ACTA SCIENTIARUM POLONORUM
Acta Sci. Pol. Hortorum Cultus, 19(2) 2020, 97–104
www.acta.media.pl ISSN 1644-0692 e-ISSN 2545-1405 DOI: 10.24326/asphc.2020.2.10

ORIGINAL PAPER

Accepted: 3.07.2019

THE EFFECTS OF DIFFERENT DOSES OF NITROGEN ON TOMATO PLANT MINERAL CONTENTS UNDER BORON TOXICITY

Fatma Aslı Gündeş, İlker Sönmez✉

Department of Plant Nutrition and Soil Science, Akdeniz University, 07058, Antalya, Turkey

ABSTRACT

The effect of different nitrogen (N) treatments on the nutrient contents of tomato (*Lycopersicon esculentum* Mill., cv. 'Tayfun F1') under different boron (B) concentrations were investigated in greenhouse conditions with four replications. Four different levels of B (0, 5, 10 and 20 mg kg^{-1}) and three levels of N (100, 200, 300 mg kg^{-1}) were used in this research. The results showed that tomato plant growth was negatively affected with increasing B concentrations and symptoms of boron toxicity were observed. The tomato leaf nutrient concentrations were increased in all plants with B and N treatments and 20 mg kg^{-1} B and 300 mg kg^{-1} N treatments were determined to be more effective compared to the others. 20 mg kg^{-1} B and 100 mg kg^{-1} N treatment caused the highest micro element concentrations of tomato leaf. This could be interpreted as N application having a dilution effect to be able to maintain development under conditions of toxicity of B. The plants growth under boron toxicity conditions showed increased vegetation with increasing N applications which was attributed to the dilution effect.

Key words: boron toxicity, nitrogen, plant nutrition, tomato

INTRODUCTION

Boron (B) is an essential micronutrient for plant nutrition and plays an important role in plant growth, metabolic events and cell functions [El-Hamdaoui et al. 2003]. It is assumed that the boron is transported by plants through xylem due to transpiration and absorbed by plants from the soil as non-ionized boric acid [Pate 1975, Shelp et al. 1987, 1992, Dordas and Brown 2000]. In the passive absorption by the roots, the boron is absorbed through transpiration and is carried to the terminal points of the plant within the xylem transmission system [Hu and Brown 1997].

The boron element is generally present in arid and semi-arid region soils. Especially in arid and semi-arid regions, excess B in the soil causes toxicity in plants and plant growth is adversely affected by boron toxicity [Nable et al. 1997]. The extractable boron level in hot water from soil is reported as >0.8 mg kg^{-1} phytotoxicity [Silanpaa 1990]. Soil pH affects boron uptake and there is a positive relationship between soil pH: 6.5 and B uptake [Bingham et al. 1970, Gupta 1979].

Boron, which is required by the plants in trace amounts, is the element closest to its limit of deficiency and toxicity. However, it is a strategic element which is important for agriculture and is difficult to study due to the narrow range [Reisenauer et al. 1973, Adriano 1986, Alkan 1998, Blevins and Lukaszewski 1998, Mortvedt et al. 1991, Brown et al. 2002, Atalay et al. 2003]. As boron has limited movement in plant organs it is generally considered to be immobile [Kacar and Katkat 1999]. Boron is necessary for plants at low concentrations but has a toxic effect at high

✉ ilkersonmez@akdeniz.edu.tr

concentrations [Uygan and Çetin 2004]. High levels of plant death and crop loss are caused by boron toxicity [Khan et al. 1999]. Toxicity is also known to result in changes in the distribution of the shoots and transpiration ratio [Marschner 1995]. Common symptoms of boron toxicity in plants are the prevention of dry matter loss and root elongation. The signs of toxicity first occur on the old leaves and especially the accumulation of boron is seen on the edges of these old leaves [Tanaka and Fujiwara 2008, Rajaie et al. 2009]. Sakal [1987] stated that there was an antagonistic relationship between boron and nitrogen. Jones et al. [1963] found that nitrogen applied to soils with high boron content decreased boron intake in citrus fruits and the toxic effect was eliminated.

