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Araştırma Makalesi

Effects of Increasing Application Doses of Borax and Boric acid on Nutrient Element Uptake of Maize (*Zea mays* L.)

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Abstract: Effects of two boron (B) sources and increasing application doses of both sources on the dry matter yield, B and some nutrients uptake by maize (*Zea mays* L.) were investigated in greenhouse conditions. Increasing doses of boron (0, 2.5, 5, and 10 mg B kg^{-1}) were applied to soil as borax ($Na_2B_4O_7.10H_2O$) and boric acid (H_3BO_3) and maize plants were grown for 37 days.

Increasing doses of B were found statistically significant on dry matter yield, boron, phosphorus (P), and magnesium (Mg) uptake. Borax and boric acid doses elevated the B (6.52 - 5.92 mg pot^{-1}) and Mg (49.73 - 49.12 mg pot^{-1}) uptake of maize and the highest values observed at 10.0 mg B kg^{-1} dose of both borax and boric acid, respectively. Dry matter yield and the nutrient elements uptake / B uptake ratios decreased with the increasing B applications. Boron sources found statistically significant on the amounts of dry matter yield, B, P, and iron (Fe) uptake. Up taken B and P amounts were found high at Borax applications, however, dry matter yield, and Fe uptake was found higher at boric acid applications.

Keywords: Boron uptake, boron toxicity, nutrient uptake, dry matter, maize.

Artan Dozlarda Uygulanan Boraks ve Borik Asidin Mısır (*Zea mays* L.) Bitkisinin Besin Elementi Alımı Üzerine Etkisi

Öz: Artan dozlarda uygulanan iki farklı bor (B) kaynağının, mısır bitkisinin kuru madde verimi ve kimi besin elementi alımı üzerine etkisi sera koşullarında araştırılmıştır. Artan dozlarda bor (0, 2.5, 5, 10 mg B kg^{-1}) toprağa boraks ($Na_2B_4O_7.10H_2O$) ve borik asit (H_3BO_3) şeklinde uygulanmış ve mısır bitkileri 37 gün süre ile yetiştirilmiştir.

Borun artan dozlarının mısır bitkisinin kuru madde verimi, B, fosfor (P) ve magnezyum (Mg) alımı üzerine etkisi istatistiksel olarak önemli bulunmuştur. Boraks ve borik asit dozları mısır bitkisinin B

(6.52 - 5.92 mg saksı$^{-1}$) ve Mg (49.73 - 49.12 mg saksı$^{-1}$) alımını artırmış ve en yüksek değerler B kaynaklarının 10 mg B kg^{-1} seviyesinden elde edilmiştir. Kuru madde verimi ve besin elementleri / B alım oranları artan B dozları ile azalma göstermiştir. Kuru madde verimi, B, P ve demir (Fe) alımı üzerine B kaynaklarının etkisi istatistiksel olarak önemli bulunmuştur. Boraks uygulamalarında kaldırılan B ve P değerleri daha yüksek bulunurken, kuru madde verimi ve kaldırılan Fe miktarı borik asit uygulamalarında daha yüksek olmuştur.

Anahtar Kelimeler: Bor alımı, bor toksisitesi, besin elementi alımı, kuru madde, mısır.

