg^{-1} P dose. MARKIEWICZ (2009) stated that the content of boron >200 mg kg^{-1} is often toxic to tomato. However, it is seen in all cases that as the B doses increase, the B concentration in the tomato plant also increases. Some researchers have previously stated that the boron intake of plants is prevented by application of phosphorus, and the negative effects of boron toxicity are reduced. Higher boron doses increase the boron concentration and accumulation in plants (AYDIN et al. 2005). KAYA et al. (2009) determined that supplementary P decreased the B concentration in tomato leaves. OZEN (2006) reported that barley varieties showed different responses to boron applied in different amounts. YAMANOUCHI (1980) stated that the B concentration in tomato leaves decreased with an increase in P supply.

The increasing B and P levels have increased the phosphorus accumulation in the plants (Table 3). The maximum B (B3 – 20 mg kg^{-1}) and P

Table 3

Change in phosphorus content (g kg^{-1}) of plants with B and P treatments

Specification	P1	P2	P3	Mean
B0	0.89*f*	1.01*f*	1.31*ef*	1.07*D*
B1	1.12*f*	1.37*edf*	1.68*ed*	1.39*C*
B2	1.35*edf*	1.81*cd*	2.32*b*	1.83*B*
B3	2.19*cb*	2.29*b*	3.47*a*	2.65*A*
Mean	1.39(*C*)	1.62(i)	2.20(*A*)	-
B	58.95***			
P	29.01***			
B×P interaction	2.48*			

* $p<0.05$, *** $p<0.001$

The values followed by uppercase letters indicate a difference between the increasing levels of boron. The values followed by uppercase letters in parentheses indicate a difference between the increasing phosphorus levels.

(P3 – 100 mg kg^{-1}) doses affected the P content in tomato plants and the high-level P content encouraged the plant growth. In this case, the absence of toxicity symptoms can be attributed to the dilution effect caused by a more intensive plant growth. AYDIN et al. (2005) stated that as the boron and phosphorus treatments applied to corn increased, so did the plant content of P and B. Boron toxicity can be alleviated by phosphorus application. MOUHTARIDOU et al. (2004) stated that high doses of boron increase the phosphorus content in apples. When the amount of boron in soil increased, the amount of phosphorus in plant leaves increased as well (Çikili et al. 2013). There is a positive interaction between P and B and the interaction B×P was affected the content of P fractions in leaves (Sinha et al. 2003).

The increasing B doses contributed to an increase in the amounts of N and K in tomato plants (Table 4), which the B and P treatments improved

Table 4

Change of N and K contents (g kg^{-1}) of plants with B and P treatments

Specification	N contents				K contents			
	P1	P2	P3	mean	P1	P2	P3	mean
B0	19.8	24.0	28.4	24.1*C*	10.4	11.2	13.2	11.6*B*
B1	21.3	25.4	29.5	25.4*CB*	11.8	13.2	11.9	12.3*B*
B2	24.4	27.3	28.8	26.9*B*	10.1	11.6	12.0	11.2*B*
B3	28.4	30.5	34.7	31.2*A*	16.2	13.0	17.2	15.5*A*
Mean	23.5(C)	26.8(B)	30.3(A)	-	12.1	12.3	13.6	-
B	21.65***				10.04***			
P	35.66***				2.37 ns			
B×P interaction	0.84 ns				1.79 ns			

*** $p<0.001$, ns – not significant
The values followed by uppercase letters indicate a difference between the increasing levels of boron. The values followed by uppercase letters in parentheses indicate a difference between the increasing phosphorus levels.

the plant growth The plant nitrogen content increased because of the MAP applications to soil used as a phosphorus source. However, the application of increasing B doses also caused an increase in the plant's N content. Lopez-Lefebre et al. (2002) reported that increasing boron doses caused an increase in the N and K content in tobacco leaves. Boron values at toxic levels can cause increases in the N uptake by plants (Hussain et al. 2001, Inal, Tarakcioglu 2001). Boron treatments significantly affected the nutrient content of tomato and pepper plants (Eraslan et al. 2007).

The B treatments improved the Ca accumulation in plants while the P treatments did not affect the Ca content in tomato leaves (Table 5). The Ca and Mg content in tomato plants was within adequate limits (Jones et al. 1991). Boron plays an important role in Ca translocation and accumulation in plants (Ganmore-Neumann, Davidov 1993). Boron application to plants increased the Ca concentration in tobacco plants (Mouhtaridou et al. 2004). Increasing B doses affected the Mg content of plants and P1 treatment ensured an effective Mg content in tomato plants. Smit, Combrink (2004) reported that increasing B doses increased Ca, Mg, Na, Zn and B concentrations in leaves. Çikili et al. (2013) stated that increasing B concentration in soil increased the Mg content of cucumber.

