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Research
Araştırma

BORON STATUS, BORON FRACTIONS AND ITS AVAILABILITY IN SUGAR BEET GROWN SOILS

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ABSTRACT: The objectives of this study are to determine boron (B) status, fractions and availability of sugar beet grown soils and their relationships with some soil properties. For this purpose, Colwell method (biological indexes) and hot water B extraction method were used to determine plant available B contents of soils. Furthermore, easily soluble, specific adsorbed, organic matter dependent, oxide dependent and residual B fractions of the soils were determined. Boron deficiency symptoms in plants were observed when plants' ages were 56 days in 4 soils and 62 days in 6 soils. B deficiency was observed in the 63.6 % of the soils taken from Çarşamba and in the 33 % of the soils taken from Bafra while Boron deficiency was not observed in the sunflower plants grown on soils taken from Suluova. The B contents extracted with hot water for the soils showed B deficiencies were generally found to be lower than 1.00 ppm.The available B contents extracted with hot water for the soils showed no B deficiencies were found to be between 1.39 and 4.61 ppm. The relationships among the biological indexes indicated that the available B content of the soils can be determined by the hot water extraction method. Easily soluble and oxide dependent B contents gave significant relationships with the biological indexes. As the clay, organic matter and exchangeable Na content increased B contents of the plants at their harvest ages and B uptakes by plants also increased significantly.
Key Words: Available boron, Boron fractions, Hot water method, Colwell method.

ŞEKER PANCARI YETİŞTİRİLEN TOPRAKLARIN BOR DURUMU, B FRAKSİYONLARI VE ALINABİLİRLİKLERİ

ÖZET: Bu çalışmanın amacı şeker pancarı yetiştirilen toprakların bitkiye yarayışlı bor (B) durumlarını, B fraksiyon dağılımları ve alınabilirliklerini ve bunların toprak özellikleriyle ilişkilerini ortaya koymaktır. Bu amaçla bitkiye yarayışlı B durumlarının belirlenmesinde Colwell (biyolojik yöntem) ve sıcak su ekstraksiyon yöntemleri kullanılmıştır. Ayrıca toprakların kolay çözünebilir, spesifik adsorbe, organik maddeye bağlı, oksitlere bağlı ve kalıntı B fraksiyonları belirlenmiştir. Yapılan çalışmada indikatör bitkide (ayçiçeği) B noksanlık simptomları toprakların 4'ünde bitki yaşı 56. günde, 6'sında ise bitki yaşı 62. günde ortaya çıkmıştır. Çarşambadan alınan toprakların % 63,6'sında, Bafradan alınan toprakların ise % 33'ünde B noksanlığı olduğu tespit edilmiştir. Suluova topraklarında yetiştirilen ayçiçeği bitkilerinde B noksanlığı gözlenmemiştir. B noksanlığı gösteren toprakların sıcak su ile ekstrakte edilebilir B kapsamları çoğunlukla 1,00 ppm'in altında bulunmuştur. Bor noksanlığı göstermeyen toprakların sıcak su ile ekstrakte edilebilir yarayışlı B kapsamları ise 1,39 ile 4,61 ppm arasında değişmiştir. Biyolojik indekslerle ilişkileri dikkate alınarak toprakların yarayışlı B kapsamlarının belirlenmesinde uygun yöntemin sıcak su ekstraksiyon yöntemi olduğu ortaya konulmuştur. Kolay çözünebilir ve oksitlere bağlı B fraksiyon kapsamları ile biyolojik indeksler arasında ilişkiler istatistiksel olarak önemli bulunmuştur. Ayrıca toprakların kil, organic madde ve değişebilir Na kapsamları arttıkça hasat ayçiçeği bitkisinin B kapsam ve alımları artmıştır.
Anahtar Kelimeler: Yarayışlı Bor, Bor fraksiyonları, Sıcak su metodu, Colwell metodu, Ayçiçeği

1. INTRODUCTION

In several plant functions, B is implicated directly and indirectly as it involves in growth of cells in newly emerging shoot and root while in some plants it is crucial for boll formation, flowering, pollination, seed development and sugar transport synthesized by the different plant components (Dordas et al., 2007; Takano et al., 2008; Miwa et al., 2008;). B deficiency at early growth stage significantly boosts chlorophyll content in leaf, minimizes carbohydrate transport from leaf to fruit, ultimately leaf photosynthetic rate and stomatal conductance is abated (Oosterhuis and Zhao, 2006). Dordas (2007) performed a series of experiments on sugar beets, alfalfa, cotton and squash crops and from his research he revealed that foliar application of B on cotton influences seed and lint yield as well as maintains seed quality.

Boron exists in the soil in five fractions. Zerrari et al. (1999) reported that these fractions are easily soluble, specific adsorbed, oxide bound, organic matter bound and residual (these are in silicate minerals, and cannot be used by plants). It has also been specified that the amount of these different fractions depends on the soil properties and the availability levels of these fractions differ. Loué (1986) suggested that B exists in soil solution as a non dissociated boric acid or borate anion forms, and borate anion formation increases with pH increases, thus it is adsorbed as borate anion. Ellis and Knezek (1972) stated that B is more strongly adsorbed by soil when compared with other anions such as Cl and NO_3, and this adsorption is realized through inorganic substance such as Fe and Al oxide and hydroxides, clay minerals and especially mica type clay, $Mg(OH)_2$ and organic matter. In general, it has been suggested that mica type clays such as vermiculite adsorbed B more and in descending order, kaolinite and montmorillonite are also effective in the adsorption of B (Loué, 1986). Akın (2009) reported that there were significant positive relationships between soil pH and readily soluble B and specifically adsorbed B fractions; whereas, negative relationships were found between oxides bound B and calcium carbonate content of soils. Keren and Gast (1981) stated that boric acid, borate and OH anions are in competition for adsorption and for clay surfaces, borate and OH anions have more adsorption capacity when compared with boric acid. Moreover, it was also suggested that boric acid is dominant and B adsorption is weak under low pH levels. On the other hand, it was stated that as pH increases, borate concentration also increases, and there is more B adsorption.

