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Yield and mineral composition of grapevine (*Vitis vinifera* L. cv. Karaerik) as affected by boron management

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Abstract: Boron (B) deficiency is widespread in the northeastern Anatolian region of Turkey. This could impact the production and quality of grapevine (*Vitis vinifera* L. cv. Karaerik). A field experiment was conducted for determining the optimum economic B rate (OEBR), critical soil test, and tissue B values for yield and quality response of grapevine to B fertilizer application method (foliar and soil) at 5 doses (0, 1, 3, 9, and 12 kg B/ha) for 2 years. OEBR of foliar and soil application ranged from 6.4 to 8.5 kg B/ha with an average yield of 20.2–12.8 t/ha, respectively. The average soil B content at the OEBR was 0.32–2.52 mg/kg. Leaf tissue B content amounted to 98.9 and 64.4 mg/kg, and berry B content amounted to 21.4 and 12.9 mg/kg for foliar and soil application methods, respectively. Independently of application method, B application increased tissue N, Ca, Mg, P, K, and Zn, yet decreased Fe, Mn, and Cu content. We concluded that a B addition of 6.4 kg/ha for foliar application and 8.5 kg/ha for soil application is sufficient to elevate soil B to nondeficient levels.

Key words: Aridisol, boron deficiency, macro and micronutrient, optimum economic yield

1. Introduction

Boron (B) is very important for the healthy growth and development of grapevine (Fortunati, 2006). B plays an important role in sugar transport, cell differentiation, cell wall synthesis, root elongation, regulation of plant hormone levels, and generative growth of plants (Marschner, 1995). B deficiency symptoms include the root tips not elongating, inhibition of RNA and DNA synthesis in young leaves (Salisbury and Ross, 1992), fruit sets containing grape bunches of abnormal varying sizes, and decreasing of berry setting (Cristensen et al., 2006; Fortunati, 2006).

The uptake of B is affected by irrigation, and under drought stress, high rainfall, and intensive irrigation it could limit plant growth, especially in sand soils, with the ion being leached from the soil profile (Pearson and Goheen, 1998). B deficiency is widespread in highly calcareous soils with loose structure and low organic content, and in vineyards leached by low B irrigation water on sandy alluvial soil of granitic origin (Cook et al., 1960; Corino et al., 1990; Csikász-Krizsics and Diofási, 2007).

The soils of northeastern Anatolia have low organic matter, high pH, high free lime content, and usually a fine texture. These properties affect the sufficiency of micronutrients, especially B (Salisbury and Ross, 1992; Kalaycı et al., 1998; Pearson and Goheen, 1998; Soylu et al., 2004; Demir and Serindağ, 2006).

In the central, southern, and eastern Anatolian regions of Turkey, about 30% of the soils are B-deficient and have a critical soil B content of 0.5 mg/kg (Kacar and Fox, 1967; Kacar et al., 1979; Keren and Bingham 1985; Gezgin et al., 2002; Gezgin and Hamurcu, 2006; Angin et al., 2008; Turan et al., 2009; Dursun et al., 2010; Turan et al., 2010). B fertilization has positive effects on plant tissue formation (Peacock, 2005), pollen germination (Ebadi et al., 2001), fruit yield (Usha and Singh, 2002), and growth (Rolshausen and Gubler, 2005) of grapevine. If 1.0 mg B/kg is used as a soil test value (Reisenauer et al., 1973), half the soils in the region are classed below the agronomic soil test for B, and this result indicates the necessity for studies on the need of grapevines for B fertilization.

The Üzümlü district is the most important grape-growing area of the northeastern Anatolian region of Turkey. The common grapevine cultivar of the region is Karaerik (*Vitis vinifera* L.), which is desirable in the region and has high market value. In order to determine the effect of B on the growth and mineral composition of Cabernet Sauvignon vine plants, Downton and Hawker

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(1980) watered them on a daily basis with a complete solution with a varying B concentration of 0–10 mg B/L. Extreme B concentration reduced plant dry, root mass, and shoot length. Excessive B concentration also reduced P concentration in the plant roots and plant leaves.

Dabas and Jindal (1985) studied the effects of B sprays on plants. Boric acid as the B source was applied at doses of 0.1%, 0.2%, and 0.3%. B fertilizers were applied 1 week before full flowering. A 0.3% boron fertilizer application significantly increased fruitful buds and reduced vegetative buds. However, the best results were obtained with 0.1% B fertilization doses. At the same time, the results showed that B application improved pollen germination.

