Gaziosmanpaşa Üniversitesi Ziraat Fakültesi Dergisi
Journal of AgriculturalFaculty of GaziosmanpasaUniversity
http://ziraatdergi.gop.edu.tr/

Araştırma Makalesi/*ResearchArticle*

JAFAG
ISSN: 1300-2910
E-ISSN: 2147-8848
(2016) 33 (3), 46-54
doi:**10.13002/jafag1121**

Effects of High Boron Containing Irrigation Waters on Plant Characteristics of Basil (*Ocimum Basilicum L.*)

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Alındığı tarih (Received): 18.09.2016 Kabul tarihi (Accepted): 03.11.2016
Online Baskı tarihi (Printed Online): 14.11.2016 Yazılı baskı tarihi (Printed): 30.12.2016

Abstract: The demand for water is increasing year after year. In contrast, water resources are deteriorating continuously in terms of both quality and quantity. The ratio of fresh water used in agriculture is decreasing in each day against the increasing demands of the other sectors. For sustainable agricultural production, low quality waters should also be used in agricultural irrigations. Turkey is quite rich in boron reservoirs. Ground and surface water resources around these reservoirs are contaminated with boron compounds. Use of these sources is a highly significant issue for efficient use of limited water resources. The present study was conducted to investigate the effects of boron-containing irrigation waters on plant characteristics of basil. Irrigation waters containing 0, 1, 2, 4 and 8 ppm boron were used in experiments and two harvests were performed. In the first harvest, plant fresh weights varied between 44.0-89.5 g/pot and plant heights varied between 32.5-44.0 cm. In the second harvest, plant fresh weights varied between 43.0-59.0 g/pot and plant heights between 31.8-35.5 cm. Differences in soil EC, pH, ESP, Na, Ca, Mg, K, B, HCO_3, Cl and SO_4 contents and plant Na, Ca, Mg, K, B, N, P, K and Cl contents were found to be significant at 5% significance level.

Keywords: Irrigation Water Quality, Boron, Basil

Bor İçeriği Yüksek Sulama Sularının Fesleğen (*OcimumBasilicum* L.) Bitki Özelliklerine Etkisi

Öz: Suya olan talep her geçen yıl katlanarak artmaktadır. Buna karşılık su kaynakları hem nitelik hem de nicelik açsından bozulmaktadır. Diğer sektörlerde artan talep nedeniyle tarımsa lüretimde kullanılan temiz suyun oranı gün geçtikçe azalmaktadır. Sürdürülebilir bir tarımsal üretim için düşük kalite olarak değerlendirilen su kaynaklarının tarımsal sulama amaçlı olarak kullanımını nsağlanması zorunludur. Türkiye gibi bor elementi bakımından zengin ülkelerin özellikle maden yatakları civarındaki yeraltı ve yer üstü su kaynaklarında yüksek oranda bor elementi bulunabilmektedir. Söz konusu bu kaynakların değerlendirilmesi son derece önemlidir. Yapılan bu çalışmada, tıbbi ve aromatik bitkilerden Fesleğenin sulamasında farklı bor içeriğine sahip sulama suları kullanılmıştır. Ardışık iki hasat (biçim) alındıktan sonra çalışma sonlandırılmıştır. İlk biçimde bitki yaş ağırlığı 44-89.5 g/saksı arasında değişirken bitki boyları 32.5-44 cm arasında değişim göstermiştir. İkinci biçimde ise yaş ağırlık 43-59 g/saksı ve bitki boyu 31.8-35.5 cm arasında değişim göstermiştir. Ayrıca, toprağın EC, pH, ESP, Na, Ca, Mg, K, B, HCO_3, Cl ve SO_4 ve bitkide de Na, Ca, Mg, K, B, N, P, K ve Cl iyon içeriğinde istatistiksel olarak %5 önem düzeyinde anlamlı değişimler belirlenmiştir.

Anahtar Kelimeler: Sulama Suyu Kalitesi, Bor, Fesleğen

1. Introduction

Current climate change trends and global warming negatively affects both the quantity and quality of fresh water resources. Reduction of water use ratios in agricultural production activities will only be possible by using low quality waters as irrigation water. Turkey has the richest boron reserves throughout the world and these reserves are mostly located around western Anatolia. Currently available reserves extends about 150 km East-West and 300 km North-South directions in South of Marmora Sea and covers the towns of Bigadiç, Sultançayır, Kestelek, Emet and Kırka (Helvacı 2003). Ground and surface water resources around these reserves contain boron compounds at high concentrations. Therefore, such compounds directly influence agricultural production since these water resources are mostly used in irrigations.

