Turk J Agric For
24 (2000) 505–509

The Effect of Zinc on Alleviation of Boron Toxicity in Tomato Plants (*Lycopersicon esculentum* L.)

Aydın GÜNEŞ, Mehmet ALPASLAN, Yakup ÇIKILI, Hesna ÖZCAN
Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Ankara University, 06110 Ankara-TURKEY

Recieved: 05.11.1998

Abstract: A greenhouse experiment involving four levels of boron (0, 5, 10 and 20 mg B kg^{-1}) and the levels of zinc (0, 10 and 20 mg Zn kg^{-1}) was conducted in tomato plants (*Lycopersicon esculentum* L., cv., 'Lale'). Boron toxicity symptoms occurred at 10 to 20 mg kg^{-1} B levels. These symptoms were somewhat lower in the plants grown with applied Zn. Fresh and dry weights of the plants clearly decreased with applied B. However Zn treatments partially depressed the inhibitory effect of B on the growth. Increased levels of B increased the concentrations of B in plant tissues and to a greater extent in the absence of applied Zn. Both Zn and B treatments caused an increase in Zn concentration in the plants.

Key Words: Boron toxicity, zinc, boron, tomato, *Lycopersion esculentum* L.

Domates (*Lycopersion esculentum* L.) Bitkisinde Bor Toksisitesinin Giderilmesinde Çinkonun Etkisi

Özet: Domates (*Lycopersicon esculentum* L. cv. 'Lale') bitkisine uygulanan dört bor (0, 5, 10 ve 20 mg B kg^{-1}) ve üç Çinko (0, 10 ve 20 mgZn kg^{-1}) düzeyinin etkisi sera koşullarında araştırılmıştır. Bor uygulamasının 10 ve 20 mg kg^{-1} düzeylerinde B toksitesi semptomları ortaya çıkmıştır. UygulananZn, görülen bu semptomların kısmen azalmasına neden olmuştur. Uygulanan B, bitkinin yaş ve kuru ağırlığını belirgin bir şekilde azaltmıştır. Bununla birlikte, borun gelişme üzerindeki bu inhibe etkisi Zn uygulamasıyla kısmen giderilmiştir. Çinko uygulamasının olmadığı koşullarda B' un artan düzeylerine bağlı olarak bitki dokularının B konsantrasyonları artmıştır. Çinko ve B uygulamaları bitkinin Zn konsantrasyonunun artmasına sebep olmuştur.

Anahtar Sözcükler: Bor toksisitesi, çinko, bor, domates, *Lycopersion Esculentum* L.

Introduction

Boron toxicity is a common problem in semiarid regions where B levels are frequently high in the soil or irrigation waters (1). Moreover, if fertilizers containing boron are applied in several consecutive years following a determination of deficient boron levels in the soil, this may cause B toxicity. Such toxicity is costly, and can result in a substantial loss in yield. In the case of boron the difference between adequate and toxic concentrations is very small, and the danger of inducing boron toxicity is therefore high.

Boron is different from other micronutrients with its nonionized form (H_3BO_3) under normal soil pH, physiological pH. The reason for that is that boric acid is weak acid with a small acid dissociation constant and high pK value. Only under a high pH, about 10 percent of boric acid exists in the borate form $B(OH_4)^-$ (3). The reaction can lead to the formation of $B(OH_4)^-$ was suggested by Greenwood (4) as follows:

$$B(OH_3)^- + 2H_2O \longrightarrow B(OH_4)^- + H_3O \quad pK=9.25$$

The borate anion could be adsorbed by clay minerals (5) or leached from the soil, in the same manner as the Cl^- anion.

Soil pH is one of the most important factors that affect boron uptake by plants. Above pH 6.5, there is an interaction between soil pH and boron uptake (6,7). Several investigators have found that increasing soil pH by liming reduces boron concentration in plants (8-10).

Lime application in calcareous and high pH-soils to overcome boron toxicity may cause micronutrient problems by increasing soli pH. Consequently, lime application is limited in calcareous soils, and alternative nutritional attempts are needed to reduce the boron toxicity in plants.

Zinc availability to plants decreases in high soil pH. Therefore, it is possible that high levels of B and low levels of available Zn for crops may occur simultaneously (11). In a solution culture study (12), it was reported that boron toxicity was more severe and appeared first in Zn deficient barley plants compared with those supplied with adequate Zn as reported by Singh et al., (11) Zn deficiency may enhance B absorption and transport to such an extent that B may possibly accumulate to toxic levels in plant tops.