B applications have also been studied for various crops such as *Arachis hypogaea* L. (Davis and Rhoads, 1994), soybean (Touchton and Boswell, 1975), cotton (*Gossypium hirsutum* L.) (Roberts et al., 2000), lucerne (Mortvedt and Woodruff, 1993; Turan et al., 2010), and peanut Brussels sprout (*Brassica olerecea* L. gemnifera) (Turan et al., 2009). These results suggest a critical soil solution content ranging from 0.15 to 1.0 mg B/kg (Peacock and Christensen, 2005) and 2.0 mg B/kg (FAO, 1990). They also suggest a grape leaf B concentration of 30 mg/kg (Peacock and Christensen, 2005).

However, more studies are needed, as the chemical and physical properties of soil and species selection influence B availability and uptake by plants in optimum economic B rates (OEBR) for various crops and soils.

The objective of this study was to evaluate the yield response of grapevine to B fertilizer, to determine the effects of B addition on the mineral nutrient composition of grapevine, and to ascertain optimum soil test B levels for grapevine under field conditions.

2. Materials and methods

2.1. Background information about the study site

This study was conducted at the Üzümlü district of Erzincan, Turkey (39°40′59.5″N and 39°40′59.5″E). The site was located at an altitude of 1161 m. This region's soils were classified as Entisol, with parent materials mostly consisting of marn- and lacustrine-transported material (Soil Survey Staff, 2006). Entisols are commonly found in parent materials resistant to weathering (e.g., sand). The productivity and fertility potential of the region's soils is low in sandy areas. The experimental region has a semiarid climate. During the growing period, the mean maximum temperature was 29 °C in both years, while the minimum temperature was 10 °C in 2008 and 13 °C in 2009. The mean relative humidity, wind speed, daily sunshine, total precipitation, and total evaporation were 54.58%, 2.72 m/s, 11.23 h, 63.4 mm, and 388.7 mm, respectively, in 2008 (20 May–29 September), and 57.95%, 3.50 m/s, 10.07 h, 48.9 mm, and 448 mm, respectively, in 2009 (28 May–10 October).

2.2. Trial design

This experiment was conducted in a randomized block design with soil and foliar application as the main plot and 5 B application levels (0, 1, 3, 9, and 12 kg B/ha) as subplots in 4 replicates. B soil application was performed once, and foliar application was performed in 3 application periods: the first was at first mature leaf, the second at prebloom, and the third at veraison. The grapevines were trained with the traditional Baran system, which is a prostrated system. A 6-m space was created between the plots to prevent water movement between them.

Before B fertilizer application, base mineral fertilizers were applied at the rates of 150 N kg/ha (as ammonium sulfate; 20.5% N), 80 kg P_2O_5/ha (as triple superphosphate; 48% P_2O_5), 100 kg K_2O/ha (as potassium sulfate; 50% K_2O), and 30 kg $MgSO_4.7H_2O$/ha (as magnesium sulfate; 18.3% Mg) and 4 kg $ZnSO_4.H_2O$/ha (as zinc sulfate monohydrate; 35% Zn), respectively, taking into consideration soil nutrient content (Sing, 2006). The crop was weeded manually with a hoe and weeding was repeated as required. No pesticide was applied.

2.3. Soil analysis

Soil samples were taken over 2 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 with 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, UK). The soil characterization data are presented in Table 1.

2.4. Plant sampling and analytical methods

Of the 25 plants per plot, 15 plants were sampled. Basal whole leaves (petiole + blade) and opposite clusters were sampled at veraison to determine their content in mineral elements (Morlat, 2008). The nutrient levels in these plant tissues most accurately reflect the uptake of nutrients by

