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YIELD AND CHEMICAL COMPOSITION OF CORN (*ZEA MAYS* L.) AS AFFECTED BY BORON MANAGEMENT

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ABSTRACT: Boron (B) deficiency is widespread in the Anatolia region of Turkey. This could impact production and quality of corn (*Zea mays* L.) A 2-yr field experiment was conducted for determine the optimum economic B rate (OEBR), critical soil test and tissue B values for yield and quality response of corn to B fertilizer soil application (SA) at 5 doses (0, 1, 3, 9 and 12 kg B ha^{-1}). OEBR of SA ranged 7.7 kg B ha^{-1} with an average yield of 75.10 Mg ha^{-1}. The average soil B content at the OEBR was 1.02 mg kg^{-1}while leaf tissue B content amounted to 20.61 mg kg^{-1} and shoot B content amounted to 13.43 mg kg^{-1}. Boron application increased shoot and leaf tissue N, Ca, Mg, P, K, and Mn but decreased tissue Fe, Zn, and Cu content. We conclude a B addition of 7.7 kg ha^{-1} for soil application is sufficient to elevate soil B levels to non-deficient levels. Similar studies with different soils and initial soil test B levels are needed to conclude if these critical soil test values and OEBR can be applied across the region.
Key Words: Boron, corn, macro and micro nutrient, optimum economic yield

Boron plays an important role in cell-wall synthesis, sugar transport, cell division, differentiation, membrane functioning, root elongation, regulation of plant hormone levels, and generative growth of plants (Marschner, 1995). Boron deficiency symptoms first become evident on the younger leaves which change color and become hardened, malformed and necrotic.

Boron is taken up as a boric acid, which is translocated slowly with in the plant. Deficiency symptoms can include a failure of root tips to elongate, inhibition of DNA and RNA synthesis and inhibition of cell division in the shoot apex of young leaves. Boron is also known to be critical in the elongation of the pollen tube (Salisbury and Ross 1992).

The soils in Eastern Anatolia are typical of those in arid and semi-arid regions. They have low organic matter, high free-lime content, high pH, and usually a fine texture. These properties are all well-known factors affecting the availability of micronutrients (Kalaycı et al. 1998). One of the challenges in corn production is its sensitivity to B deficiency (Salisbury and Ross 1992, Soylu et al. 2004).

It is estimated that currently in the central southern and eastern Anatolia regions of Turkey about 30% of the soils are B deficient (Kacar and Fox 1967, Kacar et al. 1979, Gezgin et al. 2002, Gezgin and Hamurcu 2006, Angin et al. 2008, Turan et al. 2009, Dursun et al. 2010), assuming a critical soil test B of 0.5 mg of B kg^{-1} (Keren and Bingham 1985). If 1.0 mg of B kg^{-1} is used as the critical soil test value (Reisenauer et al. 1973), 51.5% of the soils in the region test below the critical agronomic soil test B value, indicating the need for studies on B needs of corn as well as soil and/or tissue testing tools for B management.

Maize (*Zea mays* L.) is the most important silage plants in the world because of its high yield, high energy forage produced with lower labor and machinery requirements than other forage crops (Roth et al. 1995). Many environmental, cultural and genetic factors influence maize forage yield and quality. In Turkey, the agricultural area devoted annually to maize is 593710 hectare which is about 4% of cereal cultivating area and average grain production is 4 274 000 ton per year. Importance of corn production is increasing year by year because of its value for silage production as well as grain production. Maize grain production of Turkey is portioned as follow; about 35% for human nutrient requirement, about 65% for animal feed (Keskin et al. 2005). Traditional ruminant livestock production in Turkey is based predominantly on animals grazing natural pastures with low nutritive value especially during boron deficiency (Orak and Iptas 1999, Kusaksiz and Kusaksiz 2005, Yolcu and Tan 2008, Bulut et.al. 2008).