Introduction

Because of being a necessary component of the cell wall and having important roles in cell division, in synthesis of proteins and in translocation of sugars; boron (B) is known as an essential micro nutrient element for plants (Ahmad et al., 2009; Ahmad et al., 2012). Its available amounts in soil and irrigation water are also an important determinant factor in agricultural production (Tanaka and Fujiwara, 2008; Gitanjali et al., 2010; Gupta, 2016). Boron deficiency has been reported in more than over 80 countries and for 132 crops and, is known as the second most important and problematic micronutrient in crops after zinc (Ahmad et al., 2012; Haque et al., 2014). Nevertheless, boron toxicity problems have also been reported in many countries including North and South America, Australia, West Asia, North Africa, Mediterranean and East Europe (Brdar-Jokanović et al., 2013). Boron occurs in many rocks and soils. In soils, although boron shows important variations at a total concentration of 2 to 200 mg kg^{-1}, some literatures indicates less than 10 mg kg^{-1} B in soil as B deficient and containing over 5 mg L^{-1} of hot water soluble B as B-toxic (Öztürk et al., 2010; Esim et al., 2012; Ahmad et al., 2012; Bariya et al., 2014). Boron may occur naturally in the soil or in groundwater or be added at high concentrations to the soil from mining, fertilizers or irrigation water. Borax and boric acid are known as the most common water soluble fertilizers that contain B (Mattos-Jr et al. 2017). Boron exists as non-ionized boric acid [$B(OH)_3$], or ionic form [$B(OH)_4$]$^-$ and can be easily leached under high rainfall conditions leading to deficiencies in plants (Yan et al., 2006). On the contrary, under low rainfall conditions B cannot be sufficiently leached and therefore may accumulate to toxic levels for plant growth (Reid, 2007). This situation occurs very often in arid and semiarid regions which have high-boron in groundwater. Boron accumulation in top soil due to the evaporation of groundwater reaches toxic levels and lead reduces in crop yields (Tanaka and Fujiwara, 2008; Camacho--Cristóbal et al., 2008, Çikili et al., 2015). Boron concentration in soils is not only affected by environmental conditions but also parent material, texture, clay minerals, pH, lime and organic matter contents and also other nutrient element interrelation affects to its availability (Ahmad et al., 2012).

The amount of boron needed for normal crop production differs among plants and generally presents at a concentration of 10 to 50 mg kg^{-1} in plant leaf tissue (Esim et al., 2012). Boron requirement of maize (Zea mays L.) is low and can suffer from an excess B concentration over 50 mg B kg^{-1} (Hakki et al., 2007, Kaur and Nelson, 2015). Among the essential nutrient elements, boron is one of the most critical nutrients because of its deficiency and toxicity limits being so close to each other. Both deficiency and excess of boron causes reduction in crop yield and quality (Yau and Ryan, 2008). This situation leads to the growers required to pay much more attention when they fertilize crops with boron because only 1-2 % of soil applied B is removed by the crops and most of it is left as residues for years.

The relationship among nutrients is also very important for plant growth and development under both normal and stress conditions (Siddiqui et al., 2013). The up taken amount of boron under both deficient as well as in toxic conditions by plants can be affected by the presence of other nutrient elements in the soil (Bariya et al. 2014). The most well-known was reported as calcium (Ca) by Gupta (2016). Although the relation between potassium (K) and B was not as brief as Ca, there are various literatures of antagonistic and synergistic effects of boron on crops potassium concentrations (Alpaslan and Güneş, 2001; Davis et al., 2003; Olson et al., 2012). Although some antagonistic and synergistic interactions of nitrogen (N), phosphorus (P), K and Ca with B have been reported in past researches the interactions have not been clearly reported because of the conflicting results due to the different experimental systems with different plants and its varieties (Ahmad et al., 2012; Bariya et al., 2014). Knowledge about its interactions with other nutrients may be useful hint for regulating B availability in soil and preventing its excess amounts in plants.

The aim of this study was to determine the effects of borax and boric acid and their increasing application doses on dry matter yield, B and some nutrient elements uptake of maize (Zea mays L.) and also to determine their interactions with B.

Material and Methods

Experimental material: The experiment was performed in the greenhouse of the Soil Science and Plant Nutrition Department, Agricultural Faculty, University of Uludag, Bursa, Turkey during May-June of the year 2015. Soil sample used in this study was collected from 0-20 cm depth in the field located in the Agricultural Research and Application Centre of Uludag University (39°35′, 40°40′ N latitude and 28°10′, 30°00′ E longitude) in Turkey. Soil analyses were done according to methods indicated by Müftüoğlu et al. (2014) and analysis results of the soil are shown in Table 1.