Concerning its biochemical and physiological action, boron resembles phosphate. Both borate and phosphate exist in physiologically active esters which are able to form polyhydroxyl compounds with organic complexes (2). In fact, phosphorus can possibly accumulate to the toxic levels in leaves under Zn deficient conditions (13, 14). The reasons for enhanced P uptake and traslocation in Zn deficient plants are still unclear. One of the assumptions is that the root cell membrane permeability is increased under Zn deficiency, which might be related to the functions of zinc in cell membranes. Zinc is necessary for root cell membrane integrity, and in this function, it prevents excessive P uptake and transport of P from roots to leaves (14).

The objective of this study was to evaluate whether Zn has a protective mechanism, as in the case of P toxicity, on excessive boron uptake of tomato plants grown in soil containing high levels of boron.

Materials and Methods

Tomato (*Lycopersicon esculentum* L., cv. 'Lale') plants were grown under natural glasshouse conditions. Tomato seeds were germinated in a seedling tray filled with 1:1 v/v peat and perlite mixture. Three week-old seedlings were transplanted at a rate of one plant per pot filled with 2000 g of air-dried soil. Some characteristics of the soil were as follows: texture loamy clay, $CaCO_3$ 5.75%, pH (1:2.5 water) 7.61, EC 0.56 dS m^{-1}, organic matter 1.07%, total N 0.15%. The concentrations of NH_4OAc-extractable K, Ca and Na were as follows (mg kg^{-1}): 450, 4800 and 60 respectively. $NaHCO_3$-available P was 10.70 mg kg^{-1} and DTPA-extractable Zn was 0.57 mg kg^{-1} and NaOAc-extractable B was 1.5 mg kg^{-1}.

Treatments received four levels of B as H_3BO_3 (0, 5, 10, 20 mg B kg^{-1} soil) and three levels of Zn as $ZnSO_4$. ($ZnSO_4.7H_2O$) $7H_2O$ (0, 10 and 20 mg Zn kg^{-1} soil), replicated four times in a randomized complete block design. A basal dose of N, P and K were applied at 200, 100 and 125 mg kg^{-1}, respectively and mixed thoroughly with soil before the sowing. The experiment was carried out for 5 weeks. Plants were harvested, weighed, dried at 65°C until they reached a constant weight and were subsequently ground for B and Zn analysis. Zinc concentrations were assayed in concentrated HNO_3 and $HClO_4$ (4:1) digested samples by atomic absorption spectrophotometry and boron was determined as described by Wolf (15).

The experimental data were analyzed by analysis of variance and the differences were compared with the LSD test.

Results and Discussion

Boron toxicity symptoms: Increasing levels of applied boron, 10 and 20 mg kg^{-1} B, increased the symptoms of leaf injury. The initial symptoms were dark brown spots and lesions with chlorotic borders in the oldest leaves. The severity of leaf injury due to B toxicity was more pronounced in plants which had received no additional Zn supply. The leaf injury symptoms which occurred in this study agree with those previously reported by Aduayi (16); Bergmann, (2); Oyewole and Aduayi (17).

Fresh and dry weights of the plants: Added levels of B decreased the fresh and dry weights of the plants. Moreover, the inhibitory effect of B on the growth was partially depressed in the presence of Zn. The maximum growth reduction (62%) in fresh and dry weight occurred with an addition of 20 mg kg^{-1} B when compared with the control. The growth reduction decreased with the application of 10 and 20 mg kg^{-1} Zn 56% and 20% respectively. Zinc treatments had no effect on the dry and fresh weights of the plants grown with no B aplication. Whereas the dry and fresh weights increased in the presence of high amounts (10 and 20 mg kg^{-1}) of applied B (Table 1). In other words, Zn counteracted the toxic effect of B, resulting in higher fresh and dry weigts of B treated plants. This effect of Zn on the growth of tomato in the presence of applied zinc supports the findings of Graham et al., (17) and Singh et al., (11).