Although there are several studies about the impacts of boron deficiency on plants, there are limited studies about boron toxicity. Such studies are almost extinct especially in basil-like medicinal-aromatic plants. The specific role of boron in plant metabolism has not been distinctively comprehended, yet (Bozcuk 2004). Boron may exhibit significance for plants both in deficit and abundant conditions. Boron deficiency usually observed in humid and high-precipitation zones. However, the regions with toxic boron levels are mostly surrounded by boron reserves. Despite significant differences in plant response to boron, both deficiency and toxicity result in significant problems in agricultural production activities. Although it is a minor nutrient for plant growth, it is also an essential element for high yield and quality. Boron plays various significant roles in cell membrane structure, cell division, flowering and fruit formation.

Not only the irrigation method, irrigation scheduling and amount of irrigation, but also the quality of irrigation water is a significant issue in agricultural irrigations. Environmental pollution is getting a more serious concern along with the developments in agricultural activities and in other sectors. Especially the use of irrigation waters with more than 1 ppm boron concentration may result in serious problems both in plants and soils (Ayers andWestcot 1989). Soil boron concentrations increase based on boron concentration of irrigation waters and duration of irrigations.

There are significant differences in boron tolerance of plants. Such differences result from different physiological and morphological responses of plants against boron toxicity (Paul et al., 1988; Huang and Graham 1990; Nable 1991; Taban and Erdal 2000).

Medicinal plants are among the major and important group of crops (Rehm and Espig 1991) which have been used for traditional prevention and treatment of diseases and herbal medicines have a long history (Williamson 2003). Based on the World Health Organization (WHO), about 80% of the world population still rely on medicinal herbs. Herbal medicinal products are used by nearly 19% of the adult population in the United States (Kennedy 2005; Patwardhanet al. 2005); however, the quality and the quantity of secondary metabolites of medicinal plants strongly depend on environmental conditions (Aghaei and Komatsu 2013).

Although boron is an indispensable element for plants and deficient conditions directly influence plant growth and yield and limit crop productivity, substantial amounts of boron are toxic to plants and reduce plant yield (Novozámskýet al. 1993). Boron is also a beneficial and essential element for humans and animals (Nielsen, 1993). It is an important mineral in human nutrition since it is involved in maintaining the cell membrane functions and enzyme activities. Together with other minerals, such as calcium, magnesium and vitamin D, boron helps to prevent osteoporosis and osteoarthritis and stimulates immune system and inflammatory and hormonal responses. Although a minimum daily dose has not been specified, 3 mg per day is principally recommended as a nutrient supplement (Nielsen 1993). Boron deficiency symptoms have related to bone and immune system and inflammatory and hormonal responses (Hunt 1994; Sheng et al. 2001).

However, boron accumulation may result in serious hazards on plant tissues and health of humans consuming those vegetables and water with high boron contents. High doses of boron are also known to cause atrophy and degeneration in testicles (Chapin and Ku 1994).

The dominant boron species in most natural waters is free BA (H_3BO_3) since the concentrations of transition metal and fluoride (that are the principal potential ligands for boron) are generally very low (Bassett 1980). Boron concentrations of surface waters usually vary between 10 g l^{-1} and 1000g l^{-1} (Wynesset al. 2003). Such variation comes from either natural factors (weathering of rocks and leaching of salt deposits) or anthropogenic factors (waste from glass manufacture, effluents from plants manufacturing insulation products and use of boron-containing fertilizers) (Neal et al. 1998). The determination of boron concentration is a significant issue in food industry and health care products (where it is used as a preservative), metallurgy, electronics, glass manufacture and the nuclear industry (Kumar et al. 1999). It is important to know the distribution of boron between the solid and the liquid phases of soil. Factors affecting the amount of boron adsorbed by soils and the boron bioavailability in soils include soil pH, texture, moisture, temperature, and management practices (Evans and Sparks 1983). While boron supply mechanisms to plant roots primarily include mass flow, distribution in plants is commonly governed by the transpiration stream through the xylem (Raven 1980). Boron is relatively immobile in plant, and thus its availability is essential at all stages of growth, especially during fruit/seed development. However, recent physiological studies have revealed the presence of channel-mediated facilitated diffusion and energy-dependent active transport against concentration gradients in boron transport systems (Dannelet al. 2000, 2001; Stangouliset al. 2001; Ahmad et al. 2012).

In present study, irrigation waters with different boron concentrations were used to investigate the effects of boron doses on growth parameters of basil; and possible measures to be taken against boron toxicity and soil pollution were provided.

2. Material and Methods

Basil seeds to be used in boron experiments were supplied from nursery of perennial medicinal plants at Agricultural Structures and Irrigation Department of Ankara University Agricultural Faculty in 2008. The seeds were sown in viols in a greenhouse and after about 4 week, germinated seedlings were transplanted to 15 pots having 30 cm diameter and 25 cm depth containing clay-loam soils (electrical conductivity = 0.670 dS m^{-1} and pH = 7.8). Five boron levels were applied in randomized plot design with tree replicaitonsfor each level. Boron levels of 0, 1, 2, 4 and 8 ppm were maintained in the root zone.