Plant nutrients may have positive effects on boron toxicity. Güneş and Alpaslan [2000] investigated the effect of increasing levels of applied (P) and (B) on maize growth and nutrient concentration. With the application of P, there was a decrease in B concentration and uptake and an increase in P concentration and uptake of the maize genotypes. Consequently, B toxicity could be alleviated with applications of P in the calcareous soils of semi-arid areas. Similarly, Çıkılı et al. [2013] determined that K treatments (0, 200 ve 400 mg kg^{-1} K_2SO_4) had a significant effect in the alleviation of boron toxicity. Shoot and root dry weights were reduced with the application of B, but the application of K decreased the alleviation effect of the boron. Aydın et al. [2005] stated that when B and P doses were increased in maize cultivation, the N, Ca, Mg, Fe, Mn, Zn and Cu contents of maize generally decreased and phosphorus decreased with increasing boron toxicity. Koohkan and Maftoun [2015] investigated that the effect of N treatments (0, 75, 150, and 300 mg kg^{-1}) on crop yield, B, and potassium (K) concentrations of rice plants grown under B toxicity (0, 2.5, 5, 10, 20, and 40 mg kg^{-1}). Boron addition (higher than 2.5 mg kg^{-1}) significantly reduced the seed yield and N addition alleviated the growth suppression effects caused by B supplements. Boron concentration declined with increasing N levels [Petridis et al. 2013].

The main objective of this study was to evaluate the effects of different nitrogen (N) treatments on growth and nutrient contents of tomato under different boron (B) concentrations in greenhouse conditions.

MATERIAL AND METHODS

The pot experiments were conducted under greenhouse conditions as a randomized plot design with four replications. Increasing nitrogen applications have been preferred because it promotes vegetative growth in preventing negative effects of boron at toxic levels. Because nitrogen promotes vegetative growth, it has a diluting effect on the amount of toxic boron. In addition, in determining nitrogen doses, the lowest dose is planned to be the same as the basic nitrogen requirement. Tomato (*Lycopersicon esculentum* Mill., cv. 'Tayfun F1') was grown in plastic pots (6 kg pot^{-1} soil) for a period of 10 weeks for growth parameters. In the experiment, boron was applied at the rate of 0, 5, 10, and 20 mg kg^{-1} as H_3BO_3, nitrogen was applied at the rate of 0, 100, 200 and 300 mg kg^{-1} and basal fertilization was conducted with ammonium nitrate (2.5 kg ha^{-1} N), mono ammonium phosphate (1.43 kg ha^{-1} P_2O_5) and potassium nitrate (4.0 kg ha^{-1} K_2O). During the experimental period, the soil was kept at approximately 70% of the field capacity by watering. The maximum air temperature inside greenhouse was 26°C, with a minimum night temperature of 16°C, relative humidity ranged from 60 to 65% during the cultivation period. Cultural processes were carried out during the vegetation period and the plants were harvested at the end of the experiment.

Some characteristics of the experimental soil were as follows: clay in texture (44.16% clay), organic matter (4.34%), $CaCO_3$ (30.25%), pH = 7.46, EC (0.803 dS m^{-1}), 0.245% total (N), 156 mg kg^{-1} available (P), 430 mg kg^{-1} extractable potassium (K), 2581 mg kg^{-1} extractable calcium (Ca), and 441.4 mg kg^{-1} extractable magnesium (Mg), 3.31 mg kg^{-1} available iron (Fe), 0.284 mg kg^{-1} available zinc (Zn), 35.2 mg kg^{-1} available manganese (Mn), 0.59 mg kg^{-1} available copper (Cu) and 0.001 mg kg^{-1} available boron (B).

The wet weights of the harvested plants were determined, washed with distilled water and then dried in an oven at 65°C with constant weight. After drying; 0.5 g of each dried plant sample was digested with 10 mL $HNO_3/HClO_4$ (4 : 1) acid mixture on a hot plate and then the samples were heated until a clear solution was obtained. The same procedure was repeated several times. Concentrations of potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn) and copper (Cu) in the digestates were determined using inductively coupled plasma (ICP) [Kacar and İnal 2008]. Phosphorus (P) was measured by spectrophotometer [Kacar and Kovancı 1982] and nitrogen (N) was determined using a modified Kjeldahl procedure [Kacar and İnal 2008].

All data were subjected to analysis of variance and significant values ($p < 0.05$) were detected for the treatments. Duncan's Multiple Range Test was used to determine the significance of differences between the treatments using SAS software.