Table 1. Some properties of the soil used in the research

Properties	Quantities	Properties	Quantities
Texture	Clay	Extractable Cations, mg kg^{-1}	
Sand %	31.71	Sodium (Na)	96
Silt %	26.15	Potassium (K)	228
Clay %	42.14	Calcium (Ca)	9262
pH (1/2.5 soil / water)	7.48	Magnesium (Mg)	988
Electrical Conductivity (EC) mS cm^{-1}	0.45	Extractable microelements, mg kg^{-1}	
Lime % ($CaCO_3$)	1.96	Iron (Fe)	6.76
Organic matter %	2.53	Copper (Cu)	1.48
Total nitrogen (N) %	0.14	Zinc (Zn)	3.52
Available sulfur (S) mg kg^{-1}	12.75	Manganese (Mn)	92.88
Available phosphorus (P) mg kg^{-1}	15.15	Boron (B)	0.56

According to soil taxonomy, the soil used in the experiment was classified as vertisol (Typic Haploxerert) and as eutric vertisol according to the FAO classification system (Özsoy and Aksoy, 2013). Air-dried soil passed through a 4-mm sieve was filled into polyethylene plastic pots which were 20 cm in diameter and 18 cm deep and adjusted to 3.5 kg. Five maize (*Zea mays* L.) seeds, cultivar 'Euralis Es Armandi' (FAO 640) were planted in each pot and thinned-out to two plants in each pot after germination. The water content in the soil was held steady at 70 % of field capacity during the experiment.

Treatments: Four different doses of boron (0, 2.5, 5, and 10 mg kg-1) were applied to the soil as borax ($Na_2B_4O_7.10H_2O$) and boric acid (H_3BO_3). A constant value of 100 mg kg^{-1} nitrogen from ammonium nitrate (NH_4NO_3), 80 mg kg^{-1} P and 100 mg kg^{-1} K from mono potassium phosphate (KH_2PO_4) were also applied to all of the pots before planting.

Plant Harvesting: The plants were harvested 37 days after planting. Plant samples were immediately taken to the laboratory for analysis. The plant samples were dried in a forced air oven at 70°C for 72 hours after washing in tap water and twice with deionised water.

Plant Analysis: For the evaluation of the nutrient uptake in plants, the ground plant was digested using a mixture of 3 mL of nitric acid (HNO_3) and 3 mL of hydrogen peroxide (H_2O_2) in a microwave digestion system (Berghof MWS 2, Germany) (Hansen et al., 2013). The boron, magnesium (Mg), P and microelement amounts were determined by ICP-OES (Inductively Coupled Plasma – Optical Emission Spectrometry, Perkin Elmer Optima 2100 DV, United States) (Hansen et al., 2013). Potassium, sodium and calcium amounts were determined by flame photometer (Eppendorf Elex 6361) (Horneck and Hanson, 1998).

Statistical Analysis: Design of the experiment was completely randomized with three replications. Data were statistically analyzed using Tarist computer software (Ege University, İzmir). The mean values were compared with LSD (Least Significant Difference) multiple range test.

Results and Discussion

According to the analyses of the soil used in the experiment, it has clay texture and neutral pH. It has low lime and EC. The soil has also adequate concentrations of organic matter, nitrogen, phosphorus, potassium, copper and boron. Concentrations of the other nutrient elements such as iron, zinc, manganese, calcium and magnesium were found high (Marx et al. 1999).

The effects of increasing doses of boron sources (borax and boric acid) on the dry matter yield were given in Table 2. Low application doses of B (2.5 and 5.0 mg kg^{-1} B) have slight effects on the dry matter yield of maize plants and this effect was observed in group (A) with the control pots. Regardless of B sources, the increasing application doses of boron had a statistically significant negative effect on the dry matter yield of the maize plants. While the highest dry matter yield was obtained from the control pots (23.38 g pot^{-1}), the increasing doses of boron decreased the dry matter amounts and the lowest dry matter yield (21.94 g pot^{-1}) was measured at the highest dose of boron application (10.0 mg kg^{-1} B) and observed in group B.

