DETERMINATION OF BORON TOXICITY IN VINEYARDS OF MANISA, TÜRKİYE

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Abstract. The aim of this study is to determine the status of boron toxicity in vineyard areas within Manisa Province, Türkiye. The study was conducted in vineyards located in the districts of Yunusemre, Şehzadeler, Saruhanlı, Salihli, Alaşehir, Ahmetli, Gölmarmara, Sarıgöl, Turgutlu, and Akhisar. Within the scope of the study, boron concentrations in irrigation water, soil, and leaf samples collected from seedless grape cultivation areas were analyzed. According to the analysis results, boron levels in the irrigation water in Gölmarmara, Turgutlu, Salihli, and Alaşehir were found to exceed the unsuitable threshold level of 1.25 ppm. Likewise, soil boron concentrations in these areas were above the critical level of 2.5 ppm. Leaf boron levels also exceeded the high threshold of 100 ppm in Akhisar, Saruhanlı, Şehzadeler, Gölmarmara, Turgutlu, Salihli and Alaşehir.
Keywords: *boron pollution, irrigation water, leaf, soil, Vitis vinifera*

Introduction

Boron is an essential micronutrient required for the completion of plant development and the production of high-quality crops. Among all essential nutrients, boron has the narrowest range between deficiency and toxicity (Celik et al., 1998). Türkiye, which holds the largest boron reserves in the world, is experiencing issues related to excessive boron and resulting toxicity in cultivated plants. In arid and semi-arid regions in particular, excess boron in soil or water has become a significant concern due to its toxic effects on crops (Harite, 2008).

Boron toxicity can occur naturally in soils or may arise from the use of boron-rich irrigation waters (Nable et al., 1997) or compost fertilizers. Additionally, boron levels in saline and sodic soils may reach concentrations that are toxic to plants (Bergman, 1992; Marschner, 1995; Gunes et al., 2002).

Although boron is essential for plant growth, irrigation with water containing more than 1 ppm of boron can lead to problems in both soil and plants (FAO, 1976). The presence of boron at toxic concentrations in irrigation water should be considered a critical factor in assessing water quality for agricultural use (Thorne and Peterson, 1954).

High levels of boron in irrigation water or soil can result in yield losses due to boron toxicity (Staiger and Machelet, 1984). Boron exerts its effects in the soil solution, and its excess is particularly pronounced in saline soils. A boron content of 0.7 ppm or less in the saturation extract of soils is considered an acceptable limit for sensitive crops (Sezen, 1988).

Although *Vitis vinifera* L. has a higher boron requirement compared to other fruit species, they are still classified among plants that are sensitive to boron toxicity. When soil boron levels exceed 1 ppm, mild toxicity symptoms begin to appear in *Vitis* spp.; when concentrations rise above 4 ppm, symptoms become severe. Excess boron in vineyard soils is primarily due to boron-rich irrigation water and subsoil layers (Celik et al., 1998).

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Brown and Hu (1998) reported that in *Vitis* spp., symptoms of boron toxicity first appear in young leaves, which exhibit reduced size, develop rosette-like formations, and curl inward. In contrast, older leaves display brown spotting as a symptom of toxicity.

According to the National Boron Research Institute (BOREN), the boron content in our study areas has been classified as "high (2–5 ppm)" and "very high (>5 ppm)."

In a study conducted by Aksu (2008), it was found that in vineyard soils of the Aegean Region, boron levels were "high" in 28% and "very high" in 9% of the analyzed samples. The study indicated that moderate to severe boron toxicity could be expected in vineyard areas of Salihli and Alaşehir.

The groundwater within the Gediz Basin, which includes our research area, is known to have boron-related problems. Nearly all parts of the basin are affected, with groundwater in the plains of Salihli, Alaşehir, and Sarıgöl showing particularly high boron concentrations (>3.0 ppm) (Tomar, 2009). Studies conducted in the Avşar Dam Lake—constructed for irrigation purposes between Alaşehir and Sarıgöl (Minareci and Ozturk, 2012), in the Gediz River (Minareci, 2014), and in the Karaçay stream, a tributary of the Gediz River (Minareci et al., 2009), have reported boron concentrations exceeding the limit values for inorganic pollutants.

In a study examining the response of the Kalecik Karası cv. (*Vitis vinifera* L.) cultivar to increasing boron concentrations (0, 10, 20, and 30 mg/kg), it was observed that increasing boron levels led to reductions in leaf, shoot, root, and stem biomass (Gunes et al., 2006).

Nikolaou et al. (1995), in a study conducted in Italy, noted that when vineyards in the Victoria region were irrigated with boron-rich water (4.3 ppm), signs of boron toxicity were evident in the first year.