Boron concentration of the plants: Increasing levels of B in the soil increased the concentration of B in the plants. This increase was greater in the absence than in the presence of Zn (Table 2). With no Zn added, all plants contained B more, than the toxic concentrations for tomato, 40 to 80 mg kg^{-1} B dry weight, suggested by Bergmann (2). However Zn treatments, 10 to 20 mg kg^{-1}, managed to decrease the toxic B concentrations of the plants in 0 and 5 mg kg^{-1} B treatments. The concetration

Table 1. Effect of Zn and B application on the fresh and dry weights of tomato

B treatments, mg kg-1 soil	Zn treatments, mg kg^{-1} 0	10	20	Average
	Fresh weights, g pot^{-1}			
0	16.74 a A	16.88 a A	16.86 ab A	16.83
5	13.06 b B	14.82 a B	18.83 a A	15.57
10	11.32 b B	14.79 a A	14.00 bc AB	13.37
20	6.40 c B	7.42 b B	12.92 c A	8.91
Average	11.88	13.48	15.65	
F test				
B **				
Zn **				
BxZn *	Dry weights, g pot^{-1}			
0	1.61 a A	1.64 a A	1.58 ab A	1.61
5	1.19 b B	1.35 a B	1.84 a A	1.46
10	1.13 b A	1.42 a A	1.34 b A	1.30
20	0.59 c B	0.71 b B	1.25 b A	0.85
Average	1.13	1.28	1.50	
F test				
B **				
Zn **				
BxZn *				

*, ** indicate significance at the 0.05 and 0.01 probability levels. Small letters indicate the statistical differences for the B treatments. Capital letters indicate the statistical differences for the Zn treatments For fresh weight $LSD_{0.05}$: 3.21 and for dry weight $LSD_{0.05}$: 0.34

Table 2. Boron concentrations (mg kg^{-1}) of the plants as affected by Zn and B application

B treatments, mg kg^{-1}	Zn treatments, mg kg^{-1} 0	10	20	Average
0	88.50	47.50	43.50	59.83 D
5	97.25	81.25	68.00	82.17 C
10	161.25	107.25	108.50	125.83 B
20	321.75	245.25	236.75	267.92 A
Average	167.19 A	120.44 B	114.19 B	
F test				
B **				
Zn **				
BxZn NS				

**, NS indicates significance at the 0.01 probability levels significant and not significant respectively
For Zn treatments $LSD_{0.05}$:15.68, and For B treatments $LSD_{0.05}$: 18.11

of the plants also decreased by Zn treatments at 10 and 20 mg kg^{-1} B treatments. However these concentrations of B in the level of B treatments were still above the toxic B level. This effect of Zn on B uptake by plants supports the findings of Singh et al., (11) and Swietlik (18). The effect of Zn on uptake of B implies that Zn provided a protective mechanism against excessive uptake of B. As suggested by Welch et al., (19) Zn is necessary for root cell membrane integrity, and therefore, it prevents excessive P uptake by roots and the transport of P from roots to leaves. As a biochemical and physiological function, B resembles phosphate (2). Similarly, Zn may also have possibly a protective role in the absorption and translocation of B. Under Zn deficiency or environmental stress conditions, plasma membranes lose their integrity which is directly related to the control of passive ion uptake (20). Injured plasma membranes lose their control mechanism in the diffusions of ions as evidenced by a high influx of K^+, NO_3^-, Cl^-, phosphate and organic metabolites (19). The major role of Zn in membranes seems to be related tof the protection of membrane lipids and proteins against oxidation. The decrease in the lipid levels, especially unsaturated fatty acids, might be a consequence of peroxidative membrane injury resulting in increases in the membrane permeability and zinc ions interfere with both the generation and peroxidative attraction of oxygen radicals produced in the membrane environment (21).

Zinc concentrations of tomato: The concentrations of Zn in tomato plants increased with Zn and B applications (Table 3). A sufficient Zn concentration for tomato plants suggested by Bergmann (2) is 20 to 70 mg kg^{-1} dry weight. In our study, B treated plants all contained less Zn than the upper level of this critical range in the absence of applied Zn.

The results of this study indicated that supplemented Zn is of potential practical importance in the control of B absorption and toxicity where the plants are grown under Zn deficiency and boron toxicity conditions.