RESULTS AND DISCUSSIONS

Statistically significant differences were determined between the increasing B treatments in the tomato plants ($p < 0.001$). Increasing N treatments and B*N interaction were not significant (Tab. 1). The toxicity symptoms of B were observed at 10 mg kg^{-1} and 20 mg kg^{-1} treatments in tomato plants and increasing B treatments caused an increased concentration of B in the plants. The highest boron concentration in the tomato plants was obtained from 20 mg kg^{-1} treatments and as the amount of boron applied to the soil increased, so the boron accumulation in the tomato plant increased. Boron toxicity was observed in old leaves due to immobility and the leaf tips were yellowed and necrosis was formed. Increasing boron applications has been previously reported to increase the boron content of plants and B accumulation in the plants [Gupta et al. 1973, Özkan et al. 1998, Asad et al. 2002, Rashidi and Gholami 2011].

The effects of increasing B treatments on calcium and magnesium concentrations in tomato plants were found to be statistically significant ($p < 0.001$). Increasing B and N treatments caused Ca and Mg accumulation in tomato plants (Tab. 4). In particular, the maximum B dose (20 mg kg^{-1}) provided the highest Ca and Mg accumulation values. Ganmore-Neumann and Davidov [1993] and Kobayashi et al. [1999] reported that boron has a positive effect on calcium accumulation and translocation. Some researchers have reported that the relationship between B and Ca is antagonistic [Fox 1968, Chauhan and Power 1978].

The effects of increasing B and N treatments on nitrogen concentrations in tomato plants were found to be statistically significant ($p < 0.001$) but the B*N interaction was not significant. Increasing B and N treatments caused the accumulation of B and N in tomato plants. In particular, the maximum doses provided the highest accumulation values (Tab. 2). Due to the continued plants growth at high N doses, the toxic effect of boron is partially reduced and this is confirmed by the symptoms observed in the plant. The reason for the plant growth at toxic levels can be interpreted as the effect of dilution [Sing et al. 1990].

The effects of increasing B treatments on phosphorus and potassium concentrations in tomato plants were found to be statistically significant ($p < 0.001$). The effects of the B*N interaction on potassium concentrations were also found to be statistically significant ($p < 0.001$). Increasing B and N treatments caused the P accumulation in tomato plants (Tab. 3). In particular, the maximum B dose (20 mg kg^{-1}) provided the highest P and K accumulation values. The highest B*N interaction value was obtained from 200 mg kg^{-1} N dose at maximum B dose (20 mg kg^{-1}) and all N doses were in the same group. Özen [2006] reported that barley varieties have different responses to boron applied at different levels. Chhipa et al. [1993] and Hussain et al. [2001] reported that increased boron (B) levels increased the phosphorus uptake of the plant. Çıkılı et al. [2013] stated that increased B applications in cucumber plant increased P accumulation in shoots. Koohkan and Maftoun [2015] reported that K concentrations of rice plants increased at high doses of nitrogen and boron. Ismail [2003] reported that high doses of boron increased the B and K content in maize and sorghum plants.

The effects of increasing B and N treatments on iron and zinc concentrations in tomato plants were found to be statistically significant. The effects of the B*N interaction on iron and zinc concentrations were also determined to be statistically significant ($p < 0.001$). Increasing B and N treatments caused Fe and Zn accumulation in tomato plants (Tab. 5). In particular, the maximum B and N doses provided the highest Fe and Zn accumulation values. According to the interaction values, the highest Fe value was obtained from 20 mg kg^{-1} B and 100 mg kg^{-1} N interaction, and the highest Zn values were obtained from 20 mg kg^{-1} B and 100, 200, 300 mg kg^{-1} N interaction in tomato plants. Turan et al. [2010] determined that boron fertilization causes an increase in P and Fe content in alfalfa

Table 1. The effects of increasing B and N concentrations on boron concentrations (mg kg^{-1}) of tomato plants[1]

Boron doses (mg kg^{-1})	Nitrogen doses (mg kg^{-1})			
	100	200	300	Mean
0	9.59	14.78	6.53	10.30D
5	201.38	176.50	194.00	190.62C
10	423.30	452.04	401.68	425.67B
20	907.83	1053.13	988.93	983.29A
Mean	385.53	424.11	397.79	–
Boron (B)	84.86 ***			
Nitrogen (N)	0.25 ns			
B*N interaction	0.24 ns			

[1] Values are mean of four replicates (n = 4). Values in a row followed by different letters indicate significant differences ($p < 0.05$) between treatments according to a Duncan's multiple range tests. ANOVA shows significant difference at: *** $p < 0.001$, ns – not significant