Mortvedt et al. (1999) reported that at pH range of 5.50-7.50, the activeness or avalibilty of B is the highest. Boron is sorbed to Fe and Al oxides in soils and its availability is lowest at pH range 6-9. Some studies showed that there were relationships amongst B availability and the existence of Ca ions. High levels of Ca at high pH reduce the B uptake in plants (Goldberg, 1997; Gupta and MacLeod, 1977). There are many studies, which revealed that wheat crop significantly responded to B application in low B calcareous soils (Soylu *et al.,* 2005).

In soil mass, B is distributed in various soil components like soil solution, organic matter and clay minerals. Readily available B in soil solution is known as plant uptake B, nevertheless this B brand hardly represents < 3% of entire soil B (Tsadilas, 1994; Jin et al., 1987). Recent studies also clearly indicated that residual B comprised the leading fraction up to 78.75% (Zerrari et al., 1999). Other studies revealed various extraction procedures from soil to determine B concentration in soil (Datta, 1996).

It was reported that clay minerals' getting wet and dry increases boron fixation, especially getting dry increases B fixation and decreases the recycling of B (Loué, 1986). Boron adsorption on iron and aluminum hydroxides makes it an important mechanism which affects the solubility of boron in soil. $Al(OH)_3$ is one of the main fraction that adsorbs B in soils and B adsorption through iron and aluminum hydroxides depends on pH. It has been suggested that the B adsorption of iron hydroxides raises to maximum level around pH 8-9, and the B adsorption of aluminum hydroxides raises to maximum level around pH 7, and also aluminum hydroxide adsorption is more when compared with iron hydroxides (Keren and Mezuman, 1981; Loué, 1986). The researchers also stated that ferromagnesian minerals and Mg $(OH)_2$ adsorb B in a similar way to B iron and aluminum hydroxides. Moreover, it has been suggested that B is adsorbed in soil by organic matter and organic matter plays an important role in the availability of B in soils (Parker and Gardner, 1982). An important part of B, which is absorbed by organic matter, is freed with the effect of microorganisms (Sillanpaa, 1978).

The B adsorption of mineral fraction is lower in acid soils, and thus it has been stated that humic colloids form the main B reserve, and the B adsorption by organic matter is stronger than borate oxide binding. Additionally, it was suggested that there is a positive correlation between the soil's organic matter content and available B content which is easily soluble in water (Loué, 1986). Compost addition, which is rich in organic matter, increases the B content in plants (Gupta, 1979). Turan and Horuz (2012) argued that available B for plants is freed as a result of the mineralization of organic matter. Maurice (1977) claimed that the most influencing factor on water soluble B content in the acidic soils forming on silisium and aluminum rocks is the organic matter, and then soil pH follows it when compared to total boron, clay, free iron and aluminum contents. Cornillon (1970) argued that clay has more contribution to the total B content of soils and B content of the clay fraction makes up the 60% of the soil's total B content. On the contrary, there is a significant positive correlation between the B content of the silt fraction and B content of the soil. As a result of the decomposition of the organic matter in soil by hydrogen peroxide water, 1.3% of the total B content of the soil becomes soluble in water (Maurice, 1971).

Özbek et al. (1993) reported that B is bound with organic matter and clay minerals, and adsorbed by Fe and Al oxides, and also a small part of B is soluble in water. The researchers also indicated that the adsorption and desorption of B content in soil solution depends on pH, adsorption rises between pH 6.0-8.5 and reaches the highest value between pH 8.5-10 and decreases again at pH value that rises more. Besides, they reported that $B(OH)_4^-$ adsorption takes place by changing places with OH^- (or H_2O) groups on the Fe and Al oxide surfaces and on the side surfaces of clay minerals; illite and vermiculite had high amount of B adsorption capacity while simectit and kaolinite had lower amount of B adsorption capacity. Boron can be bound to the humic matter of soil, OH groups of alcohols and other functional groups, besides $B(OH)_4$ can be partially bound to these groups when the pH value is under 7. They also reported that there may be a significant high relationship between organic substance B bindings, the soil's $C_{org.}$ content and amount of B content soluble in hot water. The researchers also indicated that the most common way to determine the extractable B content in soil was Berger-Triog method, and in this method, B in soil was extracted by boiling water (5 minutes with 1:2

soil : water). Özbek (1969) reported that Colwell method was developed to determine the extractable B content in soil and this method was also used to determine whether the soil had B deficiency and if it did, to find out the level of this deficiency, sunflower plant was used for application of this method.

Niaz (2010) B fractionation study revealed that the highest mean plant available B (0.32 mg kg^{-1}) was obtained by hot water extraction followed by 0.05M HCl (0.31mg kg-1), and 1:2 water extraction whereas the lowest B concentration was extracted by 0.005M DTPA, and total soil B content of all the soils varied from 15.61 to 152.80 mg kg^{-1} and it was further fractionated by using 0.05 M HCl (readily soluble B), 0.05 M KH_2PO_4 (exchangeable B), 0.02 M HNO_3-H_2O_2 (extractable B), 0.25 M NH_4-oxalate extractable B and the residual B.