Maize has been previously considered to have a relatively low boron (B) requirement compared with other cereals (Marten and Westermann 1991). However, based on field responses to B application, B deficiency has been reported in maize across five continents (Bell and Dell 2008, Shorrocks 1997, Shorrocks and Blaza 1973). For example, maize yield increases of 10% were reported in Rhodesia (now Zimbabwe), up to 26% in India (Shorrocks and Blaza 1973), more than 10% in Switzerland (cited by Mozafar 1987) and by 9% in China (Li and Liang 1997). Deficiency of B in field grown maize was first observed in the 1960s in the United States (Shorrocks and Blaza 1973), and yield increases of more than 10% were observed in response to B application (Woodruff et al. 1987).

Crop yield responses to B application have been documented for various crops including soybean (Touchton and Boswell 1975), cotton (*Gossypium hirsutum* L.) (Roberts et al. 2000), peanut (*Arachis hypogaea* L.) (Davis and Rhoades, 1994), Brussels sprout (*Brassica olerecea* L. gemnifera) (Turan et al. 2009), lucerne (Mortvedt and Woodruff 1993, Turan et al. 2010) and strawberry (Esringü et al. 2011). Limited studies on B deficiency of various crops including corn suggest a critical soil solution content ranging from 0.15 mg of B kg^{-1} to 1.0 mg of B kg^{-1} and 2.0 mg B kg^{-1} and a critical leaf B concentration of 30 mg kg^{-1} (FAO 1990). However, additional studies are needed as soil chemical and physical properties and species selection will influence B availability to and uptake by plants possibly resulting in large variability in optimum economic B rates (OEBR) for various crops and soils.

The objectives of this study were (1) to evaluate the yield response corn to boron fertilizer, (2) to determine the effects of B addition on the mineral composition of corn, and (3) to determine optimum soil test B levels for corn under field conditions

MATERIALS AND METHODS

Background information for the study site

This study was conducted at the Agricultural Research Station of Ataturk University located in Erzurum, Turkey (long. $39^0$55' N, lat. $41^0$14' E) during the summer periods (late May to late September) of 2008 and 2009. Its altitude is 1835 m. The soil was classified as an Entisol with parent materials mostly consisting of volcanic, marn, and lacustrin transported material (Soil Survey Staff 2006). The experimental region has a semiarid climate. During the growing period, the mean maximum temperature was 28.7 ^{0}C in 2008 and 26.0 ^{0}C in 2009, whereas the minimum temperature was 11^{0}C in 2008 and 8.7 ^{0}C in 2009. The mean relative humidity, wind speed, daily sunshine, total precipitation, and total evaporation amounted to 48.27%, 2.95 m s^{-1}, 11.18 h, 42.75 mm, and 320.5 mm in 2008 (10 May to 20 Sept.), and 55.42%, 3.20 m s^{-1}, 11.10 h, 49.72 mm, and 410 mm in 2009 (15 May to 24 Sept.), respectively.

Trial design

The experiment was laid out in randomized block design with five B application levels (0, 1, 3, 9 and 12 kg B ha^{-1} as $Na_2B_4O_7.10\ H_2O$) as subplot in three replicates. B soil application was performed one times at 10 May 2008 and 15 May 2009. Individual plots were consisted (7.0 m long x 4.0 m wide). A 2 m space was left between the plots to prevent water movement from one plot to another. Row distance was 15 cm and plants were spaced 34 cm apart within rows.

Plant cultivation and fertility management

Before B fertilizer application, basal mineral fertilizer were applied at the rates of 240 N kg ha^{-1} (as ammonium sulfate; 20.5% N), 180 kg P_2O_5 ha^{-1} (as triple superphosphate; 48% P_2O_5), respectively take in to consider soil nutrient content. The crop was weeded manually with a hoe and weeding was repeated as required. No pesticide was applied.