Table 2. Effects of increasing doses of boron sources on dry matter yield of maize

Boron sources	Boron levels mg kg^{-1}										
	0		**2.5**		**5.0**		**10.0**		**Mean**		
	Dry matter yield (g pot^{-1})										
Borax	23.56		22.93		22.23		21.53		22.56	b	S LSD 0.421*
Boric Acid	23.20		23.26		23.38		22.34		23.05	a	L LSD 0.994**
Mean	**23.38**	**A**	**23.10**	**A**	**22.81**	**A**	**21.94**	**B**			SxL LSD ns
											S – boron sources L – boron levels

Notes. The differences between values by different letters are significant. Capital letters for each row and small letters for each column. ns: not significant. * P <0.05 ** *P <0.01*

Balanced uptake and amounts in plant tissues of the nutrients are emphasized for proper plant growth and development (Siddiqui et al., 2013). Low concentrations of B also improve the growth; however, high levels of boron can give damage to the plants. Boron amount of the experimental soil (0.56 mg kg^{-1}) was found enough for the proper plant development on control pots. During our past study on the sunflower plant, we found affirmative effects of B up to 2.0 mg kg^{-1} dose. However, the increasing doses of both borax and boric acid affected the dry matter yield negatively, and the elevated doses (4.0, 8.0 and 16.0 mg kg^{-1} B) gave the smallest dry matter yield (Bestas and Celik, 2016). Research made with maize cultivars showed similar decrease on the dry weight amounts (Güneş et al., 2000). Ben-Gal and Shani (2003) also reported decreases on biomass and yield of the tomatoes at high concentrations of B. Hamurcu et al. (2015) also found similar decreases at watermelon, which was influenced by B toxicity. Koohkan and Maftoun (2016) reported significant reduction on the yield of canola with the application of high boron. High amounts of B may increase the thickness of the cell wall, and this may cause difficulty for the uptake of nutrients, thus decreasing the dry matter yield. Suppressed plant growth was also attributed to the depressed cell division, cell wall expansion, chlorophyll content and photosynthetic rate (Herrera-Rodríguez et al., 2010; Siddiqui et al., 2013).

Statistically significant difference was found between the B sources on dry matter yield of maize. Highest dry matter yield (23.05 g pot^{-1}) was taken with boric acid applications and grouped as a.

The effects of increasing doses of boron sources (borax and boric acid) on the uptake of some micro nutrient elements were given in Table 3. These effects were found statistically significant at boron. The up taken amounts of B were elevated by the increasing doses of B sources. While the lowest dose for B (0.43 mg pot^{-1}) was found at control pots, regardless of B sources, the highest B amount (6.22 mg pot^{-1}) was taken from the highest dose (10.0 mg kg^{-1} B). In contrast, the increasing application doses of B had negative effects on the up taken Na, Fe, Zn and Mn amounts of the maize plants. However, these effects were not found statistically significant.

Table 3. Effects of increasing doses of boron sources on boron and some micro nutrient elements uptake of maize

Boron sources	**Boron levels mg kg^{-1}**					
	0	**2.5**	**5.0**	**10.0**	**Mean**	
	Boron (B) uptake (mg pot^{-1})					
Borax	0.44 a D	1.62 a C	3.20 a B	6.52 a A	2.95 a	S LSD 0.165**
Boric Acid	0.42 a D	1.40 a C	3.14 a B	5.92 b A	2.72 b	L LSD 0.233**
Mean	**0.43 D**	**1.51 C**	**3.17 B**	**6.22 A**		SxL LSD 0.329**
	Iron (Fe) uptake (mg pot^{-1})					
Borax	1.02	1.04	1.03	1.00	1.02 b	S LSD 0.044**
Boric Acid	1.16	1.16	1.18	1.15	1.16 a	L LSD ns
Mean	**1.09**	**1.10**	**1.10**	**1.08**		SxL LSD ns
	Copper (Cu) uptake (mg pot^{-1})					
Borax	0.11	0.11	0.11	0.12	0.11	S LSD ns
Boric Acid	0.11	0.12	0.13	0.11	0.12	L LSD ns
Mean	**0.11**	**0.12**	**0.12**	**0.12**		SxL LSD ns
	Zinc (Zn) uptake (mg pot^{-1})					
Borax	0.36	0.37	0.38	0.38	0.37	S LSD ns
Boric Acid	0.38	0.41	0.39	0.37	0.39	L LSD ns
Mean	**0.37**	**0.39**	**0.39**	**0.37**		SxL LSD ns
	Manganese (Mn) uptake (mg pot^{-1})					
Borax	0.84	0.83	0.80	0.78	0.81	S LSD ns
Boric Acid	0.77	0.81	0.81	0.80	0.80	L LSD ns
Mean	**0.81**	**0.82**	**0.80**	**0.79**		SxL LSD ns
	Sodium (Na) uptake (mg pot^{-1})					
Borax	28.29	27.96	29.06	28.19	28.38	S LSD ns
Boric Acid	26.04	27.95	28.20	28.36	27.64	L LSD ns
Mean	**27.16**	**27.96**	**28.63**	**28.28**		SxL LSD ns
				S – boron sources		L – boron levels