The objectives of this study were to determine the boron status of the sugar beet grown soils sampled around Bafra, Çarşamba and Suluova, and to find out their B fraction distribution and availability for plants, and to present their relationships with soil properties.

2. MATERIALS AND METHODS

2.1. Soil sampling locations and some physical and chemical analyses

A total number of 27 soil samples, 11 from Çarşamba plain, 9 from Bafra plain and 7 from Suluova, were taken from a depth of 0-20 cm from sugar beet grown fields (Kacar, 2009). Some soil properties were analyzed as follows: soil texture according to Soil Survey Staff (1992), organic matter, lime, total nitrogen, available phosphor for plants, exchangeable K and Na, and cation exchange capacity (CEC) according to Kacar (1994), pH and salt according to Anonymous (1996), and total boron content spectrophotometrically using Azometin-H method by wet digestion with aqua regia (3:1 HCI:HNO_3) according to Cottenie et al. (1982). The physical and chemical characteristics of the soils are presented in Table 1 and nutrient contents in Table 2.

2.2. Colwell method (Biological method).

As reported by Özbek (1969), it was formed according to Colwell (1943) to determine whether the soil has B deficiency, and if it does, to determine the level of this deficiency. B deficiency was first seen in the indicator plant which is grown to determine the extractable B amount in soil and by comparing with the calibration series done by pure quartz sand in parallel with the main experiment. In the experiment, *Tarsan 1018* sunflower variety was used as an indicator plant. In the greenhouse experiment, which was conducted according to randomized block design with three replications, 450 g of soil was put in plastic pots, based on oven dry weight, and 10 sunflower seeds were planted in each pot. In parallel with the main experiment, sand culture experiment was set up. In plastic pots, 450 g of washed quartz sand were filled and 0 - 0.05 - 0.10 - 0.30 - 0.50 - 1.00 ppm B were applied as boric acid solution and 10 sunflower seeds were planted. In sand culture or soil experiment, 9 days after the plantation, 5 plants were left in each pot. Following the tenth day, 25 ml of food solution which didn't have B and which was prepared in according to Colwell's (1943) description was put in every pot in soil or sand culture pots once in every two days. Moreover, the pots in both experiments were given 2 ml/pot of 0.5 % sequestrene-138 Fe solution once in two or three days. During the experiment, phonological observations were made on the plants grown in both soil and sand culture

and lastly, the ages (as days) of the plants which showed B deficiency were established and they were harvested. In the sand culture method, the plants were harvested at the ages in which they showed B deficiency depending on the B doses practiced. In the soil experiment, the plants were kept until their 66th day, and during this time, the grown plants were harvested at the ages when B deficiency symptoms were observed. The harvested plant samples were washed with pure water and the extra water was taken on filter paper. After this, they were dried in ovens at 65°C and their dry matter weight was determined. The dried plants samples were crushed and their B analyses were made in according to Kacar and İnal (2008). The equation ($y = a + bx_1 + cx_2$) which showed the relationship between the plant ages (x_1 day) in showing B deficiency or harvesting date, B uptake by plant (x_2, µg pot^{-1}) in sand media was used to calculate the available B contents (y, ppm B) of the soils as ppm.

2.3. The method of extraction with hot water (Berger-Triog method).

In order to determine the extractable B content in soil, the suspension prepared at 1:2 soil-water ratio was boiled for 5 minutes and filtered, and the B content in the extract was determined by Azometin-H method (Kacar, 1994).

2.4. Determination of boron fractions in soils.

The B fractions of the soils were determined by using sequential methods as proposed by Hou et al. (1994). For this purpose, 1 g of soil sample was taken and after each fraction was extracted in specified solutions, the same soil sample was washed with distilled water each time. The B content of extracts for each fraction was determined by using Azometin-H method.

Easy soluble B. Extracted by shaken with 0.01 M $CaCl_2$ solution for two hours, the specific adsorbed B same soil sample was washed with distilled water and extracted by shaking with 0.05 M KH_2PO_4 for two hours.

Oxide dependent B. The same soil was washed with distilled water again and extracted by shaking with 0.2 M ammonium oxalate + 0.1 M oxalic acid for two hours.

Organic matter dependent B. After the same soil sample was washed with distilled water, it was extracted by digesting on sand bath with 30% H_2O_2 + 0.02 N HNO_3 for three hours (twice).

Residual B. After the same soil sample was washed with distilled water, it was extracted by digesting with 1/3 HNO_3:HCI mixture (aqua regia).In the extracts taken each fraction, B content was determined spectrophotometrically by using Azometin-H method.

Total B. It was determined through sum of each fraction determined sequentially.

2.5. Statistical analyses

Statistical analyses were done by Minitab package program according to Yurtsever (1984).

3. RESULTS AND DISCUSSION

3.1. The available B contents of soils determined by Colwell method and hot water extraction method, the relationships between these two methods and B status of soils

The ages of the plants shoving B deficiency or harvesting date, their dry matter contents, B contents and

B uptakes in the sand media are given in Table 3. The ages of the plants shoving B deficiency or harvesting date,

their dry matter amounts, B contents and B uptakes, and the available B contents determined in soil samples by Colwell method, and B contents of soils determined by hot water extraction method are given in Table 4.