Overall, these studies demonstrate that elevated boron concentrations can lead to significant physiological, qualitative, and yield-related deficiencies in plants. Therefore, the aim of this study was to determine the boron levels in water, soil, and plant samples (leaves and fruit) collected from vineyard areas in the Manisa province.

Materials and methods

Study area

This study was conducted in vineyards located in the districts of Yunusemre, Şehzadeler, Saruhanlı, Salihli, Alaşehir, Ahmetli, Gölmarmara, Sarıgöl, Turgutlu, and Akhisar (*Fig. 1*). Within the scope of the study carried out in 2024, 25 sampling stations were selected to represent the vineyards (*Table 1*).

At each station, water, soil, and leaf samples were collected from three different vineyards. Water samples were collected at two different times—during leaf development and fruit set—and a total of 154 water samples were analyzed. Considering the sizes of the agricultural fields, soil and leaf samples were collected from a total of 75 vineyards.

Analysis of water samples

Sampling was conducted in two distinct periods: during the leaf development stage and the fruiting stage. In each sampling period, two water samples were collected and stored in 250 mL polyethylene bottles.

The determination of boron concentration was based on the measurement of the red-colored complex formed between boron and a specific reagent, carmine, using a spectrophotometer (Anonymous, 2005). Absorbance values were recorded at 585 nm.

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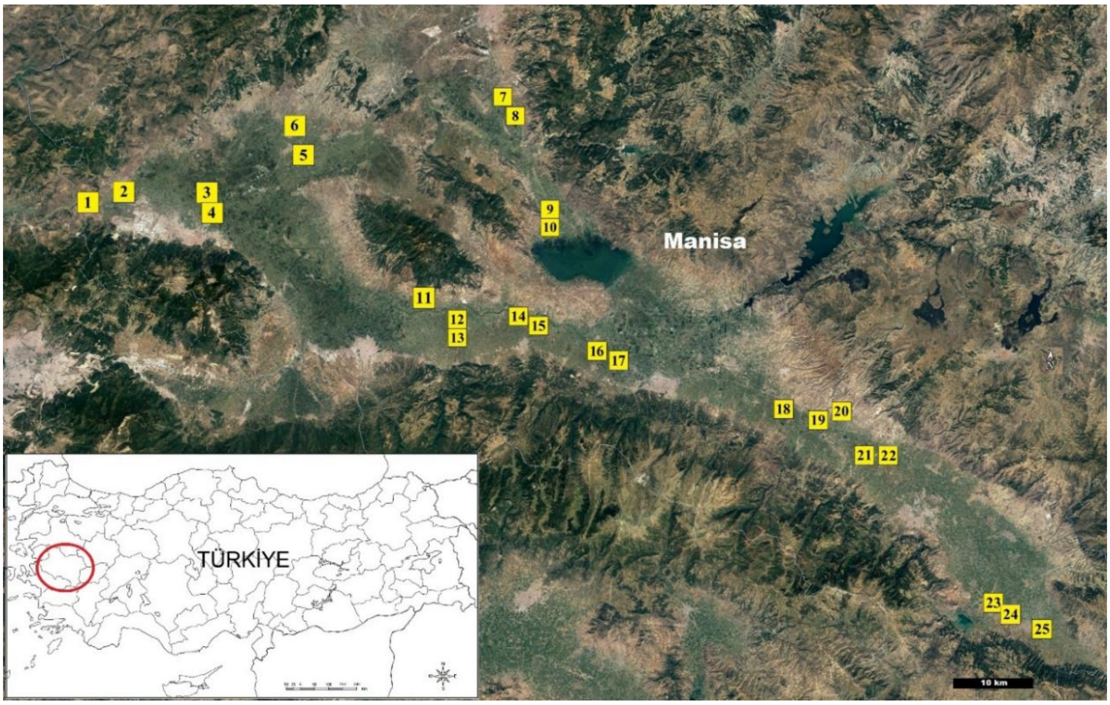