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

Soil properties	Units	Soil depth	
		0–30 cm	30–60 cm
Clay	%	17.34 ± 0.87	18.50 ± 1.10
Silt	%	29.21 ± 0.80	28.40 ± 0.90
Sand	%	53.65 ± 1.85	53.10 ± 1.60
Cation exchangeable capacity[b]	$cmol_c$/kg	26.50 ± 2.40	21.10 ± 1.35
Total N	g/kg	1.8 ± 0.03	1.44 ± 0.06
pH (1:2 soil:water)		7.70 ± 0.2	7.83 ± 1.14
Organic C	g/kg	19 ± 0.10	9 ± 1.70
$CaCO_3$	g/kg	121 ± 10	232 ± 30
Plant available P[c]	mg/kg	10.3 ± 1.60	7.2 ± 0.40
Exchangeable Ca[d]	$cmol_c$/kg	18.0 ± 2.20	20.1 ± 0.03
Exchangeable Mg[d]	$cmol_c$/kg	4.40 ± 0.50	3.20 ± 0.11
Exchangeable K[d]	$cmol_c$/kg	6.4 ± 0.80	4.5 ± 0.07
Exchangeable Na[d]	$cmol_c$/kg	0.85 ± 0.05	1.12 ± 0.11
Available Fe[e]	mg/kg	3.70 ± 0.30	3.25 ± 0.10
Available Mn[e]	mg/kg	4.60 ± 0.09	4.11 ± 0.08
Available Zn[e]	mg/kg	0.15 ± 0.15	0.10 ± 0.03
Available Cu[e]	mg/kg	2.20 ± 0.13	1.75 ± 0.03
Available B[f]	mg/kg	0.017 ± 0.006	0.015 ± 0.003
Electric conductivity	dS/m	1.15 ± 0.03	2.31 ± 0.02

[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 Norvell (1978)
[f]Azomethine-H extraction according to Wolf (1974)

the crop (Shikhamany et al., 1988; Dhillon et al., 1999; Patel and Chadha, 2002). To determine the mineral content of the berries, plants were harvested in September and October to determine season yields. Leaf and berry samples were oven-dried at 65 °C until their weight was constant, and were then ground and sieved through a 50-mesh screen. The Kjeldahl method and a Vapodest 10 Rapid Kjeldahl Distillation Unit (Gerhardt, Germany) were used to determine total N (Bremner, 1996). Macro- (P, S, K, Ca, Mg, and S) and microelements (Fe, Mn, Zn Cu, and B) were determined after wet digestion of dried and ground subsamples using a HNO_3/H_2O_2 acid mixture (2:3 v/v) in 3 steps (first step: 145 °C, 75% RF, 5 min; second step: 180 °C, 90% RF, 10 min; and third step: 100 °C, 40% RF, 10 min) in a 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 with an inductively couple plasma spectrophotometer (PerkinElmer, Optima 2100 DV, ICP/OES, USA) (Mertens, 2005b).

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 grapevine value of \$2.50/kg, and a fertilizer cost of \$0.65/

kg B. For return per ha calculations, an annual (fixed) cost of production of \$2000/ha 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 berry (ABR) (%) = (B at B_{rate} – B at control)/(B applied) × 100

2.5. Statistical analysis

All data were subjected to analysis of variance (ANOVA) and significant means were compared by Duncan's multiple range test method, performed with SPSS 13.0. Mean differences were considered significant if P ≤ 0.05.

3. Results

B fertilizer application affected the yield of grapevine in both years. There were no statistically significant differences between the mean yields of the two growing periods. The results of the experiment showed statistically significant differences between foliar application (FA) and soil application (SA) (Figure 1). The highest yields were obtained with FA. Maximum return to B fertilizer of FA and SA B application ranged from \$48,595/ha to \$28,867/ha per year, obtained with OEBR that ranged from 6.4 kg B/ha to 8.5 kg B/ha (Table 2), respectively.

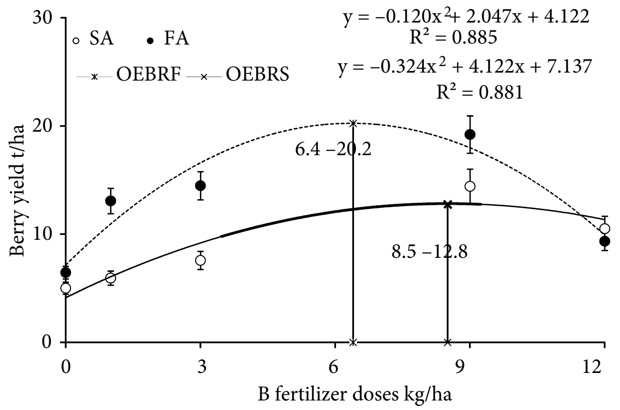

Figure 1. Grapevine Karaerik cv. yields as affected by boron (B) foliar applications (FA) and soil application (SA) (2-year average) to a B-deficient fluvaquent Entisol in northeastern Turkey. Optimum economic B rates are identified for both years and the 2-year average, assuming \$2.5/kg B and a Brussels sprout value of \$0.65/kg.