Since free drainage conditions are valid for all pots, before to initiate irrigation treatments, all pots were saturated with control treatment water. When the water discharge stopped, the pots were assumed to reach field capacity. Then, irrigation treatments were initiated.

Class-A pan was placed into the greenhouse to determine the amount of irrigation water to be applied in each irrigation. Irrigations were performed in every 3 days. As the amount of irrigation water, 3-day cumulative evaporation plus 20% leaching water was applied. Throughout the growing season, a total of 380.4 mm irrigation water including leaching water was applied to each pot.

Experiments were terminated after the second harvest. Beside anion-cation content of soil, plant Na, Ca, Mg, K, P, N, B and Cl ion contents were determined. Among the plant morphological characteristics, plant fresh weights and heights were also investigated.

Experimental data were subjected to analysis of variance (ANOVA) and significant differences between the means were compared by Tukey Multiple Range Test using JUMP statistical software.

3. Results and Discussion

Effects of Boron on Soil Properties

Soil characteristics are provided in Table 1. Significant changes were observed in soil anion and cation contents with different boron containing irrigation waters together with leaching water. However, the changes in CEC (cation exchange capacity) with relevant treatments were not found to be significant at $p<0.05$ level. The other characteristics (EC, pH, ESP, Na, Ca, Mg, K, B, HCO_3, Cl and SO_4) were also found to be significant.

Table 1. Variation in some soil characteristics
Çizelge 1. *Bazı toprak özelliklerindeki değişim*

Parameter	Unit	Control	Boron Levels (ppm)			
			1	2	4	8
EC	dS m^{-1}	0.80 d	0.81 d	0.92 c	1.25 b	1.55 a
pH		7.61 b	7.76 ab	7.78 ab	7.82 a	7.90 a
CEC	me 100 g^{-1}	33.0	33.3	33.1	33.4	34.3
ESP		8.00 e	7.25 d	6.74 c	5.63 b	4.20 a
Na	me l^{-1}	12.7 a	9.92 b	8.42 c	6.42 d	4.3 e
Ca	me l^{-1}	30.8 a	16.9 c	14.6 c	9.08 d	5.4 e
Mg	me l^{-1}	12.4 a	9.8 b	9.53 b	8.82 b	6.6 c
K	me l^{-1}	9.25 a	8.08 b	7.33 c	6.25 d	4.9 e
%Ca		67.9 a	67.8 a	66.1 ab	65.9 ab	63.0 b
%Mg		13.2 a	12.5 a	9.6 ab	7.75 b	8.1 b
CO_3	me l^{-1}	-	-	-	-	-
HCO_3	me l^{-1}	6.64 a	6.4 a	5.07 b	5.01 bc	4.9 c
Cl	me l^{-1}	24.1 a	16.0 b	13.7 c	9.57 d	7.8 e
SO_4	me l^{-1}	31.8 a	24.9 b	20.4 c	16.7 d	8.5 e
Boron	ppm	0.10 e	0.36 d	0.84 c	1.76 b	3.30 a

Parallel to increasing boron concentrations of irrigation waters, EC values of the soils also increased. Such increases were found to be significant at $p<0.05$ level. While the greatest value was observed in 8 ppm boron treatment with 1.55 dS m^{-1}, the lowest value was observed in the control treatment with 0.80 dSm^{-1}. EC value of 1 ppm treatment was relatively close to EC value of the control treatment. The reason for such close values was because of fertilizer effect and plant uptake of boron. However, EC values rapidly increased at boron concentrations equal and above 2 ppm.

Increase in soil pH with increasing boron concentrations of the irrigation water was significant at $p<0.05$ level. Additional 20% leaching water relatively decreased the rate of increase in pH levels. Increased pH levels also slightly increased plant boron uptakes. Besides, leaching water and amendments were used to detoxify B accumulated in soils.

The changes observed in sodium content and ESP of soils were also found to be significant at $p<0.05$ level. While the highest Na content was observed in control treatment with 12.7 mel^{-1}, the lowest value was observed in 8 ppm boron treatment with 4.3 mel^{-1}. Such a decrease resulted from the leaching water added to irrigation water. There is a linear relationship between Na ions and ESP values of soils. Thus, the highest ESP value was observed in control treatment with 8.0 and the lowest value was observed in 8 ppm boron treatment with 4.2.

Besides improving soil physical characteristics, Ca and Mg also balance soil reaction and thus influence plant nutrient uptake and provide proper environments for soil micro-fauna. Increasing boron concentrations in irrigation water resulted in decreases in Ca and Mg contents. Such decreases were found to be significant at $p<0.05$ level. While the lowest Ca and Mg contents were observed in 8 ppm boron treatment with 5.4 and 6.4 mel^{-1}, respectively, the highest values were observed in control treatments with 30.8 and 9.8 mel^{-1}, respectively. Similar phenomenon was also observed in %Ca and %Mg. Leaching is the primary reason of decrease in soil Ca and Mg contents.