In sand media, the sunflower plant showed B deficiency symptoms at later days as the B doses increased; in control treatment B deficiency symptoms appeared about 20 days after the seeding and the deficiency symptoms appeared about 57.7 days after the seeding in the 1.00 ppm B treatment. The equation of the relationship between B doses applied in sand media (y) and the ages of the plants grown in harvesting date (x_1) and their B uptake (x_2) found as $y = 0.181 - 0.011x_1 + 0.0044x_2$; $R^2 = 0,991^{**}$. Özbek (1969) reported that most of the experiments done in greenhouses showed that there was an important relationship between the available B content of soil or sand media and the age of plants having B deficiency in the harvesting data and their B uptake.

Table 1. Physical and chemical properties of the soils

Soil No	Soil sampling locations		Sand %	Silt %	Clay %	pH_{H2O} 1:2.5	Salt %	Lime %	OM %	CEC me 100 g^{-1}
	District*	Village								
1		Çınarcık	32.5	37.0	30.5	7.6	0.02	15.5	1.3	20.9
2		A.Karabahçe	15.7	60,3	24,0	6,9	0,03	3,2	2,7	19,8
3		Ovacık	24.3	27.4	48.3	6.9	0.03	1.3	2.2	33.5
4		Hürriyet	28.2	39.2	32.6	6.6	0.02	6.0	1.6	22.8
5	I	Durakbaşı	17.8	52.8	29.4	7.1	0.18	2.8	3.5	24.6
6		Ahubaba	18.0	36.4	45.6	6.5	0.03	0.5	2.4	32.2
7		Kurtahmetli	13.9	36.5	49.6	6.8	0.02	0.9	2.0	33.7
8		Muşcalı2	9.4	49.0	41.6	7.7	0.01	10.8	2.5	29.9
9		Bafraçalı	32.2	46.0	21.8	7.3	0.05	6.3	0.8	14.7
10		Muşçalı1	23.0	55.1	21.9	7.2	0.03	7.8	2.5	18.2
11		Yukarıdonurlu	35.3	36.0	28.7	7.6	0.03	1.2	1.6	20.5
12		Saluca	36.7	27.3	36.0	7.6	0.01	16.5	1.9	25.4
13		Uzunova	25.0	22.8	52.2	7.3	0.05	16.1	1.6	34.5
14		Yüzbey	32.9	42.6	24.5	7.5	0.01	12.3	1.0	16.7
15	II	Kurnaz	34.5	27.8	37.7	7.2	0.04	15.3	1.5	25.6
16		Saygılı	29.4	27.0	43.6	6.9	0.04	9.5	2.3	30.7
17		Eraslan	14.5	25.0	60.6	7.5	0.04	11.8	2.1	40.6
18		Hacıbayram	46.6	28.9	24.5	7.4	0.02	9.1	2.3	19.3
19		Doğanca1	15.7	20.3	64.0	7.1	0.06	0.0	3.0	44.4
20		Koşuköyü	34.5	45.6	19.9	7.7	0.02	10.5	1.9	15.7
21		Şeyhören	24.6	30.1	45.3	7.6	0.06	20.2	2.3	31.8
22		Kalaycılı	23.4	44.0	32.6	7.3	0.02	7.2	2.4	24.4
23	III	Adaköyü	22.9	44.5	32.6	7.4	0.04	10.5	2.5	24.6
24		Fenerköyü	56.8	35.7	7.5	7.2	0.03	10.3	0.7	6.0
25		Sarıkaya	19.7	45.3	35.0	5.2	0.02	0.0	2.0	25.0
26		Doğanca2	22.5	38.0	39.5	7.3	0.02	0.3	2.2	28.1
27		Sahilkent	13.4	29.0	57.6	6.7	0.03	4.8	4.1	42.7
Lowest			9.4	20.3	7.5	5.2	0.01	0.0	0.7	6.0
Highest			56.8	60.3	64.0	7.7	0.18	16.5	4.1	44.4

*: I- Carsamba, II- Suluova, III- Bafra

Table 2. Plant available nutrient contents of the soils

Soil No	Soil sampling locations: District*	Village	Exch. K me 100 g^{-1}	Exch. Na me 100 g^{-1}	Total N, %	Available P, kg P_2O_5 da^{-1}	Total B ppm
1	I	Çınarcık	1.3	0.26	0.07	7.2	43.25
2		A.Karabahçe	0,5	0,43	0.14	15.2	57.09
3		Ovacık	0.8	0.37	0.11	42.9	57.95
4		Hürriyet	0.6	0.33	0.08	18.4	76.12
5		Durakbaşı	1.4	0.37	0.17	54.8	51.04
6		Ahubaba	1.3	0.37	0.12	24.1	57.09
7		Kurtahmetli	0.8	0.35	0.10	52.0	57.95
8		Muşcalı2	1.1	0.33	0.12	6.3	75.25
9		Bafraçalı	0.4	0.22	0.04	2.0	70.93
10		Muşçalı1	0.7	0.37	0.13	12.6	83.04
11		Yukarıdonurlu	0.8	0.22	0.08	7.7	62.28
12	II	Saluca	1.9	0.41	0.10	14.4	29.41
13		Uzunova	1.7	0.39	0.08	137.6	51.04
14		Yüzbey	0.9	0.57	0.05	18.2	47.57
15		Kurnaz	2.1	0.30	0.08	14.3	31.14
16		Saygılı	2.6	0.74	0.12	29.2	57.09
17		Eraslan	1.8	0.61	0.11	25.4	69.20
18		Hacıbayram	0.6	0.39	0.12	10.4	31.14
19	III	Doğanca1	1.8	1.74	0.15	17.6	76.12
20		Koşuköyü	0.8	1.98	0.10	10.4	63.15
21		Şeyhören	0.8	1.50	0.12	28.4	64.01
22		Kalaycılı	0.7	0.46	0.12	12.0	64.88
23		Adaköyü	0.4	0.33	0.13	13.6	70.93
24		Fenerköyü	0.2	0.52	0.04	20.8	55.36
25		Sarıkaya	0.3	1.09	0.10	51.9	54.50
26		Doğanca2	0.6	0.61	0.11	17.3	66.61
27		Sahilkent	1.6	0.78	0.20	23.3	64.01
Lowest			0.2	0.22	0.04	2.0	29.41
Highest			2.6	1.98	0.20	137.6	83.04