B fertilizer applications with foliar and soil significantly affected total cluster number per vine (TCN), number of cluster per shoot (NC), cluster weight (CW), number of berries per bunch (NB), berry setting ratio (BSR), number of shot berries per bunch (NSB), shot berries ratio (SBR), berry cracking ratio (BCR), number of seed per berry (NS), and total soluble solid of must (TSS) (Table 3). In general, B application significantly increased TCN, NC, CW, NB, BSR, and BCR values, but decreased NSB, SBR, NS, and TSS. As compared with the control treatment, TCN, NC, CW, NB, BSR, and BCR values of grapevine increasing ratio for FA and SA application methods were 57%–17%, 18%–20%, 19%–23%, 36%–9%, 1%–62%, and 1%–3% for 6.4 kg/ha for foliar application and 8.5 kg/ha for soil application at OEBR, respectively. However, NSB, SBR, NS, and TSS values of grapevine plant decreasing ratio for FA and SA application methods were 50%–61%, 47%–64%, 13%–7%, and 5%–22% for 6.4 kg/ha for FA and 8.5 kg/ha for SA at OEBR, respectively, when compared to the control (Table 3).

B application reduced the apparent B recovery in berry (ABR) (Figure 2). The ABR at the OEBR varied by about 3% for SA and almost 10% for FA (Figure 2).

Without B addition, the average (2-year) soil B contents at flowering time were 0.015 and 0.017 mg/kg for FA and SA, respectively. This increased to 0.32 and 2.52 mg B/kg for FA and SA, respectively, when B fertilizer was applied at the OEBR (Figure 3).

Soil-available B content increased with FA and SA applications of different B doses. Soil B content was at its highest level in the highest B application doses (Figure 3). It was determined that the soil-available B content was 0.40–2.80 mg/kg for foliar and soil application at 12 kg B/ha doses, respectively.

B fertilizer treatment increased N, Ca, Mg, P, K, and Zn content in leaf and berry tissue, but decreased Fe, Mn, and Cu content (Tables 4 and 5). The 2-year average leaf and berry tissue B content was 9.42 mg/kg for FA and 9.10 mg/

Table 2. Yields, optimum economic B rates (assuming \$0.65/kg B and a grapevine Karaerik cv. value of \$2.5/kg), return at OEBR (assuming a fixed annual cost of production of \$2000/ha), and R^2 of the quadratic fit for the yield response data for grapevine Karaerik cv. grown in B-deficient fluvaquent Entisol in northeastern Turkey over 2 years.

B application rate									
	0	1	3	9	12	OEBR	Yield at OEBR	Annual return ha^{-1} at OEBR	R^2
	kg/ha					\$/ha			
Foliar	6450 e	13,070 c	14,480 b	19,210 a	9340 d	6.4	20,230	48,595	0.882
Soil	5010 e	5940 d	7580 c	14,430 a	10,510 b	8.5	12,750	28,867	0.898

Table 3. Effects of B application on yield component of grapevine Karaerik cv. grown in B-deficient fluvaquent Entisol in northeastern Turkey over 2 years.

B doses	TCN	NC	CW	NB	BSR	NSB	SBR	BCR	NS	TSS
kg/ha					Soil application					
0	17.67 e	1.08 d	288 d	60 d	16.01 c	12.25 b	22.40 a	20.90 b	1.70 a	15.28 b
1	20.25 d	1.18 c	223 e	53 e	13.54 d	4.38 e	8.03 d	16.69 c	1.28 c	15.13 b
3	22.50 c	1.20 c	334 c	81 b	23.53 a	7.75 c	9.72 c	24.14 a	1.50 b	16.03 a
9	28.25 b	1.38 b	374 b	69 c	19.52 b	5.13 d	7.39 d	11.34 d	1.68 a	12.65 d
12	29.08 a	1.52 a	492 a	97 a	22.52 a	14.75 a	15.49 b	7.75 e	1.50 b	14.68 c
Adjusted R^2	0.902	0.820	0.936	0.928	0.877	0.937	0.853	0.766	0.603	0.626
LSD	15.71	1.79	75.73	30.35	17.30	6.44	13.89	0.41	5.67	0.60
kg/ha					Foliar application					
0	19.75 d	1.22 d	334 e	68 e	21.97 c	12.00 a	15.54 a	14.37 a	1.53 c	13.80 b
1	23.92 c	1.26 c	539 b	100 b	24.38 b	9.25 b	8.58 b	11.17 b	1.33d	14.25 a
3	31.00 a	1.56 a	469 c	90 c	23.42 b	7.13 d	6.23 c	6.65 d	1.50 c	13.38 c
9	26.67 b	1.39 b	356 d	74 d	19.46 d	6.38 e	8.81 b	14.59 a	1.90 a	13.08 d
12	24.17 c	1.28 c	793 a	155 a	35.27 a	9.00 c	5.42 d	7.47 c	1.80 b	13.55 c
Adjusted R^2	0.914	0.853	0.903	0.917	0.758	0.879	0.811	0.813	0.740	0.768
LSD	19.81	1.24	148.48	22.74	15.32	6.22	11.75	0.67	4.55	0.65