Notes. The differences between values by different letters are significant. Capital letters for each row and small letters for each column. ns: not significant. * *P* <0.05 ** *P* <0.01

Increasing the amounts of B in the soil may stimulate plant growth, the dry matter yield, the concentrations of the B, and the uptake of some nutrients by the plant. However, the high dose of B has negative effect and lower dry matter yield. Of the B sources, borax was up taken much more than boric acid and this situation was reflected to the decrease on dry matter yield (Table 2).

The effects of increasing doses of boron sources (borax and boric acid) on the uptake of some macro nutrient elements were given in Table 4.

Table 4. Effects of increasing doses of boron sources on some macro nutrient elements uptake of maize

Boron sources	Boron levels mg kg^{-1}									
	0		2.5		5.0		10.0		Mean		
	Nitrogen (N) uptake (mg pot^{-1})										
Borax	327.33		313.42		322.29		311.98		318.76		S LSD ns
Boric Acid	318.12		309.99		312.84		326.47		318.10		L LSD ns
Mean	**322.72**		**311.71**		**320.10**		**319.23**				SxL LSD ns
	Phosphorus (P) uptake (mg pot^{-1})										
Borax	150.00		150.12		150.023		143.10		148.31	a	S LSD 3.885**
Boric Acid	109.17		111.72		115.76		98.05		108.68	b	L LSD 5.494**
Mean	**129.58**	**A**	**130.92**	**A**	**132.89**	**A**	**120.58**	**B**			SxL LSD ns
	Potassium (K) uptake (mg pot^{-1})										
Borax	686.66		704.56		706.61		687.86		696.42		S LSD ns
Boric Acid	639.27		676.93		686.05		681.11		670.84		L LSD ns
Mean	**662.97**		**690.75**		**696.33**		**684.49**				SxL LSD ns
	Calcium (Ca) uptake (mg pot^{-1})										
Borax	170.15		166.69		156.51		163.74		164.27		S LSD ns
Boric Acid	156.39		157.52		159.90		164.39		159.55		L LSD ns
Mean	**163.27**		**162.10**		**158.20**		**164.07**				SxL LSD ns
	Magnesium (Mg) uptake (mg pot^{-1})										
Borax	43.60		46.02		47.82		49.73		46.79		S LSD ns
Boric Acid	43.14		43.93		45.16		49.12		45.34		L LSD 3.411*
Mean	**43.37**	**B**	**44.97**	**B**	**46.49**	**AB**	**49.43**	**A**			SxL LSD ns
									S – boron sources		L – boron levels

Notes. The differences between values by different letters are significant. Capital letters for each row and small letters for each column. ns: not significant. * P <0.05 ** P <0.01

Toxicity of boron was also reported by depletion of photosynthesis which was the result of the reduction of N concentration, known as the basic member of chlorophyll (Gimeno et al 2012). Interrelation of some nutrients and B is reported and found influential in regulating the availability of B or others in soils and plants (Ahmad et al., 2012). It was reported that with the addition of B, crop biomass could be escalated without changing the nitrogen amount or could be depressed the zinc amount in the plants or vice versa (Ahmad et al., 2012).