Irrigation water applications

Good quality underground water with an electrical conductivity of 0.28 dS m-1, Na adsorption ratio of 0.42, and pH of 7.5 was used for surface irrigation. The moisture content (0-30 cm soil depth) was increased to field capacity after planting and soil moisture contents at 0-30 cm soil depths were determined daily by time domain reflectometer (TDR 300, Spectrum Technologies, East Plainfield, Illinois, USA). Water was supplied by furrow irrigation when available soil water content had decreased to 50% of field capacity with 52.7 mm of ground water, assuming an effective root depth of 60 cm (Allen et al. 1998).

Soil analysis

Before B application, soil samples were taken over two depths (0-30 and 30-60 cm, 20 subsamples) to determine baseline soil properties. Soil samples were air-dried, crushed, and passed through a 2-mm sieve prior to chemical analysis. Cation exchange capacity (CEC) was determined using sodium acetate (buffered at pH 8.2) and ammonium acetate (buffered at pH 7.0) according to Sumner and Miller (1996). The Kjeldahl method (Bremner 1996) was used to determine total N while plant-available P was determined by using the sodium bicarbonate method of Olsen et al. (1954). Electrical conductivity (EC) was measured in saturation extracts according to Rhoades (1996). Soil pH was determined in 1:2 extracts, and calcium carbonate concentrations were determined according to McLean (1982). Soil organic matter was determined using the Smith-Weldon method according to Nelson and Sommers (1982). Ammonium acetate buffered at pH 7 (Thomas 1982) was used to determine exchangeable cations. Available Fe, Mn, Zn, and Cu in the soils were determined by Diethylene Triamine Pentaacetic Acid (DTPA) extraction methods (Lindsay and Norvell, 1978). Available B was analyzed for extractable B using the azomethine-H extraction of Wolf (1974) and a UV/VIS (Aqumat) spectrophotometer (Thermo Electron Spectroscopy LTD, Cambridge, UK). These soil characterization data are presented in Table 1.

Plant sampling and analytical methods

Of the 24 plants per plot, the total above-ground 15 plants were sampled (shoot and with six leaves that the youngest fully developed leaf). The nutrient levels in these plant tissues most accurately reflect the uptake of nutrients by the crop, (Dhillon et al. 1999) and to determine the mineral contents of the plants were harvested on September 20 in 2008 and September 24 in 2009 to determine season yields. Samples were oven-dried at 68ºC for 48 h and ground to pass 1 mm. The Kjeldahl method and a Vapodest 10 Rapid Kjeldahl Distillation Unit (Gerhardt, Konigswinter, Germany) were used to determine total N (Bremner 1996).

Table 1 Chemical properties of the experimental field soils before seedling (mean ± standard deviation, n = 20)

Soil Properties	Units	2008		2009	
		Soil Depth		Soil Depth	
		0-30 cm	30-60 cm	0-30 cm	30-60 cm
Clay	%	25.34±0.80	18.50±1.10	aND	ND
Silt	%	37.66±0.88	28.40±0.79	ND	ND
Sand	%	37.00±1.20	53.10±1.60	ND	ND
Cation exchangeable capacityb	cmolc kg^{-1}	22.13±2.83	19.46±1.75	ND	ND
Total N	g kg^{-1}	1.2±0.11	0.86±0.05	1.1±0.12	0.73±0.09
pH (1:2 soil:water)		7.44±0.3	7.57±1.02	7.32± 0.15	7.48±1.27
Organic C	g kg^{-1}	8.06±0.17	7.62±1.12	7.78±0.21	7.14±1.65
CaCO3	g kg^{-1}	65±6	98±17	78±0.20	108±0.20
Plant available Pc	mg kg^{-1}	4.47±1.12	2.76±0.63	5.36±0.70	4.14±0.30
Exchangeable Cad	cmolc kg^{-1}	11.6±1.67	17.3±0.12	12.0±1.00	16.7±0.13
Exchangeable Mgd	cmolc kg^{-1}	2.13±0.68	2.86±0.08	2.33±0.42	2.73±0.24
Exchangeable Kd	cmolc kg^{-1}	5.2±0.63	4.9±0.18	5.5±0.55	4.11±0.17
Exchangeable Nad	cmolc kg^{-1}	0.65±0.12	1.06±0.19	0.91±0.13	1.23±0.26
Available Fee	mg kg^{-1}	4.23±0.25	3.66±0.23	4.65±0.14	3.76±0.25
Available Mne	mg kg^{-1}	5.26±0.09	4.73±0.17	5.44±0.23	4.10±0.15
Available Zne	mg kg^{-1}	3.22±0.23	1.65±0.15	4.34±0.43	4.76±0.30
Available Cue	mg kg^{-1}	4.34±0.19	2.17±0.28	4.79±0.48	3.54±0.17
Available Bf	mg kg^{-1}	0.13±0.01	0.08±0.01	0.30±0.11	0.18±0.09
Electric conductivity	dS m^{-1}	1.03±0.02	2.10±0.14	1.72±0.13	2.35±0.17