Table 5

Change of Ca and Mg contents (g kg^{-1}) of plants with B and P treatments

Specification	Ca contents				Mg contents			
	P1	P2	P3	mean	P1	P2	P3	mean
B0	63.6	58.0	66.5	62.7*C*	7.2	6.5	7.9	7.2*B*
B1	81.2	69.5	62.9	71.2*BC*	9.5	7.9	7.3	8.2*B*
B2	75.1	72.8	85.5	77.8*BA*	9.8	9.1	10.6	9.8*A*
B3	89.5	75.2	77.8	80.9*A*	11.9	9.8	10.4	10.7*A*
Mean	77.4	68.9	73.2	-	9.6(*A*)	8.3(*B*)	9.0(*BA*)	-
B	7.01***				16.04***			
P	2.58 ns				3.58*			
B×P interaction	1.64 ns				1.35 ns			

* p<0.05, *** p<0.001, ns – not significant
The values followed by uppercase letters shows a difference between the increasing levels of boron. The values followed by uppercase letters in parentheses indicate a difference between the increasing phosphorus levels.

The increasing P doses caused an increase in the Fe content of tomato plants. The Fe content in the plants was within adequate limits (CAMPBELL 2000). Also, B and P treatments affected the Zn content of tomato leaves (Table 6). The Zn content in plants was modified by the highest B treatment. Particularly B3 and P1 treatments resulted in the highest Zn accumulation compared to the other treatments. But the Zn content of leaves determined

Table 6

Change of Fe and Zn contents (mg kg^{-1}) of plants with B and P treatments

Specification	Fe contents				Zn contents			
	P1	P2	P3	mean	P1	P2	P3	mean
B0	92.26	95.30	147.53	111.70	16.00*dc*	12.23*d*	14.77*dc*	14.33*B*
B1	108.28	128.78	129.08	122.05	18.23*bc*	16.63*dc*	14.96*dc*	16.60*B*
B2	92.43	127.65	147.50	122.53	12.23*d*	13.32*dc*	17.09*dc*	14.33*B*
B3	129.13	132.13	151.10	137.45	26.28*a*	17.64*dc*	23.02*ba*	22.31*A*
Mean	105.52(*B*)	120.96(*B*)	143.80(*A*)	-	18.18(*A*)	14.95(*B*)	17.45(*A*)	-
B	2.78 ns				15.24***			
P	12.22***				4.06*			
B×P interaction	1.49 ns				2.4*			

* p<0.05, *** p<0.001, ns – not significant
The values followed by uppercase letters shows a difference between the increasing levels of boron. The values followed by uppercase letters in parentheses indicate a difference between the increasing phosphorus levels.

was below the critical range (<18 mg kg^{-1}) for Zn by Campbell (2000). Increasing levels of phosphorus may decrease the availability of zinc or trigger zinc deficiency associated with phosphorus fertilisation (Mousavi et al. 2012). There is a negative interaction between P and Zn, which is an important parameter affecting plant growth (Salimpour et al. 2010), and Zn alleviates the excessive P absorption, similarly to the B×P interaction (Bergmann 1992). The high boron concentration in the plant increased plant levels of some micronutrients (Zn and Fe) – Sinha et al. (2000). Gunes et al. (1999) stated that supplementary Zn alleviated the negative impacts of boron toxicity in tomato plants.

The increasing B doses increased the Mn and Cu content in tomato plants, and B3×P1 doses particularly caused the maximum Mn accumulation of tomato leaves (Table 7). Increasing P doses did not affect the Cu content

Table 7

Change of Mn and Cu contents (mg kg^{-1}) of plants with B and P treatments

Specification	Mn contents				Cu contents			
	P1	P2	P3	mean	P1	P2	P3	mean
B0	102.55bc	93.15c	100.37*c*	98.68*B*	7.56	6.79	7.09	7.14*B*
B1	132.63ba	110.82bc	90.73*c*	111.39*BA*	6.86	6.19	7.17	6.74*B*
B2	108.58bc	97.87c	116.90*bc*	107.78*B*	5.56	7.07	8.15	6.92*B*
B3	156.68a	116.65bc	105.22*bc*	126.18*A*	10.38	7.18	10.50	9.35*A*
Mean	125.10(*A*)	104.61(*B*)	103.30(*B*)	-	7.59	6.81	8.23	-
B	4.6**				6.28***			
P	7***				2.85 ns			
B×P interaction	2.68*				1.69 ns			

* p<0.05, ** p<0.01, *** p<0.001, ns: not significant
The values followed by uppercase letters indicate a difference between the increasing levels of boron. The values followed by uppercase letters in parentheses indicate a difference between the increasing phosphorus levels.

of tomato plants. The Mn and Cu content of the tomato plants was within adequate limits (Jones et al. 1991). Excessive boron levels have been previously shown to cause Mn increases in some plants (Smit, Combrink 2004). Dangarwala (2001) stated that different doses of boron in the rice plant increased microelement (Zn and Cu) concentrations of some plants. Cikili et al. (2013) stated that increasing B concentration in soil increased the Mn and Cu content of cucumber.

CONCLUSIONS

1. Alleviation of boron toxicity by plant nutrition methods was investigated, and the effects of increasing phosphorus fertilisation on boron contained in soils in toxic levels on the development of tomato plants were evaluated.

2. Increasing B and P doses led to an increase in nutrient concentrations in tomato plants. It was observed that plants accumulated more nutrients under stress conditions.

3. Under boron toxicity conditions, symptoms of toxicity were observed on some leaf edges, but the growth rate did not change significantly compared to the control plants.

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