The increasing application doses of B had statistically significant positive effect on the up taken P and Mg amounts of the maize plants. Irrespective of B sources, the up taken amounts of Mg were elevated by the increasing doses of B. While the lowest dose for Mg (43.37 mg pot^{-1}) was found at control pots, the highest amount (49.43 mg pot^{-1}) was taken from the last boron dose (10.0 mg kg^{-1} B). Irrespective of B sources, the increasing application doses of B had a statistically significant negative effect on the up taken P amounts of the maize plants. While the up taken amounts of P tend to elevate with the increasing doses of B, it was significantly decreased with the highest dose from 132.89 to

120.58 mg pot^{-1}. Similar to the findings on P uptake, up taken amounts of K were increased up to 5.0 mg kg^{-1} B and the last dose of boron affected the increase in negative way. However, these effects were not found statistically significant.

Parallel to our findings, some literatures also reported increases on the K concentrations with the B applications but these increases were realized at small application doses (2 kg B ha^{-1}) of boron (Gezgin and Hamurcu, 2006). In our past research dealing with sunflower plant, highest K uptake was found at 4.0 and 8.0 mg kg^{-1} B doses and the amounts tended to decrease by the increasing B doses, also confirms the findings (Bestas and Celik, 2016). The ratio of the nutrients uptake and B uptake also describes this decrease briefly in Figure 1. Between control and the first dose (2.5 mg kg^{-1} B) of B sources, the ratios of all of the nutrient elements up taken amount to B uptake have severe decreases. These decreases continue to the maximum dose of B with a slight slope. This situation exhibits the antagonistic effect between high B doses and the decreased nutrient uptake.

Parallel to our findings, Bariya et al. (2014) reported the adverse effects of deficient or toxic B amounts on plants and their effects to the uptake of other nutrients. Although increasing the B supply may increase nutrient use efficiency, higher levels lead antagonistic effects on uptake of nutrients and decrease the nutrient use efficiency.

Koohkan and Maftoun (2016) also reported the decreases of K/B and Ca/B ratios with the application of B. Increasing B levels have been reported as significant increases of B, P, Ca and Mg but decreases of Fe, Mn, and Zn contents in apple rootstock (Mouhtaridou et al., 2004). Sotiropoulos et al. (2007) reported decreases in Mn but increases in Zn concentration of quince genotype. Different responses of the nutrients to B fertilization are concluded as a result of the genotypic effect of the plants (Eraslan et al., 2016).

Effects of the B sources (borax and boric acid) on dry matter yield and on uptake of B, P, and Fe were found statistically significant. There was no statistically significant difference between B sources (borax and boric acid) and up taken N, K, Ca, Mg, Na, Cu, Zn and Mn amounts. While borax application was found effective on B and P uptake of the maize plant, boric acid application was found effective on dry matter yield and on the uptake of Fe. Boron uptake of the maize plants was found higher on borax applications than boric acid.

Ahmad et al. (2012) reported borax, as the most commonly used B fertilizer among the B sources and boric acid is considered to be more suitable on highly leached sandy soils owing to its low solubility. In this study B uptake of the maize plants was also found higher on borax applications than boric acid. This is related with the uptake mechanism and the solubility of the material. High up taken B amounts with borax applications also negatively affected the dry matter yield of the maize plants than that of boric acid. This result also confirms our finding which is related with the toxic effect of high B concentrations on the dry matter yield amounts of crops.