[a]ND: Not done [b]Sodium acetate at pH 8.2 according to Sumner and Miller (1996)
[c]Sodium bicarbonate according to Olsen et al. (1954) [d] Ammonium acetate at pH 7.0 according to Thomas (1982) [e] DTPA extraction according to Lindsay and Norwell (1978) [f]Azomethine-H extraction according to Wolf (1974)

Macro- (P, S, K, Ca Mg and S) and micro-elements (Fe, Mn, Zn Cu, and B) were determined after wet digestion of dried and ground sub-samples using a HNO_3-H_2O_2 acid mixture (2:3 v/v) with three step (first step; 145ºC, 75%RF, 5 min; second step; 180ºC, 90%RF, 10 min and third step; 100ºC, 40%RF, 10 min) in microwave (Bergof Speedwave Microwave Digestion Equipment MWS-2) (Mertens 2005a). Tissue P, K, S, Ca, Mg, S, Fe, Mn, Zn, Cu and B were determined Inductively Couple Plasma spectrophotometer (Perkin-Elmer, Optima 2100 DV, ICP/OES, Shelton, CT 06484-4794, USA) (Mertens 2005b).

Statistical analysis

The experiment was laid out in randomized block design with as main plot and five B application levels (0, 1, 3, 9 and 12 kg B ha^{-1}) as subplot in three replicates. All data were subjected to analysis of variance (ANOVA) and significant means were compared by Duncan's multiple range test method, performed using SPSS 13.0 (SPSS Inc., 2004). Mean differences were considered significant if $P \leq 0.05$. The optimum economic B rate (OEBR) was defined as the B rate at which the highest returns to B fertilizer were obtained assuming a quadratic-plus-plateau model, a corn value of US$0.25 kg^{-1} and a fertilizer cost of US$0.65 kg^{-1} B. For return per ha calculations, an annual (fixed) cost of production of $200 ha^{-1} was assumed. For each B application rate, the apparent B recovery (ABR) was calculated as the B removal in harvest per kg B applied:

Apparent B recovery for corn (%) = (B at B_{rate} – B at control) / (B applied) * 100 [1]

RESULTS

Boron fertilizer application affected the yield of corn in each of the two years although there were no statistically significant differences between the mean yields of two years, there were statistically significant differences between application B doses (Figure 1). The highest yields were obtained from 9 kg B ha^{-1} doses. Maximum return to B fertilizer of soil B application ranged US$18572 ha^{-1} yr^{-1}, obtained with OEBR that 7.7 kg B ha^{-1} with an average yield of 75.10 Mg ha^{-1} (Table 2).