Table 2. The effects of increasing B and N concentrations on nitrogen concentrations (mg kg^{-1}) of tomato plants[1]

Boron doses (mg kg^{-1})	Nitrogen doses (mg kg^{-1})			
	100	200	300	Mean
0	2.56	3.04	3.17	2.92B
5	2.30	2.94	3.28	2.84B
10	2.32	2.93	3.22	2.83B
20	2.95	3.29	3.61	3.28A
Mean	2.53(C)	3.05(B)	3.32(A)	–
Boron (B)	13.25 ***			
Nitrogen (N)	60.97 ***			
B*N interaction	0.96 ns			

[1] Values are mean of four replicates (n = 4). Values in a row followed by different letters indicate significant differences ($p < 0.05$) between treatments according to a Duncan's multiple range tests. ANOVA shows significant difference at: *** $p < 0.001$, ns – not significant

Table 3. The effects of increasing B and N concentrations on P and K concentrations (mg kg^{-1}) of tomato plants[1]

Boron doses (mg kg^{-1})	Phosphorus concentrations Nitrogen doses (mg kg^{-1})				Potassium concentrations Nitrogen doses (mg kg^{-1})			
	100	200	300	Mean	100	200	300	Mean
0	0.081	0.105	0.099	0.095C	1.07bc	1.35ba	1.19bc	1.20B
5	0.090	0.092	0.125	0.102CB	1.33ba	0.87dc	0.48e	0.89C
10	0.103	0.121	0.121	0.115B	0.42e	0.66de	1.13bc	0.73C
20	0.180	0.183	0.179	0.181A	1.58a	1.67a	1.60a	1.62A
Mean	0.114	0.125	0.131	–	1.05	1.14	1.10	–
Boron (B)	38.94 ***				29.93 ***			
Nitrogen (N)	2.61 ns				0.14 ns			
B*N interaction	0.98 ns				7.22 ***			

[1] Values are mean of four replicates (n = 4). Values in a row followed by different letters indicate significant differences ($p < 0.05$) between treatments according to a Duncan's multiple range tests. ANOVA shows significant difference at: *** $p < 0.001$, ns – not significant

Table 4. The effects of increasing B and N concentrations on Ca and Mg concentrations (mg kg^{-1}) of tomato plants[1]

Boron doses (mg kg^{-1})	Calcium concentrations Nitrogen doses (mg kg^{-1})				Magnesium concentrations Nitrogen doses (mg kg^{-1})			
	100	200	300	Mean	100	200	300	Mean
0	6.24	7.76	7.00	7.00B	0.70	0.88	0.82	0.80C
5	6.78	7.93	7.99	7.56BA	0.89	1.02	1.00	0.97B
10	7.32	8.15	9.21	8.23A	0.99	1.10	1.23	1.11A
20	9.24	8.06	7.80	8.37A	1.35	1.22	1.12	1.23A
Mean	7.40	7.98	8.00	–	0.98	1.06	1.04	–
Boron (B)	4.09 *				16.78 ***			
Nitrogen (N)	1.6 ns				0.95 ns			
B*N interaction	2.35 ns				1.98 ns			

[1] Values are mean of four replicates (n = 4). Values in a row followed by different letters indicate significant differences ($p < 0.05$) between treatments according to a Duncan's multiple range tests. ANOVA shows significant difference at: * $p < 0.05$, *** $p < 0.001$, ns – not significant

Table 5. The effects of increasing B and N concentrations on Fe and Zn concentrations (mg kg^{-1}) of tomato plants[1]

Boron doses (mg kg^{-1})	Iron concentrations Nitrogen doses (mg kg^{-1})				Zinc concentrations Nitrogen doses (mg kg^{-1})			
	100	200	300	Mean	100	200	300	Mean
0	56.4d	55.9d	135.0bac	82.5C	5.0d	5.1d	16.8c	8.9C
5	92.8bcd	130.8bac	115.6bac	113.1B	17.7c	18.3c	20.7bc	18.9B
10	87.9dc	107.8bac	139.9ba	111.9B	17.6c	20.7bc	23.5ba	20.6B
20	157.0a	131.2bac	131.2bac	139.8A	27.7a	27.1a	26.4a	27.1A
Mean	98.5(B)	106.4(B)	130.4(A)	–	17.0(B)	17.8(B)	21.9(A)	–
Boron (B)	6.95 ***				61.97 ***			
Nitrogen (N)	4.67 *				10.01 ***			
B*N interaction	3.16 *				3.74 ***			