Figure 1. *Stations*

Table 1. *Coordinates*

Station	District	Village/neighborhood	Location
St1	Yunusemre	Akgedik	38°38’46.7”N 27°15’24.2”E
St2	Yunusemre	Yagcılar	38°39’45.0”N 27°18’31.3”E
St3	Şehzadeler	Güzelköy	38°40’10.1”N 27°26’06.5”E
St4	Şehzadeler	Veziroglu	38°38’42.7”N 27°26’51.7”E
St5	Saruhanlı	Saruhanlı	38°43’28.9”N 27°34’28.6”E
St6	Saruhanlı	Adiloba	38°45’36.2”N 27°33’19.8”E
St7	Akhisar	Sarıçalı	38°48’56.4”N 27°52’08.4”E
St8	Akhisar	Akselendi	38°47’34.4”N 27°53’29.0”E
St9	Gölmarmara	İsmetpaşa	38°40’04.8”N 27°57’32.4”E
St10	Gölmarmara	Hacıveliler	38°39’16.9”N 27°57’23.0”E
St11	Turgutlu	Musacalı	38°33’45.0”N 27°46’53.5”E
St12	Turgutlu	Urganlı	38°31’40.4”N 27°50’10.3”E
St13	Turgutlu	Yeniköy	38°30’24.9”N 27°50’21.0”E
St14	Ahmetli	Ataköy	38°32’57.8”N 27°55’29.5”E
St15	Ahmetli	Dibekdere	38°32’24.2”N 27°57’22.5”E
St16	Salihli	Kapancı	38°30’55.5”N 28°02’46.1”E
St17	Salihli	Hasalan	38°30’31.2”N 28°04’02.2”E
St18	Salihli	Mevlütlü	38°27’48.3”N 28°19’37.6”E
St19	Alaşehir	İsmetiye-2	38°27’12.6”N 28°22’43.7”E
St20	Alaşehir	İsmetiye-1	38°27’27.0”N 28°22’57.8”E
St21	Alaşehir	Piyadeler	38°25’00.5”N 28°26’55.3”E
St22	Alaşehir	Kasaplı	38°25’06.3”N 28°29’01.0”E
St23	Sarıgöl	Bereketli	38°15’37.8”N 28°38’35.5”E
St24	Sarıgöl	Selimiye	38°15’00.8”N 28°39’58.6”E
St25	Sarıgöl	Siteler	38°14’46.8”N 28°40’34.3”E

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Analysis of soil samples

Soil samples were collected as composite samples in accordance with the principles recommended by Plazt (1975). These samples were air-dried in the laboratory until reaching a constant weight and then sieved through a 2 mm mesh to prepare them for analysis.

The sand, silt, and clay fractions of the soil samples were determined using the hydrometer method as described by Bouyoucos (1951), and soil texture classes were assigned based on the Soil Survey Manual (Anonymous, 1951).

Soil reaction (pH) was measured using a glass electrode pH meter in a 1:2.5 soil-to-water suspension (Jackson, 1958).

Electrical conductivity (EC) was determined using an EC meter in soil samples diluted with deionized water at a 1:2.5 ratio (Richards, 1954).

Organic matter content was determined using the Walkley-Black wet oxidation method (Jackson, 1958).

Calcium carbonate (lime) content was measured with a Scheibler calcimeter (Hızalan and Unal, 1966).

Total nitrogen (N) was determined using the Kjeldahl method (Bremner, 1965).

Available phosphorus in soil was extracted with 0.5 N $NaHCO_3$ (pH 8.5) and determined by the molybdenum blue colorimetric method (Olsen et al., 1954).

Plant-available boron was extracted using a sodium acetate solution (100 g CH_3COONa L^{-1}, pH 4.8) and measured using the azomethine-H method (Wolf, 1971).

Leaf sampling and analysis

Leaf sampling was conducted at two different growth stages: an early stage (fruitless period, during vegetative growth) and a late stage (post-fruit maturation). In the late period, leaves were sampled from opposite the matured grape clusters (*Fig. 2*). The collected leaf samples were digested using a microwave-assisted digestion process in the laboratory, allowing the boron in the plant tissue to be brought into solution. Total boron in the resulting solution was determined using the micro-analytical azomethine-H method developed by Bingham (1982).