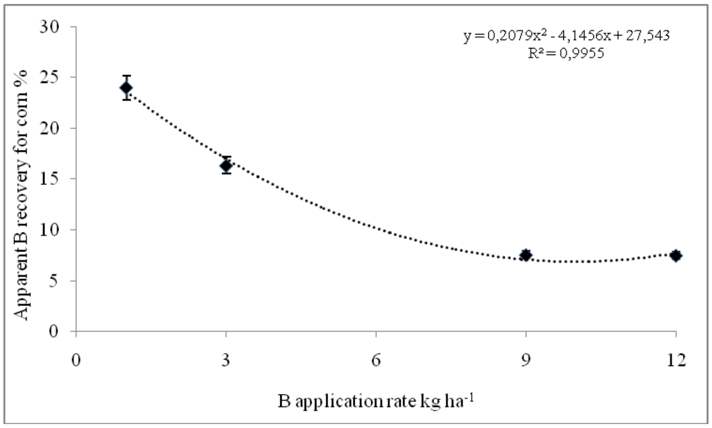

Figure 1 *Zea mays* L. yields as affected by boron (B) soil application (SA) to a B-deficient flavuaquent Entisol in Eastern Turkey. Identified are optimum economic B rates for each of the two years and the 2-year average assuming US$0.65 kg^{-1} B and a corn value of US$0.25 kg^{-}

Table 2 Yields, optimum economic B rates (assuming US$0.65 kg^{-1} B and a corn *Zea mays* L. value of US$0.25 kg^{-1}), return at OEBR (assuming a fixed annual cost of production of $200 ha^{-1}) and R^2 of the quadratic fit for the yield response data for corn *Zea mays* L. grown on a B-deficient flavuquent Entisol in Eastern Turkey in 2- year average.

	B application rate								
Application time	0	1	3	9	12	OEBR	Yield at OEBR	Annual return ha^{-1} at OEBR	R2
		kg ha^{-1}						US$ ha^{-1}	
1- year	41105 d	58478 c	57731 c	76929 a	63058 b	7.6	75818	18749	0.990
2-year	50337 e	54400 d	68435 c	72715 a	69364 b	7.7	74398	18395	0.980
2-year average	45721 e	56439 d	63083 c	74822 a	66211 b	7.7	75108	18572	0.976

Boron application reduced the ABR (Figure 2). The ABR at the OEBR varied from about 7.95% for soil application (Figure 2).

Without B addition, the average (2-yr) soil B contents at harvesting time were 0.29 mg B kg^{-1} but this increased to 1.02 mg B kg^{-1}, when B fertilizer was applied at the OEBR (Figure 3).

Boron fertilizer application increased both leaves and shoot tissue N, Ca, Mg, P, K, and Mn but decreased tissue Fe, Zn, and Cu content (Table 3), respectively. The 2-yr average leaf and shoot tissue B content in the control treatments was 5.59 and 3.63 mg kg^{-1} DW, respectively. This increased to 20.61 for leaf and 13.43 mg B kg^{-1} for shoot, when B fertilizer was applied at the OEBR (Table 3).

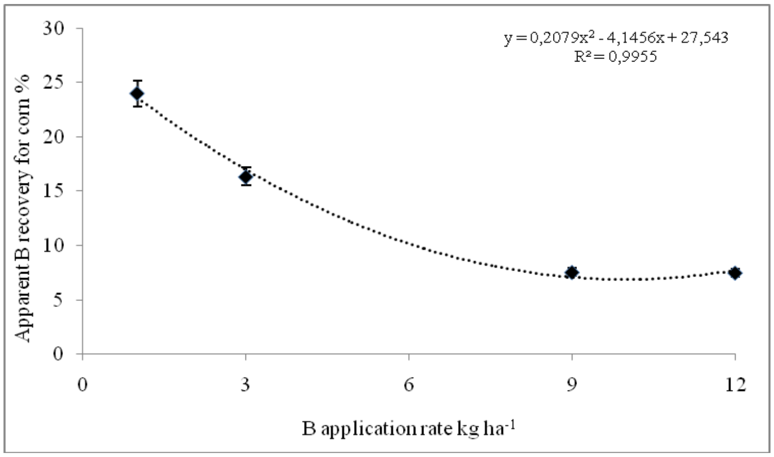

Figure 2 Apparent B recovery for corn grown on a B-deficient flavuaquent Entisol in Eastern Turkey. At the economic optimum B rates of 7.7 kg B ha^{-1} yr^{-1} (averaged over the two years) for soil application (SA) method, the apparent B recovery for corn was 7.95%.