[1] Values are mean of four replicates (n = 4). Values in a row followed by different letters indicate significant differences ($p < 0.05$) between treatments according to a Duncan's multiple range tests. ANOVA shows significant difference at: * $p < 0.05$, *** $p < 0.001$

Table 6. The effects of increasing B and N concentrations on Mn and Cu concentrations (mg kg^{-1}) of tomato plants[1]

Boron doses (mg kg^{-1})	Manganese concentrations Nitrogen doses (mg kg^{-1})				Copper concentrations Nitrogen doses (mg kg^{-1})			
	100	200	300	Mean	100	200	300	Mean
0	59.2d	74.7d	128.5c	87.5C	4.9c	6.4cb	8.9b	6.8B
5	117.1c	132.3c	146.1bac	131.8B	6.8cb	6.8cb	7.1cb	6.9B
10	133.4c	140.6bac	165.8ba	146.6BA	6.7cb	8.4b	7.8cb	7.6B
20	168.6a	165.8ba	136.8bc	157.1A	12.6a	9.3b	8.4b	10.1A
Mean	119.5(B)	128.3(B)	144.3(A)	–	7.8	7.7	8.0	–
Boron (B)	31.04 ***				7.33 ***			
Nitrogen (N)	6.94 ***				0.13 ns			
B*N interaction	5.51 ***				3.29 *			

[1] Values are mean of four replicates (n = 4). Values in a row followed by different letters indicate significant differences ($p < 0.05$) between treatments according to a Duncan's multiple range tests. ANOVA shows significant difference at: * $p < 0.05$, *** $p < 0.001$, ns – not significant

plants. The increase in boron levels increased the Fe concentration in the cowpea from 142.5 mg kg^{-1} to 245 mg kg^{-1} [Singh 1988]. Koohkan and Maftoun [2015] reported that boron applications increased B, K, P and Zn concentrations in rice under nitrogen and boron toxicity conditions. Sinha et al. [2000] determined that increasing applications of boron in the mustard plant increased the Zn content of the plant.

The effects of increasing B and B*N treatments on manganese and copper concentrations in tomato plants were found to be statistically significant. The effects of N treatments on Mn concentrations were also determined to be statistically significant ($p < 0.001$) and the highest Mn concentration was obtained from 300 mg kg^{-1} treatment. Increasing B treatments caused Mn and Cu accumulation in tomato plants (Tab. 6). In particular, the maximum B doses provided the highest Mn and Cu accumulation values. According to the interaction values, the highest Mn and Zn values were obtained from 20 mg kg^{-1} B and 100 mg kg^{-1} N interaction in tomato plants. Lopez-Lefebre et al. [2002] reported that increased boron treatments caused Fe, Mn, N, P and K increases in tobacco roots and leaves. Esringü et al. [2011] reported that increasing boron applications increased the N, P, K, Zn, Fe, Cu and Mn ratios in wheat. Turan et al. [2009] determined that increased B doses in Brussels sprouts increased phosphorus, potassium, iron, manganese, zinc and copper in the leaf. Chaplin and Martin [1980] evaluated the effects of boron and nitrogen on the red blackberry plant and observed an increased level of Mn in the leaf with nitrogen application. Seferoğlu et al. [2011] reported that N and K fertilizers significantly increased Fe, Mn, and Zn contents in pistachio leaves.

CONCLUSION

The results of this study demonstrated that the harmful effect of B toxicity on the mineral nutrient concentration of tomato plants was partially diminished by the addition of N. The increase of added B significantly affected the nutrient content of the tomato plants and the nutrient concentrations of the plants increased at the concentration of B at toxic levels. In particular, increased N applications caused an increase in N, Fe, Zn, Mn contents in tomato plants. Increased nutrient concentrations were observed in all plants with increasing B and N treatments, and 20 mg kg^{-1} B and 100 mg kg^{-1} N were the most effective treatments compared to the others in respect of the B*N interaction. In addition, treatments of 20 mg kg^{-1} B and 300 mg kg^{-1} N resulted in the accumulation of nutrients.

Turkey is rich in agricultural land in terms of boron element, and boron toxicity problems may occur from time to time in different locations. Especially in areas where thermal waters are present, boron dissolved in irrigation water is significantly higher and can cause toxicity in agriculture. It has been reported in many studies in literature that increasing levels of elements such as nitrogen, phosphorus, potassium, zinc etc. can be effective in eliminating the negative effects of boron toxicity. In this study, it was aimed to reduce the negative effects of toxicity problems and it was observed that the plants accumulate more nutrients under conditions of stress.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the Scientific Fund of Akdeniz University (Project No: FYL-2017-2421).