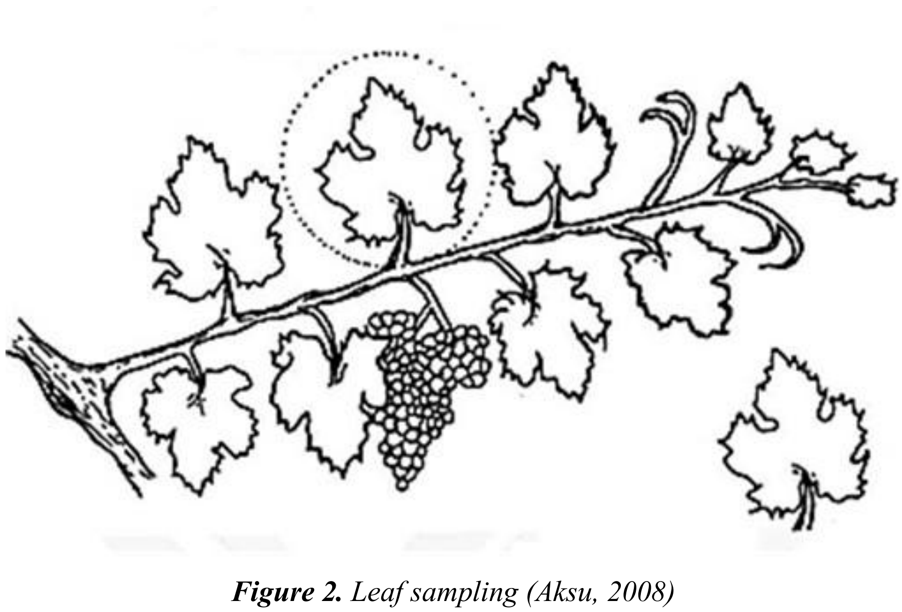

Figure 2. *Leaf sampling (Aksu, 2008)*

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Results and discussion

The boron concentration in irrigation water samples ranged from a minimum of 0.12 ppm to a maximum of 8.06 ppm. These values were compared with the permissible limits of boron in irrigation water for crops (Official Gazette, 1991; McCarthy et al., 1994) (*Table 2*). Findings from soil analyses were found to be fully consistent with the water analysis results. In all samples from Alaşehir, Salihli, Turgutlu, and Gölmarmara, boron concentrations in irrigation water exceeded the threshold levels for inorganic pollution. This clearly indicates that excessive boron in soils is primarily due to the use of boron-rich irrigation water. Excess boron levels in vineyard soils are generally attributed to the high boron content of irrigation sources (Celik, 1998).

Table 2. *Permissible limits of boron in irrigation water for crops (Official Gazette, 1991; McCarthy et al., 1994)*

Range Semi-sensitive crops (ppm)	Boron class
< 0.33	Excellent
0.33-0.67	Good
0.67-1.00	Permissible
1.00-1.25	Doubtful
> 1.25	Unsuitable

Studies on geothermal systems and their environmental effects in the Gediz Basin have reported that geothermal waters exhibit temperatures ranging between 25°C and 95°C, and that boron concentrations in these waters can reach up to 86.6 ppm (Gemici et al., 2005).

In a study investigating the impact of geothermal waters on groundwater in the Alaşehir plain, geothermal discharge was observed, and a boron concentration of 127.62 ppm was measured in a sample taken from a hot water stream flowing into a local creek (Rabet, 2015). This value represents the highest boron concentration recorded in Türkiye to date.

Recent studies have highlighted contamination in cold groundwater sources, attributed to faults and mismanagement in geothermal drilling activities (Dogdu and Bayari, 2005; Aksoy et al., 2009).

Groundwater across the basin exhibits significant boron-related issues. Almost all parts of the basin are affected, particularly the plains of Salihli, Alaşehir, and Turgutlu, where groundwater boron concentrations frequently exceed 1.25 ppm (Tomar, 2009). In geothermal regions such as Salihli, Turgutlu, and Alaşehir, boron pollution detected in irrigation water is likely a result of geothermal activity. Moreover, it has been reported that geothermal well blowouts in these areas have caused substantial surface damage, leading to significant destruction in surrounding vineyards (Rabet, 2015).

In a study conducted in the Avşar Dam Lake, located between Alaşehir and Sarıgöl and constructed for vineyard irrigation in the region, boron concentrations were found to exceed the permissible limits for inorganic pollution. Based on boron parameters, the Avşar Dam Lake has been classified as class IV (heavily polluted water) (Minareci and Ozturk, 2012).

A study on boron concentrations in the Gediz River revealed levels ranging between 0.125–4.548 ppm, with an average of 2.428 ppm. According to boron parameter

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classifications, the Gediz River is also categorized as Class IV (highly contaminated water) (Minareci, 2014). Similarly, in the Karaçay stream, a tributary of the Gediz River, boron concentrations were recorded between 0.134–3.937 ppm, placing the water once again in Class IV due to inorganic pollution levels (Minareci et al., 2009). Even regions distant from direct geothermal influence are exposed to boron contamination as a result of irrigation with water from polluted rivers and reservoirs.

The results obtained from the analysis of soil samples collected from vineyard areas are presented in *Table 3*. The available phosphorus content in the soils ranged from 4.48 to 65.18 ppm. According to the classification by Ulgen and Yurtsever (1995), phosphorus levels in these soils were categorized as high to very high.