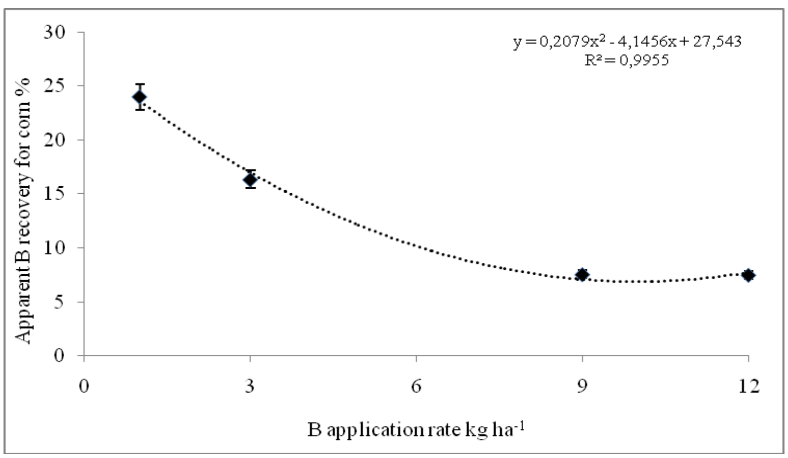

Figure 3 Soil solution B concentration (2-yr average) for corn grown on a B-deficient flavuaquent Entisol in Eastern Turkey. At the optimum economic B rate (OEBR), soil solution B ranged from 0.29 to 1.02 mg B kg^{-1} for soil application (SA) method.

DISCUSSION

The OEBR for soil application in our study were higher than the 1.5 to 4.4. kg B ha^{-1} rates obtained by Stangoulis et al. (2000), Guertal (2004), Vaughan (1977), mustard (*Brassica juncea* (L.) Czern.), bentgrass (*Agrostis palustris* Huds.), and maize (*Zea mays Zea mays* L.). The higher OEBR our study might have reflected the low initial soil B level (0.29 mg kg^{-1}) for corn sensitivity to B deficiency (Shorrocks 1997).

B application significantly increased yield values. The response to B application regarding vegetative growth is in line with those observed by Christensen et al. (2006), Mustafa et al. (2006) and Westover and Kamas (2009).

Table 3 Leaf and stem macro-micro element concentration of corn *Zea mays* L. when grown in two consecutive years under five different B application treatments on a B-deficient flavuquent Entisol in Eastern Turkey in 2008 and 2009 grown on.