Table 3. Zinc concentrations (mg kg^{-1}) of the plants as affected by Zn and B application

B treatments, mg kg^{-1}	Zn treatments, mg kg^{-1} 0	10	20	Average
0	40.00	76.50	106.00	74.17 C
5	38.50	93.75	121.25	84.50 B
10	56.25	94.75	125.50	92.17 A
20	61.75	98.00	121.50	93.75 A
Average	49.13 C	90.75 B	118.56 A	
F test				
B **				
Zn **				
BxZn NS				

**, NS indicates significance at the 0.01 probability levels significant and not significant respectively

For Zn treatments $LSD_{0.05}$:4.97, and for B treatments $LSD_{0.05}$: 5.75

References

1. Staiger, K., Machelet, B., Grenzwerte für Schwermetalle und Bor im Bewasserungswasser. Proc. Mengen. u. Spurenelemente Arbeitst., Karl-Marx Univ. Leipzig. 236-239, 1984.
2. Begrmann, W., Nutritional Disorders of Plants. Development, Visual and Analytical Diagnosis. Gustav Fisher Verlag Jena. Stuttgart. New York, 1992.
3. Hutchinson, G.L., Viets, F.G., Detoxification of Boron in Plants with Triisopropanolamine. Soil Sci. 108(3): 217-221, 1969.
4. Greenwood, H.N., Boron. In: Comprehensive Inorganic Chemistry. Bailan, J.C. et al., (eds.) Vol I., 665-991. Pergamon Press, Oxford, 1973.
5. Mengel, K., Kirkby, E.A., Principles of Plant Nutrition. Publ. Int. Potash Inst. Bern, Switzerland, 1982.
6. Gupta, U.C., Boron Nutrition in Crops. Adv. in Agron. 31: 273-307, 1979.
7. Bingham, F.T., Elseewi, A., Oertli, J.J., Characteristics of boron adsorbtion by excised barley roots. Soil. Sci. Soc. Am. Proc. 34: 613-617, 1970.
8. Peterson, L.A., Newman, R., Influence of soil pH on the availability of added boron. Soil Sci. Soc. Am. J. 40: 280-282, 1976.
9. Gupta, U.C., Macleod, J.A., Plant and soil boron as influenced by soil pH and calcium sources on podzol soils. Soil Sci. 131(1): 20-25, 1981.
10. Bartlett, R.J., Picarellin, C.J., Availability of boron and phosphorus as affected by liming in acid potato soil. Soil Sci. 116: 77-83, 1973.
11. Singh, J.P., Dahiya, D.J., Narwal, R.P., Boron uptake and toxicity in wheat in relation to zinc supply. Fertilizer Research 24: 105-110, 1990.
12. Graham, R.D., Welch, R.M., Grunes, D.L., Cary, E.E., Norvell, W.A., Effect of zinc deficiency on the accumulation of boron and other mineral nutrients in barley. Soil Sci. Soc. Am. J. 51: 652-657, 1987.
13. Loneragen, J.F., Grunes, D.L., Welch, R.M., Aduayi, E.A., Tengap, A., Lazar, V.A., Cary, E.E., Phosphorus accmulation and toxicity in leaves in relation to zinc supply. Soil Sci. Soc. Am. J., 46: 345-352, 1992.
14. Marshner, H., Çakmak, İ., Mechanism of phosphorus-induced zinc deficiency in cotton. II. evidence for impaired shoot control on phosphorus uptake and translocation under zinc deficiency. Physiol. Plantarum. 68: 491-496, 1986.

15. Wolf, B., Improvements in the Azomethine-H method for the determination of boron. Comm. in Soil Sci. and Plant Anal. 5(1): 39-44, 1974.

16. Aduayi, E.A., Role of boron on growth components and elemental composition of 'Ife Plum' tomato. Comm. in Soil Sci. and Plant Anal. 9(1): 1-11, 1978.

17. Oyewole, O.I., Aduayi, E.A., Evaluation of the growth and quality of 'Ife Plum' tomato as affected by boron and calcium fertilization. J. of Plant Nutr. 15(2): 199-209, 1992.

18. Swietlik, D., Interaction between zinc deficiency and boron toxicity on the growth and mineral nutrition of sour orange seedlings. J. of Plant Nutr. 18 (6): 1191-1207, 1995.

19. Welch, R.M., Webb, M.J., Loneragan, J.F., Zinc in membrane function and its role in phosphorus toxicity. In: Proc 9th Int. Plant Nutrit. Coll. (A. Scaife Ed.) 710-715. Commonwealth Agric. Bur., Farnham Royal. Bucks. ISBN O-85198-505-X, 1982.

20. Marschner, H., Mineral Nutrition of Higher Plants. 2nd ed. Academic Press. New York, 1988.

21. Çakmak, İ., Marschner, H., Zinc-dependent changes in ESR signals, NADPH oxidase and plasma membrane permeability in cotton roots. Physiol. Plantarum 73: 182-186, 1988.