*: I- Carsamba, II- Suluova, III- Bafra

Table 3. Results obtained in the sand media

B doses, ppm (y)	Plant age when B deficiency observed, day (x_1)*	Dry matter in harvesting date when B deficiency observed, g pot^{-1}	Plant B content in harvesting date when B deficiency observed, ppm	Plant B uptake in harvesting date when B deficiency observed, µg pot^{-1} (x_2)*
0.00	20.0f	1.20f	14.07f	16.9f
0.05	23.7e	1.69de	18.80e	31.8de
0.10	26.3d	2.08d	21.44d	44.6d
0.30	39.0c	4.50c	24.99c	112.5c
0.50	54.0b	8.08b	26.93b	217.6b
1.00	57.7a	10.64a	30.69a	326.5a
LSD 5%	1.417	0.461	1.464	13.530

According to the experiment, done with soil media the plant ages having B deficiency or harvesting date, their dry matter contents, B contents and B uptakes, and available B contents determined by Colwell method and hot water extraction method showed differences among the soil samples (Table 4). Deficiency symptoms in the soils numbered as 9, 10, 24 and 25 were observed when the plants were 56 days old; and the deficiency in the soils numbered as 1, 3, 7, 8, 11 and 23 was observed when the plants were 62 days old. Boron deficiency was observed in the 63.6% of the soil samples taken from Çarşamba and in the 33% of the soil samples taken from Bafra. Boron deficiency in the all plants grown in the Suluova soil was not observed, and the plants were harvested in 66 days. When B deficiency was observed in the plants grown in the soil samples, the

Table 4. Results obtained in the soil media and the hot water extractable B contents of soils

Soils	The available B contents by Colwell method, ppm (y)*	Boron deficiency status of soils, plant age in harvesting date day (x_1)	Plant dry matter amount in harvesting date, g pot^{-1}	Plant B content in harvesting date, ppm	Boron uptake by plant in harvesting date, µg / pot^{-1} (x_2)	Hot water extraction method B, ppm
1	1.75	Inadequate, 62	17.51c-g	28.94ı-l	506.7gh	0.86
2	2.39	Adequate, 66	18.48b-e	35.82j-f	662.0c-e	2.09
3	1.84	Inadequate, 62	17.33c-g	30.46h-j	527.9g	1.62
4	1.89	Adequate, 66	16.61f-g	33.01f-h	548.33fg	1.39
5	1.66	Adequate, 66	18.08b-f	27.47k-m	496.7gh	2.16
6	2.40	Adequate, 66	18.13b-f	36.58c-e	663.2c-e	1.80
7	1.69	Inadequate, 62	18.00b-f	27.47k-m	494.5gh	0.94
8	1.89	Inadequate, 62	17.21dg	31.36g-ı	539.7fg	0.94
9	1.05	Inadequate, 56	14.53ıj	23.05n	334.9j	0.90
10	1.32	Inadequate, 56	15.02hı	26.26lm	394.4ıj	0.50
11	1.73	Inadequate, 62	18.26b-e	27.51j-m	502.3gh	0.54
12	2.15	Adequate, 66	18.07b-f	33.63eg	607.7ef	1.42
13	2.39	Adequate, 66	18.53b-e	35.64d-f	660.4c-e	2.09
14	2.23	Adequate, 66	18.36b-e	34.04eg	625.0de	2.48
15	2.48	Adequate, 66	19.38ab	35.15d-f	681.2c-e	2.12
16	3.03	Adequate, 66	18.81bc	42.79a	804.9a	4.61
17	2.58	Adequate, 66	17.08d-g	41.18ab	703.4bc	2.41
18	1.90	Adequate, 66	18.18b-e	30.37h-k	552.1fg	1.66
19	2.91	Adequate, 66	18.46b-e	42.21a	779.2a	2.56
20	2.38	Adequate, 66	17.01e-g	38.73bc	658.8c-e	4.03
21	2.95	Adequate, 66	20.83a	37.83cd	788.0a	2.30
22	2.31	Adequate, 66	18.59b-d	34.62ef	643.6c-e	1.76
23	2.52	Inadequate, 62	19.38ab	35.15d-f	681.2cd	1.08
24	1.49	Inadequate, 56	16.43gh	26.44lm	434.4hı	0.86
25	1.08	Inadequate, 56	13.44j	25.46mn	342.1j	0.65
26	2.35	Adequate, 66	15.00hı	43.55a	653.3c-e	2.59
27	2.85	Adequate, 66	17.75d-g	43.10a	765.0ab	2.59
	LSD 5%		0.886	1.722	41.934	-