REFERENCES

Adriano, D.C. (1986). Trace Elements in the Terrestrail Environment. Springer-Verlag, New York, 73–79.

Alkan, A. (1998). Farklı tahıl türleri ile buğday ve arpa çeşitlerinin B toksisitesine dayanıklılığının araştırılması ve dayanıklılıkta rol alan faktörlerin belirlenmesi [Studies on differential response of wheat and barley cultivar to boron toxicity and determination of factors that play a role in resistance]. Phd Thesis, Çukurova University, Graduate School of Natural and Applied Sciences, Adana [in Turkish].

Asad, A., Blamey, F.P.C., Edwards, D.G. (2002). Dry matter production and boron concentrations of vegetative and reproductive tissues of canola and sunflower plants grown in nutrient solution. Plant Soil, 243(2), 243–252. DOI: 10.1023/A:1019909130031

Atalay, E., Gezgin, S., Babaoğlu, M. (2003). Boron uptake of in vitro seedlings of wheat (*Triticum durum* Desf.) and barley (*Hordeum vulgare* L.) as determined by ICP-AES. Selçuk J. Agric. Food Sci., 17(32), 47–52 [in Turkish].

Aydın, A., Kant, C., Ataoğlu, N. (2005). Effect of boron and phosphorus application on the growth and mineral content of corn in Erzurum and Rize soils. J. Fac. Agric., Atatürk Univ., 36(2) [in Turkish].

Bingham, F.T., Elseewi, A., Oertli, J.J. (1970). Characteristics of boron absorption by excised barley roots. Proc. – Soil Sci. Soc. Am., 34, 613–617.

Blevins, D.G., Lukaszewski, K.M. (1998). Boron in plant structure and function. Annu. Rev. Plant Physiol. Plant Mol. Biol., 49, 481–500. DOI: 10.1146/annurev.arplant.49.1.481

Brown, P.H., Bellaloui, N., Wimmer, M.A., Bassil, E.S., Ruiz, J., Hu, H., Pfeffer, H., Dannel, F., Römheld, V. (2002). Boron in plant biology. Plant Biol., 4, 205–223. DOI: 10.1055/s-2002-25740

Chaplin, M.H., Martin, L.W. (1980). The effect of nitrogen and boron fertilizer applications on leaf levels, yield and fruit size of the red raspberry. Commun. Soil Sci. Plant Anal., 11(6), 547–556. DOI: 10.1080/00103628009367062

Chauhan, R.P.S., Power, S.L. (1978). Tolerance of wheat and pea to boron in irrigation water. Plant Soil, 50, 145–190. DOI: 10.1007/BF02107164

Chhipa, B.R., Lal, P., Paliwal, R. (1993). Effect of presoaking treatments on wheat grown on soils with graded levels of boron. J. Indian Soc. Soil Sci., 41(3), 531–534.

Çıkılı, Y., Samet, H., Dursun, S. (2013). Effects of potassium treatment on alleviation of boron toxicity in cucumber plant (*Cucumis sativus* L.). Soil-Water J., 2(2), 719–726.

Dordas, C., Brown, P.H. (2000). Permeability of boric acid across lipid bilayers and factors affecting it. J. Membr. Biol., 175, 95–105. DOI: 10.1007/s002320001058

El-Hamdaoui, A., Redondo-Nieto, M., Rivilla, R., Bonilla, I., Bolanos, L. (2003). Effects of boron and calcium nutrition on the establishment of the Rhizobium leguminosarum pea (*Pisum sativum*) symbiosis and nodule development under salt stress. Plant Cell Environ., 26, 1003–1011. DOI: 10.1046/j.1365-3040.2003.00995.x

Esringü, A., Turan, M., Gunes, A., Ataoglu, N., Uzun, O. (2011). Optimum economic boron fertilizer doses of wheat grown on calcareous soil. J. Plant Nutr., 34(11), 1625–1641. 10.1080/01904167.2011.592560

Fox, R.H. (1968). The effect of calcium and pH on boron uptake from high concentrations of boron by cotton and alfalfa. Soil Sci., 106, 435–439.