Soil texture (% saturation) in the vineyard areas varied between 25.46 and 69.11 (*Table 3*). Based on the texture classification thresholds defined by Ulgen and Yurtsever (1995), the soils were identified as loam (48%) and clay-loam (52%). A study conducted by Ates (2022) in Sarıgöl reported that vineyard soils in the region were predominantly loam (86%) and clay-loam (14%).

Boron is retained more in soils with high silt and clay content, which can increase the risk of toxicity. Silt and clay facilitate the adsorption of boron to soil particles; therefore, fine-textured soils (with higher silt and clay content) are more prone to boron toxicity. In contrast, sandy soils retain less boron, which may lead to boron deficiency. However, in terms of toxicity, sand reduces the risk by facilitating the leaching of boron (Budak and Gunal, 2015).

Electrical conductivity of the soil samples collected from selected vineyards ranged from 0.080 to 2.030 dS m^{-1}. According to the threshold values provided by Tuzuner (1990) and Celik et al. (1998), none of the analyzed soils posed a salinity risk (Gunes, 2009).

High electrical conductivity values can increase boron toxicity. Because the increase in electrical conductivity affects the ion concentrations in the soil solution and facilitates boron mobility and uptake by plant roots. There is a positive correlation between electrical conductivity and boron, and this situation varies depending on soil structure (El-Motaium et al., 1994).

A study on soil quality in Sarıgöl, conducted on 100 vineyard soils, reported total soluble salt values between 0.01 and 0.10. Based on the classification of the Soil Survey Staff (1951), soils in the study area were considered non-saline (Ates, 2022). The findings from the present study align closely with those previous results.

Soil pH values in the study area ranged from 7.71 to 8.9 (*Table 3*). Similar studies have reported pH values ranging from 5.98 to 9.13 (Ates, 2022). In a study conducted in Manisa by Gunes (2009), soil pH values ranged between 7.0 and 8.7. Likewise, Celik (1998) reported that pH values in vineyard soils in Erciş district of Van province ranged from 5.5 to 8.5. The soils in the present study are generally slightly alkaline, which is considered favorable for viticulture. The critical threshold pH level of > 9, which is considered problematic for vineyards, was not recorded in any of the samples (Gunes, 2009; Celik, 1998; Ates, 2022).

Boron is positively correlated with soil pH. High pH values can increase the retention of boron by soil and this situation can increase the risk of toxicity. However, highly acidic soils (pH < 5.0) can induce boron deficiency. Because boron binds to iron and aluminum oxides (Arrobas et al., 2023).

The calcium carbonate content of vineyard soils ranged from a minimum of 3.02% to a maximum of 19.24%. Based on the classification by Hızalan and Unal (1966), 16% of

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the soils were slightly calcareous, 56% moderately calcareous, 20% calcareous, and 8% highly calcareous (*Table 3*). A similar study conducted in Sarıgöl found that vineyard soils generally had low lime content (Ates, 2022). Another study conducted in vineyard areas of Manisa, Saruhanlı, Alaşehir, Salihli, and Çal reported lime contents ranging from 0.27% to 37.93%. In that study, 10% of soils were classified as very low, 19% as low, 59% as medium, 4% as high, and 8% as very high in lime content (Gunes, 2009). These findings are consistent with those of the present study.