* – Calculated the available B contents of soils (y) according to Colwell method by using the equation ($y = 0.181 - 0.011x_1 + 0.0044x_2$; $R^2 = 0.991$**). x_1: the ages of the plants grown by soil media in harvesting date and x_2: B uptake of the plants grown by soil media in harvesting data

dry matter content of the harvested plants varied between 13.44 and 19.38 g pot^{-1}. The dry matter content of the plants having sufficient B varied between 15.00 and 20.83 g pot^{-1} due to having a longer growing period. Showing B deficiency in the plant, B contents and uptake of the plants at the harvesting date were ordered the sample number of the soil as follows : 9 < 25 < 10 < 24 < 7 < 11 < 1 < 3 < 8 < 23. Boron contents of the plants having B deficiency varied between 23.05 and 35.15 ppm at the harvest. Average boron content of the plants having B deficiency was found as 28.21 ± 2.47 ppm. While the B uptakes of plants having B deficiency were between 334.9 and 681.2 µg pot^{-1}, the B uptakes of the plants which didn't show B deficiency were between 496.7 and 804.9 µg pot^{-1}. Blamey et al. (1979) reported that the critical B content in the sunflower leaves was between 32 and 35 ppm, and the critical B content in leaves could be considered as 34 ppm. Loué (1986) suggested that in the previous studies, B deficiency symptoms of sunflower plant were observed when the B content in the leaves was lower than 25 ppm. However, the lowest value for B deficiency differed between 25 and 35 ppm, and there was a lost in yield when the plants had boron content lower than these values. The plants which showed no boron deficiency had a B content between 27.47 and 43.55 ppm at the harvest.

The available B contents of the soils calculated by Colwell method were between 1.05 and 1.89 ppm in B deficient soils and between 1.66 and 3.03 ppm in soils which had sufficient B. According to the hot water extractable boron contents, the soil samples having B deficiency were ordered as follows: 10 (0.50 ppm) < 11 (0.54 ppm) < 25 (0.65 ppm) < 24 (0.86 ppm) = 1 (0.86 ppm) < 9 (0.90 ppm) < 8 (0.94 ppm) = 7 (0.94 ppm) < 23 (1.08 ppm) < 3 (1.62 ppm). In the other words, the hot water extractable B contents of the soils having B deficiency were found to be mostly lower than 1.00 ppm while it was 1.62 ppm only for one soil samples. Hot water extractable B contents of the soils which showed no B deficiency were above 1.00 ppm and varied between 1.39 and 4.61 ppm. According to hot water extractable B contents of soils, Wolf (1971) classified soils as insufficient if the B content was lower than 0.4 ppm, as low if it was between 0.5 and 0.9 ppm, as sufficient if it was between 1.0 and 2.4 ppm, as high if it was between 2.5 and 4.9 ppm and as toxic if it was above 5 ppm. The results obtained in this study are the similar to the values given by Wolf (1971). The available B content of the soils determined by Colwell method showed a significant correlations with B content (r = 0.926**) and B uptake (r = 0.999**) of the plants in the harvesting date. These high correlations showed that there are strong relationships among the available B content of the soils determined, B content and B uptake of the plants. The correlation coefficients of the relationships between hot water extraction method and the available B contents determined by biological method of the soils and plant B content in the harvesting date or when B deficiency observed was found to be significant statistically (r = 0.739**, r = 0.783** respectively). These results indicated that the available B content of the soils can be determined by the hot water extraction method. Özbek et al. (1993) reported that the most common method to determine the available B content of soils was the hot water extraction method. On the other hand, available boron contents of the soils determined by hot water extraction method gave a significant correlations with the B uptakes of the plants in the harvesting date (r = 0.744**). Boron uptake by Chinese cabbage was significantly correlated with the water soluble B fraction in soil (Hwang et al., 1990).

3.2. The boron fraction distributions of the soils

Boron fraction contents of Bafra, Çarşamba and Suluova soils samples are given in Table 5. The easily soluble B content of the soils is between 0.48 and 1.70 ppm at Çarşamba plain, 1.08 and 2.58 ppm at Suluova, 0.73 and 2.41 ppm at Bafra plain. The 10 soils in B deficiency, easily soluble B contents were found between 0.48 and 1.55 ppm. The easily soluble B contents of the other soils, between 1.04 and 2.58 ppm, did not show B deficiency. The easily soluble B content was about 1.72% of the total B content in the soils having B deficiency, and about 2.89% of the total B content in the soils that did not B deficiency. This result indicates that the B solubility is low in the soils having boron deficiency. Zerrari et al. (1999) reported that the easily soluble B fraction of the soils was 0.31% of the total B fractions while Gupta (1979) reported that the B content of the soils determined by hot water method was less than 5% of the total B. The easily soluble B content of the soils showed significant correlations with available B content of soils by Colwell method (r = 0.690**), the B content (r = 0.735**), and B uptake (r = 0.697**) of the plants in harvesting date. This result indicates that there is a strong relationship between the available B content of the soils and their easily soluble B content. On the other hand, the correlation coefficient of the relationship between the easily soluble B content of the soils and the B content determined by hot water method was found to be r = 0.808**. Hwang et al. (1990) indicated that boron uptake by Chinese cabbage was significantly correlated with the water soluble B fraction in soil.

The specific adsorbed B content of the soils were between 1.17 and 3.08 ppm in Çarşamba plain, 1.22 and 3.03 ppm in Suluova, 1.58 and 3.21 ppm in Bafra plain. It was found that the specific adsorbed B content in the soils of Bafra plain was more than the others. The specific adsorbed B content of the 10 soils having B deficiency symptoms were between 1.17 and 3.08 ppm. The specific adsorbed B content of the other soils which showed no B deficiency were between 1.22 and 3.21 ppm. The values for the specific adsorbed B content of the soils with and without B deficiency were found to be close each other. The adsorbed B in soils having B deficiency was 3.35% of the total B fraction. and 3.70% of the total B fraction in soils which did not have B deficiency. Zerrari et al. (1999) reported that the adsorbed B content of the soils was 0.87% of the total B fractions.