B application doses				
kg ha-1	Leaf	Stem	Leaf	Stem
	% of DM		mg kg^{-1}	
	N		Fe	
0	2.31 d	1.43 d	197.71 a	130.44 a
1	2.79 c	1.73 c	168.94 b	111.47 b
3	3.49 b	2.16 b	170.09 b	112.14 b
9	4.74 a	2.94 a	160.19 b	105.71 b
12	3.35 c	2.08 b	142.35 c	93.85 c
Adjusted R2	0.957	0.958	0.782	0.787
LSD	0.145	0.089	7.697	5.064
	P		Cu	
0	0.35 d	0.21 d	17.09 a	5.27 a
1	0.40 c	0.24 c	15.27 ab	4.71 ab
3	0.46 b	0.27 b	14.42 bc	4.47 bc
9	0.55 a	0.33 a	12.65 c	3.91 c
12	0.57 a	0.33 a	10.06 d	3.11 d
Adjusted R2	0.975	0.975	0.836	0.841
LSD	0.112	0.066	0.872	0.259
	Ca		Mn	
0	0.70 d	0.20 d	52.13 b	33.37 d
1	0.79 c	0.22 c	51.85 b	39.78 c
3	0.91 b	0.26 b	63.83 a	45.43 b
9	0.99 a	0.29 a	64.73 a	49.54 a
12	0.78 c	0.22 c	66.96 a	44.92 b
Adjusted R2	0.989	0.989	0.868	0.877
LSD	0.108	0.030	2.117	1.729
	K		Zn	
0	0.66 d	0.27 d	25.44 a	17.00 a
1	0.83c	0.34 c	21.18 b	14.08 b
3	1.10 a	0.45 a	16.76 c	10.99 c
9	1.09 a	0.45 a	12.83 d	8.59 d
12	0.95 b	0.39 b	10.52 e	7.04 e
Adjusted R2	0.991	0.991	0.961	0.966
LSD	0.136	0.056	0.916	0.568
	Mg			
0	0.29 c	0.12 c		
1	0.31 bc	0.13 bc		
3	0.35 a	0.15 a		
9	0.32 b	0.14 b		
12	0.32 b	0.14 b		
Adjusted R2	0.744	0.743		
LSD	0.847	0.359		

The ABR for boron application in our study were higher than those obtained by Byju et al. (2007) for sweet potato where the highest ABR was 0.4% at a B application rate of 1.0 kg ha^{-1} but lower than those obtained by Santos et al. (2004) for alfalfa where the ABR decreased from 48% upon application of 0.25 kg ha^{-1} B to 10% when 2.0 kg B ha^{-1} was applied, most likely reflecting the very low initial soil B concentration (0.29 mg B kg^{-1}) in the study by Santos et al. (2004).

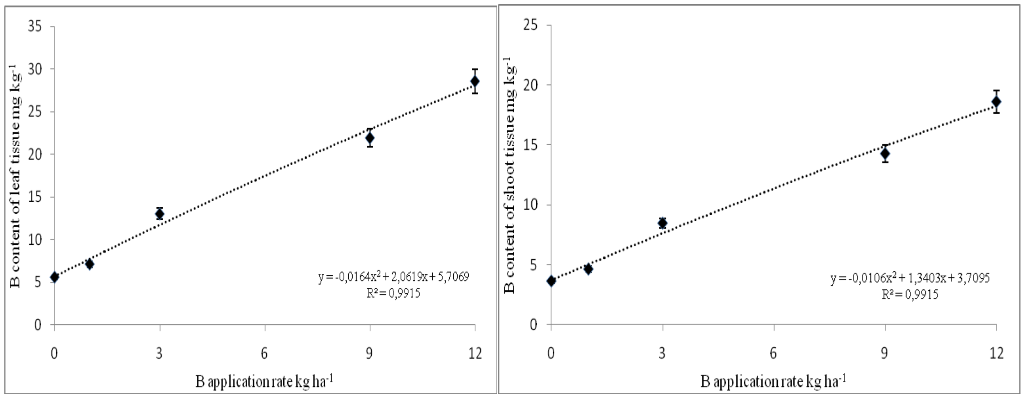

Figure 4 Relationship between leaf and shoot tissue B content (2-yr average) for corn grown on a B-deficient flavuaquent Entisol in Eastern Turkey. At the optimum economic B rate (OEBR), plant leaf and shoot tissue B ranged from 20.61 to 13.43mg B kg^{-1} soil B application.

Soil B content for soil application at the optimum yield in our study was higher than the 0.28 mg B kg^{-1} reported by Asad et al. (1997) for canola (*Brassica napus* L.) grown under greenhouse conditions. On the other hand our study showed lower optimum soil B levels than the 3 mg kg^{-1} reported for alfalfa grown in a greenhouse (Santos et al. 2004) and muskmelon (*Cucumis melo* L.) grown in field conditions (Goldberg et al. 2003), possibly reflecting species-specific differences in optimum soil B content.