Table 3. *Values obtained from the analysis of soil samples*

Stations	Depth	P (ppm)	Saturation	Types of soil	EC %	pH	$CaCO_3$ %	N %	Organic matter %
St1	0-30	16.84	41.27	Loam	0.0086	7.78	7.14	0.08	0.81
	30-60	11.48	39.93	Loam	0.0075	7.83	7.79	0.07	0.76
St2	0-30	14.48	44.52	Loam	0.0087	7.85	7.37	0.06	0.98
	30-60	12.15	41.84	Loam	0.0072	7.96	7.48	0.06	1.12
St3	0-30	65.18	65.27	Clay loam	0.0342	7.71	15.16	0.14	2.75
	30-60	52.44	65.06	Clay loam	0.0296	7.82	18.45	0.13	2.84
St4	0-30	56.85	69.11	Clay loam	0.0255	7.88	19.24	0.15	3.12
	30-60	48.11	60.39	Clay loam	0.0212	8.01	19.18	0.14	3.11
St5	0-30	10.56	66.58	Clay loam	0.0187	7.93	8.81	0.08	1.51
	30-60	9.81	60.32	Clay loam	0.0096	8.06	9.08	0.09	1.56
St6	0-30	15.15	57.58	Clay loam	0.0264	8.37	10.09	0.07	1.43
	30-60	12.28	52.61	Clay loam	0.0133	8.44	11.11	0.06	1.47
St7	0-30	35.36	48.56	Loam	0.0185	8.15	12.12	0.09	1.92
	30-60	32.81	40.38	Loam	0.0153	8.22	11.59	0.08	1.95
St8	0-30	44.27	63.48	Clay loam	0.0309	8.27	13.81	0.11	2.16
	30-60	39.65	57.45	Clay loam	0.0247	8.36	13.09	0.11	2.04
St9	0-30	28.82	49.44	Loam	0.0281	7.87	5.65	0.09	1.65
	30-60	21.66	41.56	Loam	0.0166	7.96	5.49	0.09	1.47
St10	0-30	20.04	45.23	Loam	0.0179	7.83	5.88	0.09	1.38
	30-60	17.37	40.67	Loam	0.0152	7.99	5.91	0.09	1.44
St11	0-30	11.87	33.73	Loam	0.0068	8.76	6.09	0.06	1.63
	30-60	9.92	30.48	Loam	0.0046	8.89	6.01	0.05	1.66
St12	0-30	26.82	39.58	Loam	0.0155	8.18	5.15	0.11	2.07
	30-60	21.8	38.81	Loam	0.0101	8.21	5.42	0.12	1.89
St13	0-30	27.23	41.18	Loam	0.0243	8.25	6.39	0.13	1.57
	30-60	20.65	33.17	Loam	0.0167	8.33	6.65	0.11	1.65
St14	0-30	19.58	42.59	Loam	0.0069	8.15	8.39	0.09	0.86
	30-60	13.67	39.39	Loam	0.0045	8.19	8.57	0.08	0.81
St15	0-30	23.99	39.65	Loam	0.0088	8.03	6.65	0.08	0.75
	30-60	20.21	37.28	Loam	0.0071	8.14	7.01	0.06	0.66
St16	0-30	39.22	53.66	Clay loam	0.0137	8.18	4.23	0.14	2.11
	30-60	27.16	50.17	Clay loam	0.0118	8.22	4.03	0.14	1.95
St17	0-30	48.55	61.26	Clay loam	0.0108	8.23	4.19	0.15	1.89
	30-60	23.13	55.85	Clay loam	0.0096	8.25	4.56	0.12	2.06

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St18	0-30	27.16	47.11	Loam	0.0058	8.23	4.59	0.05	1.66
	30-60	18.18	40.35	Loam	0.0051	8.29	5.15	0.05	1.73
St19	0-30	33.51	63.34	Clay loam	0.0187	8.33	3.69	0.09	1.23
	30-60	21.36	58.21	Clay loam	0.0114	8.38	3.71	0.08	1.16
St20	0-30	30.45	55.16	Clay loam	0.0256	8.36	4.04	0.07	1.11
	30-60	21.57	55.1	Clay loam	0.0202	8.41	4.46	0.08	1.21
St21	0-30	25.63	60.84	Clay loam	0.0312	8.44	3.32	0.08	1.31
	30-60	16.69	55.89	Clay loam	0.0288	8.44	3.35	0.06	1.19
St22	0-30	29.33	66.73	Clay loam	0.0232	8.27	3.02	0.08	1.02
	30-60	26.79	56.33	Clay loam	0.0185	8.33	3.19	0.09	1.24
St23	0-30	33.66	65.84	Clay loam	0.0218	8.21	5.61	0.04	0.95
	30-60	16.45	63.61	Clay loam	0.0183	8.28	5.59	0.04	1.15
St24	0-30	21.21	61.67	Clay loam	0.0374	8.45	6.67	0.05	0.68
	30-60	10.16	52.37	Clay loam	0.0331	8.49	6.28	0.05	0.61
St25	0-30	9.52	33.15	Loam	0.0465	7.95	3.71	0.03	0.44
	30-60	4.48	25.46	Loam	0.0381	8.12	3.65	0.04	0.55

Lime affects boron adsorption in the soil because it increases soil pH and creates retention surfaces for boron (Goldberg, 1997).

Soil organic matter is known to influence many physical, chemical, and biological properties of soils, ultimately enhancing crop productivity through both improved nutrient availability and enhanced soil structure (Emerson, 1991; Charman and Roper, 2000). Kurtural (2011) suggested that, from a viticultural standpoint, soil organic matter content should range between 2% and 3%. In this study, the organic matter content of vineyard soils ranged from 0.44% to 3.12%. According to the classification by Walkley and Black (1934), all soils in the study area were classified as low in organic matter (<2%) (*Table 3*). A study conducted in Sarıgöl reported organic matter contents between 0.09% and 1.13%, indicating that all vineyard soils in that area were also low in organic matter (Ates, 2022). Similarly, other studies conducted in Manisa vineyard regions also reported low levels of organic matter in all vineyard soils (Gunes, 2009).