Ganmore-Neumann, R., Davidov, S. (1993). Uptake and distribution of calcium in rose plantlets as affected by calcium and boron concentration in culture solution. Plant Soil, 155(1), 151–154. DOI: 10.1007/BF00025006

Gupta, U.C. (1979). Boron nutrition of crops. Advance in Agronomy, 31, 273–307.

Gupta, U.C., Sterlinga, J.D.E. Nass, H.G. (1973). Influence of various rates of compost and nitrogen on the boron toxicity symptoms in barley and wheat. Can. J. Plant Sci., 53, 451–456.

Güneş, A., Alpaslan, M. (2000). Boron uptake and toxicity in maize genotypes in relation to boron and phosphorus supply. J. Plant Nutr., 23(4), 541–550. 10.1080/01904160009382038

Hu, B., Brown, H.P. (1997). Absorption of boron by plant Roots. Plant Soil, 193, 49–58.

Hussain, I., Liqa, R., Munir, A.H., Fuard, M., Wim, V.D.H. (2001). Framework for analyzing socioeconomic, health and environmental impacts of wastewater use in agriculture. IWMI working paper 26. International Water Management Institute. Colombo, Sri Lanka.

Ismail, A.M. (2003). Response of maize and sorghum to excess boron and salinity. Biol. Plant., 47(2), 313–316. DOI: 10.1023/B:BIOP.0000022274.72111.12

Jones, W.W., Embleton, T.W., Boswell, S.B., Steinacker, M.L., Lee B.W., Barnhart, E.L. (1963). Nitrogen control program for oranges and high sulfate and/or high boron. Calif. Citrogr., 48(107), 128–130.

Kacar, B., Kovancı, İ. (1982). Bitki, Toprak ve Gübrelerde Kimyasal Fosfor Analizleri ve Sonuçlarının Değerlendirilmesi [Chemical Phosphorus Analysis in Plants, Soil and Fertilizers and Evaluation of Analysis Results]. Ege Üniv. Ziraat Fak. Yayınları, 354, İzmir [in Turkish].

Kacar, B., Katkat, A.V. (1999). Plant Nutrition. Vipaş Yayınları, 3, 417–441, Bursa, Turkey [in Turkish].

Kacar, B., İnal, A. (2008). Plant Analysis. Nobel Publications, 1241(63).

Khan, N., Young, K.J., Gartrell, J.N. (1999). Boron toxicity in barley. Division of Plant Research Agriculture, pp. 85.

Kobayashi, M., Nakagawa, H., Asaka, T., Matoh, T. (1999). Borate-rhamnogalacturonan II bonding reinforced by Ca^{2+} retains pectic polysaccharides in higher-plant cell walls. Plant Physiol., 119(1), 199–204. DOI: 10.1104/pp.119.1.199

Koohkan, H., Maftoun, M. (2015). Effect of Nitrogen on the Alleviation of Boron Toxicity in Rice (*Oryza Sativa* L.). J. Plant Nutr., 38(9), 1323–1335. DOI: 10.1080/01904167.2014.991035

Lopez-Lefebre, L.R., Rivero, R.M., Garcia, P.C., Sanchez, E., Ruiz, J.M., Romero, L. (2002). Boron effect on mineral nutrients of tobacco. J. Plant Nutr., 25(3), 509–522. DOI: 10.1081/PLN-120003379

Marschner, H. (1995). Mineral Nutrition of Higher Plants, 2nd ed. Academic Press, San Diego, 379–396.

Mortvedt, J.J., Cox, F.R., Shuman, L.M., Welch, R.M. (1991). Micronutrients in agriculture. 2nd ed. SSSA Book Ser. 4. SSSA, Madison, WI.

Nable, O.N., Banuelous, S.G., Paull, G.J. (1997). Boron Toxicity. Plant Soil, 198, 181–198.

Özen, D. (2006). Effects of boron on boron content and some yield and quality components of barley (*Hordeum vulgare* l.) varieties having different response level. Phd Thesis, Ankara University, Graduate School of Natural and Applied Sciences, Ankara.

Özkan, F., Özçelik, A., Arı, N., Polat, T., Arpacıoğlu, A., Köseoğlu, A.T. (1998). Antalya bölgesinde yetiştirilen karanfillerde görülen kaliks çatlamasına borun etkisi üzerine araştırmalar [Effect of boron on calyx splitting in carnations grown in Antalya region]. I. Ulusal Süs Bitkileri Kongresi [In Turkish].