The organic matter dependent B content of the soils were found to be between 4.30 and 16.34 ppm in Çarşamba plain, 6.88 and 10.32 ppm in Suluova, 4.30 and 18.06 ppm in Bafra plain. The organic matter dependent B content of the 10 soils having B deficiency symptoms were between 4.30 and 16.34 ppm. The organic matter dependent B content of the other soils which showed no B deficiency was between 4.30 and 18.06 ppm. The organic matter dependent B content of the soils having B deficiency was approximately 8.51 ppm and the organic matter dependent B content of the soils which showed no B deficiency was approximately 11.08 ppm. The organic matter dependent B was found to be low in soils having B deficiency. The organic matter dependent B in B deficient soils was about 13.96% of the total B fractions, and 18.40% of the total B fraction in non deficient soils. Zerrari et al. (1999) reported that the organic matter dependent B content of the soils was 12.4% of the total B fractions.

The oxide dependent B content of the soils were found to be between 2.51 and 11.63 ppm in Çarşamba plain, 6.23 and 9.39 ppm in Suluova, 1.21 and 10.23 ppm in Bafra plain. The oxide dependent B content of the 10 soils having B deficiency was between 1.67 and 10.79 ppm. The oxide dependent B content of the other soils which showed no B deficiency was between 1.21 and 11.63 ppm. The oxide dependent B content of the B deficient soils was approximately 4.78 ppm, and the oxide dependent B content of the non deficient soils was approximately 7.78 ppm. The oxide dependent B was found to be low in soils having B deficiency. The oxide dependent B in soils having B

Table 5. Boron fraction contents of Bafra, Çarşamba and Suluova soils

Soil number	Easy soluble B, ppm	Specific adsorbed B, ppm	Organic matter dependent B ppm	Oxide dependent B, ppm	Residual B, ppm	Fraction total B ppm
1	1.55	2.06	7.74	4.65	38.23	54.25
2	1.05	2.19	15.48	11.63	42.50	72.85
3	1.26	1.79	9.46	7.44	35.70	55.65
4	1.45	2.11	13.76	8.84	43.35	69.51
5	1.70	2.31	14.62	10.42	44.20	73.25
6	1.19	2.87	8.60	10.60	30.60	53.86
7	1.04	1.17	4.30	2.51	43.35	52.37
8	1.45	1.22	6.02	10.79	52.70	72.18
9	0.95	1.97	5.16	2.60	63.75	74.43
10	0.48	2.07	16.34	2.70	45.05	66.64
11	0.66	3.08	13.76	2.60	35.70	55.80
12	1.09	2.02	8.60	6.23	42.50	60.44
13	1.68	1.22	9.46	9.02	47.60	68.98
14	1.04	3.03	10.32	7.44	30.60	52.43
15	2.38	2.65	10.32	8.09	28.05	51.49
16	2.58	2.86	8.60	9.02	34.00	57.06
17	1.90	1.34	6.88	9.39	48.45	67.96
18	1.73	2.55	10.32	8.84	21.25	44.69
19	2.18	1.79	18.06	7.53	33.15	62.71
20	2.41	3.21	4.30	1.21	45.05	56.18
21	1.80	1.75	15.48	2.33	29.75	51.11
22	1.48	2.77	16.34	5.49	30.60	56.68
23	1.31	2.94	8.60	4.93	45.90	63.68
24	0.73	2.38	11.18	7.91	43.35	65.55
25	1.04	1.77	11.18	1.67	33.15	48.81
26	2.13	1.72	7.74	5.95	45.90	63.44
27	1.84	1.58	9.46	10.23	38.25	61.36
Lowest	0.48	1.22	4.30	1.21	21.35	44.69
Highest	2.58	3.21	18.06	11.63	63.75	74.43

deficiency was about 7.84% of the total B fractions, and 12.92% of the total B fractions in non deficient soils. Zerrari et al. (1999) reported that the oxide dependent B content of the soils was 8.04% of the total B fractions.

The residual B content of the soils were found to be between 30.60 and 63.75 ppm in Çarşamba plain, 21.25 and 48.45 ppm in Suluova, 29.75 and 45.90 ppm in Bafra plain. The residual B content of the 10 soils having B deficiency was between 33.15 and 63.75 ppm.

The residual B content of the other soils which showed no B deficiency was between 21.25 and 48.45 ppm. The residual B content of the soils having B deficiency was approximately 43.69 ppm, and the residual B content of the soils which showed no B deficiency was approximately 37.40 ppm. The residual B was found to be higher in soils having B deficiency. This result shows that the soils having B deficiency had more minerals including residual B. The residual B in soils having B deficiency was about 71.69% of the total B fraction and 62.10% of the total B fraction in soils which did not have B deficiency. Zerrari et al. (1999) reported that the residual B content of the soils was 78.75% of the total B fractions. Xu et al. (2001) reported that the nonspecifically adsorbed B and specifically adsorbed B comprised <1% of total B, by contrast, B occluded in Mn oxyhydroxide, in amorphous Fe and Al oxides and in crystalline Fe and Al oxides comprised from 0.01 to 7.6% of total B. Diana and Beni (2006) determinated that in soils water soluble and adsorbed B fractions represented only a smal proportion of the total soil B content (0.66-1.21 % of total soil B), althoug in the most soil, residual B fraction accounted for between 86.3 and 88.2 % of total soil B.