Boron is positively correlated with organic matter. High organic matter can increase boron retention by soil, which can cause toxicity (Tsadilas, 1997).

Total nitrogen (N) content in soils is a critical parameter both for determining soil fertility and for planning fertilization strategies (Bruce and Rayment, 1982). In this study, total nitrogen levels in vineyard soils ranged from 0.03% to 0.15% (*Table 3*). According to the threshold values established by Kacar (1995), all soil samples were classified as low in nitrogen content. Previous studies also reported low total nitrogen levels in soils across the Manisa region (Ates, 2022; Gunes, 2009).

Available boron concentrations in the soil samples ranged from a minimum of 0.77 mg/kg to a maximum of 7.12 mg/kg (*Table 4*). In a study by Gunes (2009), the average boron concentration in vineyard soils was found to be 2.61 mg/kg, with a notably high value of 16.96 mg/kg reported specifically in Alaşehir. Another study by Yalcın (2023) in the Arsuz region of Hatay province reported available boron levels between 0.09 and 1.22 ppm.

Soil boron concentrations in this study were evaluated based on the boron toxicity scale developed by Celik et al. (1998) for grapevines (*Table 5*). No vineyard was found

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to be free of toxicity symptoms. The classification revealed 20% of the sites had very mild toxicity, 8% mild, 24% moderate, 16% severe, and 32% very severe toxicity. At the district level, all vineyard soils in Alaşehir, Salihli, Turgutlu, and Gölmarmara were classified as having severe boron toxicity. Morphological symptoms observed in plant samples collected from these areas were consistent with the toxicity levels determined through chemical analysis. Similarly, Gunes (2009) reported that moderate to severe boron toxicity could be observed in the Salihli and Alaşehir regions.

Table 4. *Boron concentrations in soil, irrigation water and leaf samples*

Station	District	Village/neighborhood	Boron concentrations (ppm) mean ± SD		
			Soil	**Water**	**Leaf (n = 12)**
St1	Yunusemre	Akgedik	0.86 ± 0.028	0.55 ± 0.473	92 ± 3.51
St2	Yunusemre	Yagcılar	0.92 ± 0.042	0.12 ± 0.416	56 ± 9.54
St3	Şehzadeler	Güzelköy	2.08 ± 0.042	0.39 ± 0.306	**158 ± 4.04**
St4	Şehzadeler	Veziroglu	2.07 ± 0.163	0.51 ± 0.231	**170 ± 3.79**
St5	Saruhanlı	Saruhanlı	1.80 ± 0.099	0.83 ± 0.300	**177 ± 5.86**
St6	Saruhanlı	Adiloba	1.77 ± 0.028	0.54 ± 0.208	**163 ± 5.51**
St7	Akhisar	Sarıçalı	1.53 ± 0.170	0.65 ± 0.361	**133 ± 7.09**
St8	Akhisar	Akselendi	1.70 ± 0.049	0.57 ± 0.379	**118 ± 7.94**
St9	Gölmarmara	İsmetpaşa	**2.58 ± 0.049**	**2.02 ± 1.436**	**212 ± 7.51**
St10	Gölmarmara	Hacıveliler	**2.67 ± 0.127**	**1.89 ± 1.389**	**187 ± 6.03**
St11	Turgutlu	Musacalı	**4.32 ± 0.474**	**8.06 ± 0.473**	**313 ± 6.56**
St12	Turgutlu	Urganlı	**3.92 ± 0.467**	**7.62 ± 0.557**	**321 ± 9.07**
St13	Turgutlu	Yeniköy	**3.44 ± 0.318**	**7.01 ± 0.551**	**284 ± 4.51**
St14	Ahmetli	Ataköy	0.92 ± 0.049	0.51 ± 0.306	66 ± 2.52
St15	Ahmetli	Dibekdere	0.84 ± 0.042	0.48 ± 0.503	73 ± 3.06
St16	Salihli	Kapancı	**6.07 ± 0.247**	**3.52 ± 0.265**	**319 ± 7.02**
St17	Salihli	Hasalan	**7.12 ± 0.672**	**3.21 ± 0.451**	**355 ± 8.62**
St18	Salihli	Mevlütlü	**4.70 ± 0.403**	**4.19 ± 0.306**	**327 ± 10.69**
St19	Alaşehir	İsmetiye-2	**6.06 ± 0.177**	**5.15 ± 1.323**	**349 ± 10.07**
St20	Alaşehir	İsmetiye-1	**5.85 ± 0.290**	**4.98 ± 1.815**	**351 ± 7.77**
St21	Alaşehir	Piyadeler	**6.41 ± 1.442**	**4.63 ± 1.206**	**344 ± 5.69**
St22	Alaşehir	Kasaplı	**6.21 ± 1.499**	**2.37 ± 0.351**	**298 ± 4.04**
St23	Sarıgöl	Bereketli	1.04 ± 0.156	0.43 ± 0.404	86 ± 3.61
St24	Sarıgöl	Selimiye	1.08 ± 0.276	0.41 ± 0.737	75 ± 3.51
St25	Sarıgöl	Siteler	0.77 ± 0.171	0.33 ± 0.611	51 ± 5.03