Compiling results from the greenhouse and field experiments published during 10 years, Guertal (2004), Santos et al. (2004), Ross et al. (2006) and suggested 10 mg kg^{-1}, 66 mg kg^{-1}, 44.1 mg kg^{-1} in plant tissue to be the critical level for boron in bentgrass (*Agrostis palustris* Huds.), alfalfa (*Medicago sativa* cv. Crioula) and soybean (*Glycine max* (Merr.) L). B concentration in plants vary, but B above, 50–100 mg kg^{-1} has been considered high for many plants (Jones et.al., 1991; Reuter 1986). For maize (*Zea mays* L.), B has been considered to be high at 25 mg kg^{-1} in shoots of young plants (Jones et.al. 1991) and at 100 mg kg^{-1} in leaves of plants near tasselling or ear formation (Reuter 1986). For maize grown to maturity where nutrients were continuously supplied (nutrient solutions), ear leaves had, 50 mg kg^{-1} B near silking, and increased to 100–130 mg kg^{-1} at maturity (Clark 1975). Concentrations of B for severe toxicity have been reported at 270–570 mg kg^{-1} for grasses and 960 mg kg^{-1} for the needles of conifer trees (Mengel and Kirkby 1982).

The range in leaf tissue B content at the OEBR in our study (20.61 mg B kg^{-1}) suggests similar critical tissue B contents for corn as for bentgrass.

Boron fertilizer application increased both leaves and shoot tissue N, Ca, Mg, P, K, and Mn but decreased tissue Fe, Zn, and Cu content. The concentrations of plant nutrients measured were generally within accepted critical levels. Mills and Jones (1996) suggested critical leaf and shoot values for optimum corn growing as 3.0-3.5%, 3.0-5.0% for N, 0.2-0.4%, 0.3-0.5 for P, 2.0-2.5%, 2.5-4.0% for K, 0.2- 0.5%, 0.3-0.7%, for Ca, 0.13-0.3%, 0.15-0.45% for Mg, 10-200 mg kg^{-1}, 50-250 mg kg^{-1} for Fe, 15-60 mg kg^{-1}, 20-60 mg kg^{-1} for Zn, 15-300 mg kg^{-1}, 20-300 mg kg^{-1} for Mn, and 3-15 mg kg^{-1}, 4-20 mg kg^{-1} for Cu . An increase in tissue N, P, K, Ca, Mg and S was also reported for chickpea (*Cicer arientinum* L.) P content, lentil (*Lens culinaris* Medikus) K content (Singh and Singh 1990) sugar beet (*Beta vulgaris* L.). The concentrations of all plant nutrients measured for leaf and shoot were within agronomic critical levels defined in Mills and Jones (1996).

Boron application increased corn yield, indicating a B deficiency. Averaged over the two years, the maximum return to B fertilizer was obtained for SA at an OEBR of 7.7 kg B ha^{-1}. Leaf and shoot tissue B content in the control treatments was 5.58 and 3.63 mg kg^{-1} DW for soil application, respectively and increased to 20.61 and 13.43 mg B kg^{-1} when B was applied at the OEBR. In B application, soil B levels ranged from to 0.29, and 1.02 mg B kg^{-1} at OEBR that ranged from 7.7 kg B ha^{-1} for SA. B application increased both leaves and shoot tissue N, Ca, Mg, P, K, and Mn but decreased tissue Fe, Zn, and Cu content. We conclude B addition of 7.7 kg ha^{-1} for SA is sufficient to elevate soil B levels of this soil with an initial B content of 0.13 mg kg^{-1} to non-deficient levels of 0.29-1.19 mg kg^{-1}. Similar studies with different soils and initial soil test B levels are needed to conclude if these B application rates and critical soil test values can be applied across the region.

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