TCN: total cluster number per vine; NC: number of clusters per shoot; CW: cluster weight; NB: number of berries per bunch; BSR: berry setting ratio; NSB: number of shot berries per bunch; SBR: shot berries ratio; BCR: berry cracking ratio; NS: number of seeds per berry; TSS: total soluble solid of must.

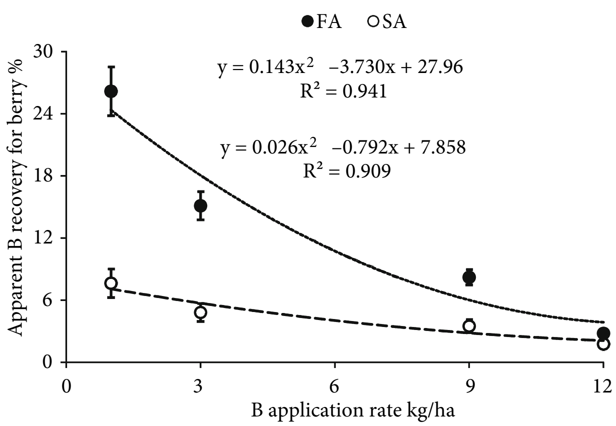

Figure 2. Relationship between B application and apparent B recovery for grapevine Karaerik cv. grown in B-deficient fluvaquent Entisol in northeastern Turkey. At the economic optimum B rates of 6.4 and 8.5 kg B/ha per year (averaged over both years) for FA and SA methods, the apparent B recovery for berry was 9.97% and 3.02%, respectively.

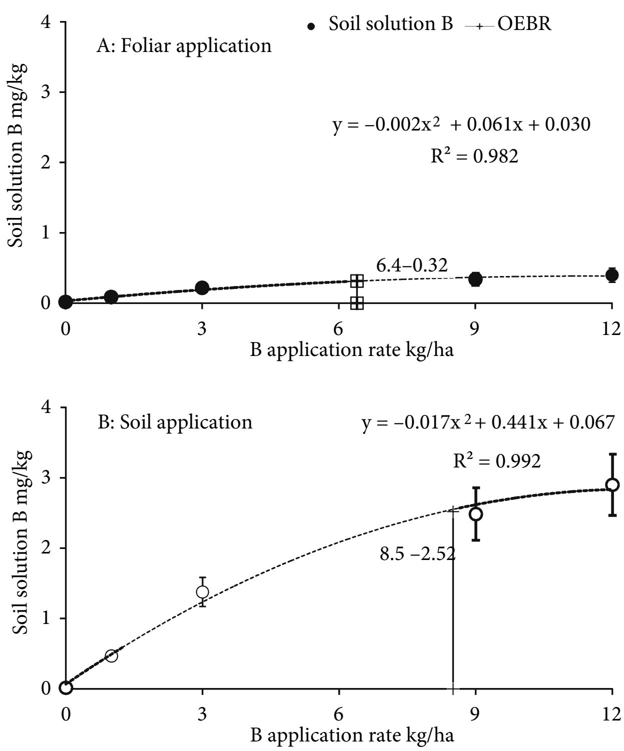

Figure 3. Relationship between B application and soil solution B concentration (2-year average) for grapevine Karaerik cv. grown in B-deficient fluvaquent Entisol in northeastern Turkey. At the optimum economic B rate (OEBR), soil solution B ranged from 0.32 to 2.52 mg B/kg for FA and SA methods, respectively.

kg for SA in the control treatments, respectively (Figure 4). B content of leaf and berry tissue increased to 98.88 and 21.37 mg/kg for FA and to 62.42 and 22.95 mg B/kg for SA, respectively, when B fertilizer was applied at the OEBR (Tables 4 and 5).

Table 4. Leaf macroelement concentration of grapevine Karaerik cv., when grown in two consecutive years with two different application methods and five different B application treatments in B-deficient fluvaquent Entisol in northeastern Turkey.