Pate, J.S. (1975). Exchange of solutes between phloem and xylem and circulation in the whole plant. In: Transport in Plants I, Zimmermann, M.H., Milburn, J.A. (eds.). Springer Berlin, Heidelberg, 451–473.

Petridis, A., Gasparatos, D., Haidouti, C., Paschalidis, C., Zamanidis, P. (2013). Effects of nitrogen and boron fertilization on lettuce mineral nutrition in a calcareous soil. Commun. Soil Sci. Plant Anal., 44, 733–740. DOI: 10.1080/00103624.2013.748125

Rajaie, M., Ejraie, A.K., Owliaie, H.R., Tavakol, A.R. (2009). Effect of zinc and boron interaction on growth and mineral composition of lemon seedlings in a calcareous soil. Int. J. Plant Prod., 3(1), 39–50. DOI: 10.22069/IJPP.2012.630

Rashidi, M., Gholami, M. (2011). Nitrogen and boron effects on yield and quality of cotton (*Gossypium hirsutum* L.). Int. Res. J. Agric. Sci. Soil Sci., 1(4), 118–125.

Reisenauer, H.M., Walsh, L.M., Hoeft, R.G. (1973). Testing soil for sulphur, boron, molybdenum and chlorine. In: Soil Testing and Plant Analysis, Walsh, L.M., Beaton, J.D., (eds.). Soil Science Society of America, Madison, Wisconsin, 173–200.

Sakal, R. (1987). Boron and sulphur-nutrition of groundnut in calcareous soil. Annual Progress Report of the All India Co-ordinated Scheme of Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants, (ICAR) Rajendra Agril. Univ., Pusa, Bihar 37–40.

Seferoğlu, S., Seferoğlu, G., Tekintaş, E. (2011). Effect of Potassium and Nitrogen Fertilizer on Micro-Nutrient Contents of Pistachio Leaves. J. Ege Univ. Fac. Agric., Special Issue, s. 152 [in Turkish].

Shelp, B.J., Shattuck, V.I., Proctor, J.T.A. (1987). Boron nutrition and mobility, and its relation to the elemental composition of greenhouse grown root crops. II Radish. Commun. Soil Sci. Plant Anal., 18(2), 203–219. DOI: 10.1080/00103628709367811

Shelp, B.J., Shattuck, V.I., McLellan, D., Liu, L. (1992). Boron nutrition and composition of glucosinolates and soluble nitrogen compounds in two broccoli (*Brassica oleracea* var. *Italica*) cultivars. Can. J. Plant Sci., 72, 889–899. DOI: 10.4141/cjps92-112

Silanpaa, M. (1990). Micronutrient Assessment at the Country Level: An international study. FAO Soils Bulletin, Rome, Italy.

Singh, D.P. (1988). Effect of gypsum on boron tolerance in cowpea. New Bot., 15, 145–148.

Singh, J.P., Dahiya, D.J., Narwal, R.P. (1990). Boron uptake and toxicity in wheat in relation to zinc supply. Fertilizer Research, 24(2), 105–110. DOI: 10.1007/BF01073228

Sinha, P., Jain, R., Chatterjee, C. (2000). Interactive effect of boron and zinc on growth and metabolism of mustard. Commun. Soil Sci. Plant Anal., 31(1–2), 41–49. DOI: 10.1080/00103620009370419

Tanaka, M., Fujiwara, T. (2008). Physiological roles and transport mechanisms of boron: perspectives from plants. Europ. J. Physiol., 456, 671–677. DOI: 10.1007/s00424-007-0370-8

Turan, M.A., Taban, N., Taban, S. (2009). Effect of calcium on the alleviation of boron toxicity and localization of boron and calcium in cell wall of wheat. Not. Bot. Horti Agrobot. Cluj-Napoca, 37(2), 99. DOI: 10.15835/nbha3723241

Turan, M., Ketterings, Q.M, Gunes, A., Ataoglu, N. Esringu, A., Bilgili, A.V., Huang, Y.M. (2010). Boron fertilization of Mediterranean Aridisols improves lucerne (*Medicago sativa* L.) yields and quality. Acta Agric. Scand., B Soil Plant Sci., 60, 427–436.

Uygan, D., Çetin, O. (2004). Agricultural and Environmental Effects of Boron: Seydisuyu Water Deposit. The 2nd International Boron Symposium, 23–25 Eylül, Ankara, Turkey.