Table 5. *Response of Vitis spp. to boron levels in the soil (Celik et al., 1998)*

Boron levels in soil (ppm)	Sign of toxicity in *Vitis* spp.
< 0.7	No sign
0.7 -1.0	Very mild
1.0-1.5	Mild
1.5-2.5	Moderate
2.5-4.0	Severe
> 4.0	Very severe

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Soils with high boron content are defined as those containing 1.5–3.75 ppm of boron, which is considered hazardous to many plants, including grapevines. Soils with very high boron concentrations, exceeding 3.75 ppm, are deemed dangerous to all plant species (Ozgul, 1974). According to this classification, in this study, it was concluded that boron levels were hazardous and very hazardous in the soils of other districts except Yunusemre, Ahmetli, and Sarıgöl districts.

Boron concentrations in leaf samples ranged from a minimum of 51 ppm to a maximum of 355 ppm (*Table 4*). These values were compared with the threshold values reported by Jones et al. (1991) (*Table 6*). Leaf samples from Yunusemre, Ahmetli, and Sarıgöl exhibited sufficient boron levels, while all other districts showed excessive boron accumulation in leaf tissues. Results obtained from leaf analyses were consistent with those from soil and water analyses, confirming the high boron availability in the vineyard environments (*Table 6*).

Table 6. *Boron limit values of proficiency groups in Vitis spp. (Jones et al., 1991)*

	***Vitis* spp. leaf**		
Boron (ppm)	**Insufficient**	**Sufficient**	**Excess**
	<30	30-100	>100

The excessive boron concentrations observed in leaf samples from Alaşehir, Salihli, Turgutlu, and Gölmarmara are consistent with the high boron levels detected in the soil and irrigation water from these areas. In contrast, high boron concentrations in leaf samples collected from Şehzadeler, Saruhanlı, and Akhisar vineyards—despite soil and water boron concentrations being below threshold levels—are thought to be primarily caused by foliar fertilizers rich in boron, which are extensively used in these regions. These fertilizers are commonly applied to correct boron deficiency but, when misused, can lead to excessive boron accumulation in plant tissues even in areas with borderline soil and water boron levels. Kacar and Katkat (2007) stated that it is necessary to be very careful when applying boron fertilization to boron-sensitive plants.

Aksu (2008) reported that boron concentrations were excessive in 77% of the analyzed plants, with high boron levels in leaf samples from Salihli (94%), Cal (84%), and Alaşehir (100%). The findings of the present study are consistent with Aksu's results. In many vineyards with high boron levels, visual symptoms of boron toxicity were observed, and in those where such symptoms are not yet visible, they are likely to emerge in the coming years.

In another study, leaf samples from vineyards in İzmir, Manisa, and Denizli revealed that 30.98% had excessive boron concentrations (Ozden et al., 2016). The difference between those findings and our results, especially for vineyards in the İzmir region, can be attributed to the absence of boron contamination in their soil and water resources.

Conclusions and recommendations

The analysis of soil and water samples from vineyard areas across Manisa province revealed that 48% of the grape-growing areas and 72% of the vines in these areas are exposed to critical levels of boron excess. There is an urgent need to develop spatial distribution maps that quantify boron levels in irrigation water and soils throughout the

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region. These maps would help identify boron-safe agricultural zones and guide farmers to concentrate production in these areas. Additionally, the quality of irrigation water in vineyard areas should be evaluated in terms of boron content. Where necessary, farmers should be encouraged to use alternative water sources, and, if required, irrigation water should be diluted with potable water to reduce boron concentrations.

In the study region, especially in vineyards reported to have widespread boron contamination, inter-row planting of boron-tolerant monoculture or polyculture species is not currently practiced. These plantings significantly reduce soil boron concentrations. Implementing these intercropping systems is expected to contribute not only to increased yield and quality but also to a reduction in soil boron levels. In areas where these mitigation strategies fail to resolve the boron problem, the cultivation of more boron-tolerant grapevine cultivars or alternative plant variants should be considered.

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