B application doses	Berry		Leaf	
kg/ha	Soil application	Foliar application	Soil application	Foliar application
	% of DM			
	N			
0	1.86 c	1.88 d	2.23 e	2.61 d
1	1.89 c	2.09 c	2.63 d	3.01 c
3	1.97 c	2.41 b	2.74 c	3.03 c
9	2.16 b	2.92 a	2.90 b	3.36 a
12	2.71 a	1.74 e	3.35 a	3.10 b
Adjusted R^2	0.931	0.965	0.947	0.885
LSD	0.084	0.032	0.044	0.126
	P			
0	0.27 c	0.25 d	0.20 d	0.24 b
1	0.27 c	0.26 c	0.25 c	0.31 a
3	0.28 b	0.26 c	0.26 b	0.32 a
9	0.29 a	0.28 a	0.28 a	0.36 a
12	0.29 a	0.25 d	0.28 a	0.30 a
Adjusted R^2	0.860	0.894	0.986	0.756
LSD	0.179	0.143	0.002	0.040
	Ca			
0	1.37 c	1.36 c	0.49 d	0.59 c
1	1.54 b	1.45 b	0.52 c	0.62 b
3	1.57 b	1.47 b	0.54 b	0.76 a
9	1.59 b	1.50 a	0.55 b	0.79 a
12	1.69 a	1.50 a	0.62 a	0.63 b
Adjusted R^2	0.879	0.740	0.824	0.904
LSD	0.080	0.213	0.146	0.036
	K			
0	0.86 d	0.82 c	1.40 c	1.43 c
1	0.88 c	1.01 b	1.41 c	1.53 b
3	0.98 b	103 a	1.42 c	1.68 a
9	0.99 b	1.02 ab	1.45 b	1.68 a
12	1.00 a	1.04 a	1.46 a	1.42 c
Adjusted R^2	0.967	0.730	0.730	0.967
LSD	0.011	0.230	0.230	0.011
	Mg			
0	0.15 c	0.16 c	0.14 d	0.15 d
1	0.16 c	0.18 b	0.18 c	0.18 c
3	0.20 b	0.18 b	0.19 b	0.19 b
9	0.21 b	0.21 a	0.20 a	0.22 a
12	0.26 a	0.19 b	0.19 b	0.20 b
Adjusted R^2	0.863	0.793	0.848	0.780
LSD	0.018	0.139	0.014	0.146
	S			
0	0.15 b	0.15 a	0.25 c	0.22 c
1	0.14 c	0.12 c	0.25 c	0.22 c
3	0.15 b	0.13 b	0.28 b	0.30 a
9	0.18 a	0.13 b	0.29 b	0.28 b
12	0.12 d	0.13 b	0.33 a	0.23 c
Adjusted R^2	0.911	0.821	0.746	0.938
LSD	0.013	0.018	0.023	0.012

Table 5. Leaf microelement concentration of grapevine Karaerik cv. when grown in two consecutive years with two different application methods and five different B application treatments in B-deficient fluvaquent Entisol in northeastern Turkey.

B application doses	Berry		Leaf	
kg/ha	Soil application	Foliar application	Soil application	Foliar application
	mg/kg			
	Fe			
0	369 a	375 a	390 a	396 b
1	329 b	372 a	347 b	393 b
3	326 b	353 b	344 b	373 c
9	310 c	353 b	328 c	378 a
12	291 d	291 c	308 d	308 d
Adjusted R^2	0.740	0.788	0.746	0.763
LSD	22.02	20.10	22.53	21.35
	Cu			
0	29 a	27 a	30 a	30 a
1	27 b	24 b	31 a	25 b
3	26 b	24 b	20 b	18 c
9	19 c	23 b	20 b	18 c
12	17 d	20 c	19 b	16 d
Adjusted R^2	0.678	0.782	0.634	0.715
LSD	1.703	1.610	1.840	1.760
	Mn			
0	58 a	60 a	63a	62a
1	51 b	49 b	60b	57b
3	46 c	45 c	59c	54c
9	45 c	40 d	46d	50d
12	45 c	40 d	44e	45e
Adjusted R^2	0.925	0.680	0.775	0.675
LSD	1.451	3.720	3.109	3.833
	Zn			
0	41 b	48 c	43 c	43 d
1	42 b	50 c	44 c	48 c
3	46 b	51 b	45 b	52 b
9	48 a	54 a	48 a	59 a
12	45 ab	51 b	42 d	52 b
Adjusted R^2	0.720	0.810	0.782	0.851
LSD	3.832	2.654	3.410	2.344