The total B fraction of the soils were found to be between 52.37 and 74.43 ppm in Çarşamba plain, 51.49 and 68.98 ppm in Suluova, 48.81 and 65.55 ppm in Bafra plain. The total B fraction of the 10 soils having B deficiency was between 48.81 and 74.43 ppm. The total B fraction of the other soils which showed no B deficiency symptoms were between 44.69 and 73.25 ppm. The total B fraction of the B deficient soils was approximately 60.94 ppm, and the total B fraction of the non deficient soils was approximately 60.23 ppm. In terms of total B content, no difference was observed between the B deficient and non deficient soils. Loué (1986) reported that the total B content of the soils were between 2 and 200 ppm, and the total B content of the soils were higher than the total B content of the rocks on which they were formed.

The available B content of the soils determined by Colwell method did not show significant relationships with the adsorbed, organic matter dependent, oxide dependent, residual and total B fraction contents. However, there was a statistically significant correlation (r=0.375*) between B uptake of the plants in harvesting date and the oxide dependent B content of the soils at the level of 5%. The relationship between the B content of the plants in harvesting date and the oxide dependent B content of the soils was not statistically significant (r=0.358). Similarly, no strong relationships were found among the B content and B uptake of the plants in the harvesting date, and the adsorbed B, organic matter dependent B, residual B and total B fraction. Also, no strong relationships were found among the B content of the soils by hot water method, B fractions and total B fraction.

3.3. The relationships between B fractions and soil properties

As clay and exchangeable Na increased, the easily soluble B content of the soils also increased significantly at the level of 5% and 1% (*r* = 0.436*, 0.485**, respectively). The increase in the easily soluble B content of the soils as a result of the increase in the Na content of the soils can be explained with the formation of high soluble sodium borate in Na high soils (Rai et al., 1970). No significant effect of pH, sand, organic matter, lime, salt and extractable phosphor was observed on the easily soluble B content of the soils.

As clay content and extractable phosphor increased, adsorbed B content of the soils decreased significantly at the level of 1% and 5% (*r* = −0.553**, −0.418* respectively) and increased significantly as the sand content increased at the level of 1% (*r* = 0.495**). Increase in clay content decreased extractable B content due to increase in adsorbed B fractions in the soils. Xu et al. (2001) reported that the content of the nonspecifically adsorbed B fraction increased with increasing soil pH and exchangeable Ca. However, the increase in the sand content increased extractable B content due to decrease in the adsorbed B fractions in soils. Loué (1986) reported that B was strongly adsorbed on the surfaces of clay minerals. It was observed that the organic matter dependent, oxide dependent and residue B contents and the total of B fractions were not dependent on clay, sand, salt, exchangeable Na and extractable phosphor content of the soils. The relationships among the total B content of the soils determined through aqua regia, the available B content of the soils by Colwell method and hot water extraction method, and the B content and B uptake of the plants in the harvesting date were not significant. On the other hand, as the sand and clay content of the soils increased. the total B contents determined through aqua regia decreased significantly at the level of 1% and 5% (*r* = -0.488** and -0.419* respectively). As the soils' clay, organic matter and exchangeable Na content increased, their useful B content, B content and B uptake of the plants in the harvesting date increased significantly (r=0.560**, 0.410* and 0.416*; r=0.573**, 0.423* and 0.461*; r=0.559**, 0.415* and 0.407* respectively). There was a significant correlation (r=0.547**) between the available B content of the soils by hot water extraction method and the exchangeable Na content. As the exchangeable Na content of the soils increased, a significant increase was observed in the available B content. Wojcik (2000) indicated that simple correlation analysis showed positive correlation between B contents in M.26 apple rootstocks and amounts of B in soil solution (r=0.77), B non-specifically adsorbed on soil colloid surfaces (r=0.65), B specifically adsorbed on soil surface (r=0.76) and B occluded in Mn oxyhydroxides (r=0.77), and no relation was found between plant B contents and amounts of B occluded in noncrystalline and crystalline Al and Fe oxides, B fixed with soil silicates and total B. Xu et al. (2001) investigated that the B occluded in Mn oxyhydroxide fraction was positively correlated with soil pH and cation-exchange capacity (CEC) and the crystalline Fe and Al oxides-B fraction was positively correlated with pH and exchangeable Ca.

Tsadilas et al. (1994) reported that soil boron occurring in various forms was correlated with boron contents in the leaves of olive trees in 51 and in barley leaves in 20 soils. Also, the amounts of boron: in soil solution non specifically adsorbed, specifically adsorbed, occluded in Mn oxides, occluded in amorphous Fe-Al oxyhydroxides, were correlated with soil properties such as: organic matter content, pH, free aluminum and iron oxyhydroxides, amorphous aluminum and iron oxyhydroxides.

4. CONCLUSIONS

The results of this study can be concluded as follows;

1. B deficiency symptoms in plants were found when plants' ages were 56 and 62 days.
2. B deficiency was found in the 63.6 % of the soils taken from Çarşamba and in the 33 % of the soils taken from Bafra while B deficiency did not found in the sunflower plants grown on soils taken from Suluova.
3. The B contents extracted with hot water for the soils showed B deficiencies were generally found to be lower than 1.00 ppm.
4. The available B contents extracted with hot water for the soils showed no B deficiencies were found to be between 1.39 and 4.61 ppm.

This study showed that the available B content of the soils can be determined by the hot water extraction method. Easily soluble and oxide dependent B contents had significant relationships with the biological indexes such as; plant age when boron deficiency observed, dry matter, B content and uptake of sunflower plants.

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