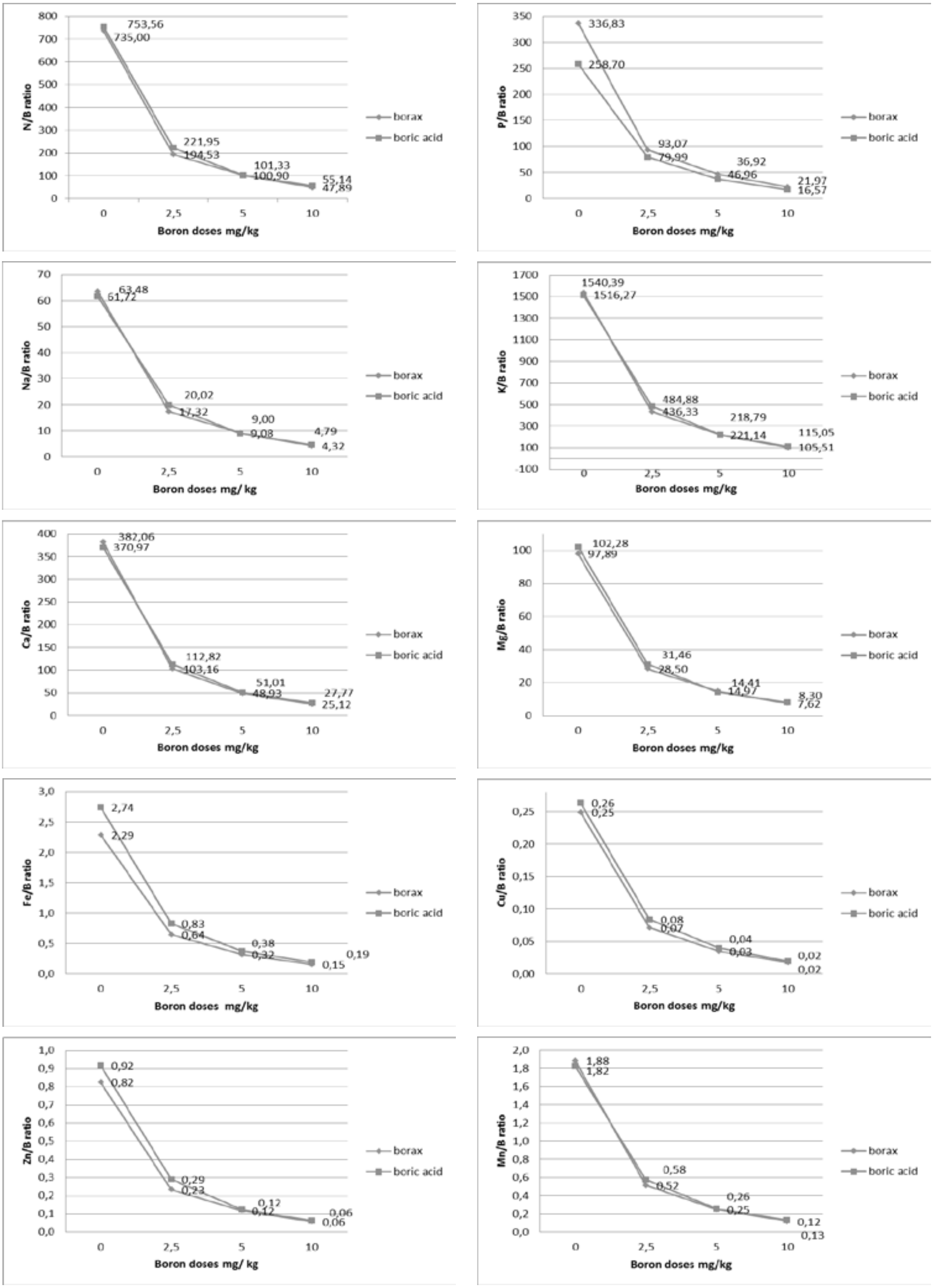

Figure 1. Nutrient / boron uptake ratios

Conclusion

Boron deficiency causes weak development and severe chlorosis symptoms in the maize plant. We can ameliorate the deficiency symptoms by B fertilizers such as boric acid and borax. Increasing the amounts of B stimulates the plant growth, the dry matter yield, the concentrations of the B in the plant and their uptake. However, high doses have negative effect and decrease the plant growth and other nutrients uptake. The highest dose of B sources not only lower dry matter yield in the plant but also decrease the uptake of nutrient elements. Therefore, extreme care is needed for choosing the right source, doses and methods during the B fertilization. With the further studies deal with determining the harmful threshold, this antagonistic effect between the nutrients might be useful way to stop the access uptake of B from the soil and by the way it might prevent the high consumption of the fertilizers. As a consequence of high concentrations of B which lead toxicity, degradation on the nutrients uptake and also degradation on the ratio between the nutrients and B; adequate amounts of B must be applied to plants. On the fields having high amounts of B; much more attention must be paid to mineral nutrition of the plants to prevent the crop losses due to the antagonistic effect with B. These essential nutrients should be used in correct doses for increasing soil fertility and to boost up crop production so further researches should be done on the field.

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