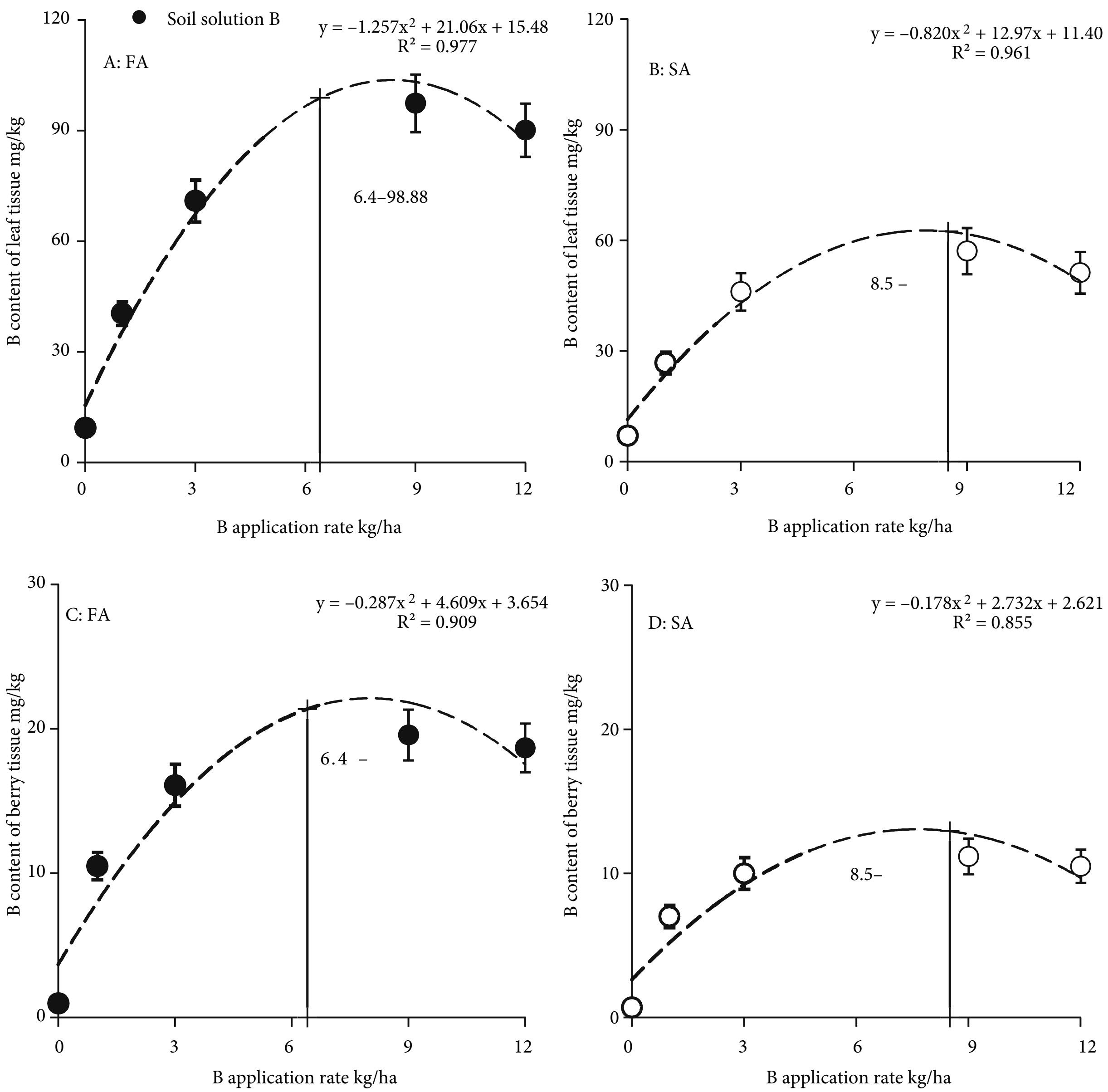

Figure 4. Relationship between B application and leaf and berry tissue B content (2-year average) for grapevine Karaerik cv. grown in B-deficient fluvaquent Entisol in eastern Turkey. At the optimum economic B rate (OEBR), plant leaf and berry tissue B ranged from 98.88 to 62.42 mg B/kg and 21.37 to 12.95 mg B/kg for FA and SA B application methods, respectively.

4. Discussion

In our study, the OEBR for soil and foliar applications was higher than the rates (1.5–4.4. kg B/ha) obtained by other studies on mustard (*Brassica juncea* L.) and bent grass (*Agrostis palustris* Huds.) plants (Stangoulis et al., 2000; Guertal, 2004). The date of our results may have mirrored the low initial soil B level (0.015–0.017 mg/kg) for grapevine (Shorrocks, 1997).

B fertilizer applications significantly increased yield parameters such as TCN, NC, CW, NB, BSR, and BCR, yet decreased NSB, SBR, NS, and TSS values (Peacock and Christensen, 2005; Christensen et al., 2006; Mostafa et al., 2006; Westover and Kamas, 2009).

In our study, the ABR value for FA and SA was higher than in other studies. In the study by Byju et al. (2007), the highest ABR was 0.4% at a B application rate of 1.0 kg/ha in sweet potato; however, it was lower than in alfalfa plant (Santos et al., 2004).

After the application of B fertilization, soil B content was higher than canola plant B contents by 0.28 mg B/kg (Asad et al., 1997). Our study showed a lower optimum soil B value than muskmelon (*Cucumis melo* L.) (Goldberg et al., 2003). In our study, leaf tissue B content at the OEBR was similar to the B content of grapevine. Several scientists, such as Guertal (2004), Santos et al. (2004), and Ross et al. (2006) suggested that 10 mg/kg, 66 mg/kg, and 44.1 mg/kg in some plant tissues is the critical level for B in bentgrass, alfalfa, and soybean, respectively.

Mills and Jones (1996) suggested critical leaf and berry values for optimum grapevine growing as follows: 1.6%–2.8%, 2.0%–2.6% for N; 0.2%–0.6%, 0.3%–0.5% for P; 1.5%–5.0%, 0.8%–2.2% for K; 0.4%–2.5%, 1.5%–5.5%, for Ca; 0.13%–0.4%, 0.2%–1.0% for Mg; 35–200 mg/kg, 60–200 mg/kg for Fe; 10–100 mg/kg, 25–150 mg/kg for Zn; 40–600 mg/kg, 25–200 mg/kg for Mn; and 4–20 mg/kg, 5–20 mg/kg for Cu.

In this study, B fertilizer application doses increased the content of N, Ca, Mg, P, K, and Zn in both leaves and berry tissue, but decreased the content of Fe, Mn, and Cu in plant tissue. These results were similar to those obtained by Mills and Jones (1996) for grapevine, and Singh and Singh (1983, 1990) for chickpea (*Cicer arientinum* L.) and sugar beet (*Beta vulgaris* L.).

Micronutrients, especially B, improve fruit-set, increase the fertilization of seeds, and enlarge berry size. A study by Christensen et al. (2006) in California reported that when B fertilizer is sprayed on leaves, it is taken in more effectively by the plant. Foliar sprays of B were also reported to reduce fruit set deficiency symptoms in Thompson seedless grapes (Christensen et al., 2006).

In our study, both FA and SA application of B increased grapevine yield. Averaged over 2 years, the maximum return to B fertilizer was obtained for FA at an OEBR of 6.4 kg B/ha. It is evaluated that the leaf and berry B content in the control group was measured as 9.42 and 9.10 mg/kg in FA and SA, respectively. The leaf and berry B contents in the OEBR increased with FA and reached 98.88 and 21.37 mg B/kg, respectively. The leaf and berry B contents in the OEBR increased 62.42 and 22.95 mg B/kg by SA, respectively. Soil B content was determined as 0.32 mg/kg in 6.4 kg B/ha OEBR for FA and 2.52 mg/kg in 8.5 kg B/ha OEBR for SA. B application increased the content of N, Ca, Mg, P, K, and Zn in both plant leaves and berry tissue.

We conclude that the addition of 6.4 kg/ha of B for FA and 8.5 kg/ha for SA is sufficient to elevate soil B levels, with an initial B content of 0.016 mg/kg, to nondeficient levels of 0.32–2.32 mg/kg.

Soil B mobility increased in the Entisol big soil group, whose initial soil B content is low depending on increasing B doses. Regression analysis showed that soil-available B content will decrease in the B application doses after repeated doses, whereas B fixation and absorption will increase. It was also observed that problems may arise. Therefore, it is considered that B application must be taken seriously in the cultivation of Entisol big soil group and must be conducted in OEBR for obtaining optimum products.

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