The change in soil potassium (K) contents were also found to be significant at $p<0.05$ level. While the lowest K content was observed in 8 ppm boron treatment with 4.9 mel^{-1}, the highest value was observed in control treatment with 9.25 mel^{-1}.

Similar to cation values, increased boron concentrations of irrigation water and leaching water also resulted in similar changes in the anion contents of soils. The changes observed in HCO_3, Cl and SO_4 values were all found to be significant at $p<0.05$ level. While the highest values were observed in control treatments with 6.64, 24.1 and 31.8 mel^{-1} respectively, the lowest values were observed in 8 ppm boron treatments with 4.9, 7.8 and 8.5 mel^{-1} respectively.

Soil boron concentration increased with increasing boron concentrations of irrigation water. Such an increase was also found to be significant at $p<0.05$ level. While the lowest boron content was observed in control treatment with 0.1 ppm, the highest value was observed in 8 ppm boron treatment with 3.3 ppm. The low level of boron accumulation in soil despite 8 ppm irrigation water boron content was because of leaching water applied together with irrigations.

Effects of Baron Stress on Plant Physiology

In present study, boron toxicity was not observed in plant physiology (Table 2). Different boron concentrations had different impacts on plant fresh weights (Figure 1) and plant heights (Figure 2). The differences in these parameters of treatments were found to be significant (Table 2). At the first harvest, both the fresh weight (89.5 $gpot^{-1}$) and plant height (44 cm) had the highest values in 1 ppm boron treatment. These highest values were resulted from fertilizer impact of that dose.

Table 2. Plant phsiological characteristics
Çizelge 2. *Bitki fizyolojik özellikleri*

Prameter	Control	Boron Levels (ppm)			
		1	2	4	8
1HFW (g pot^{-1})	54.5 ab	89.5 a	63.5 ab	55.5 ab	44.0 b
2HFW (g pot^{-1})	43.0 b	46.5 ab	50.5 ab	49.0 ab	59.0 a
1HPH (cm)	40.3 ab	44.0 a	37.8 ab	37.0 ab	32.5 b
2HPH (cm)	35.5	33.8	33.5	31.8	34.0

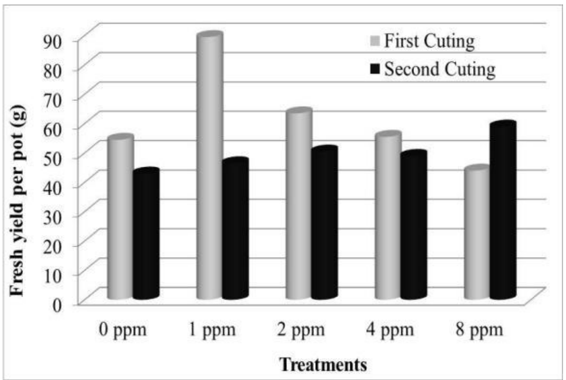

Figure 1. Effect of treatments on fresh yield per pot
Şekil 1. *Uygulamaların saksı başına bitki yaş ağırlığına etkisi*

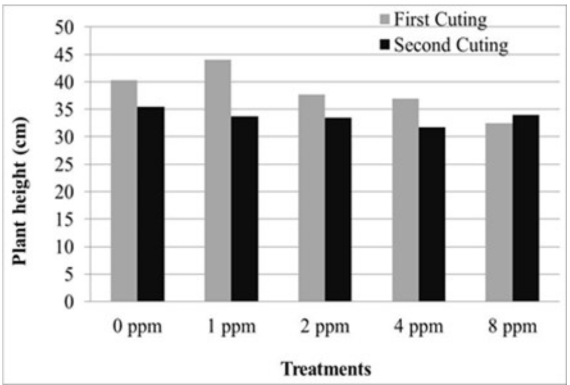

Figure 2. Effect of treatments on plant height
Şekil 2. *Uygulamaların bitki boyuna etkisi*

Effects of boron treatments were more distinctive at the second harvest. While the yield per pot was 43 g in control treatment, the value was observed as 47 g in 1 ppm, 49 g in 2 ppm, 51 g in 4 ppm and ultimately reached to 59 g in 8 ppm treatments. Despite the decrease in plant fresh weights at the second harvest, boron treated plants had higher fresh weights than the control plants. While the plant heights varied between 33 and 44 cm at the first harvest, the values varied between 32 and 36 cm at the second harvest (Figure 2). As it was in plant fresh weight, plant heights also decreased in all treatments. Under normal conditions, plant heights shorten and fresh weights decrease when they are exposed to boron toxicity.

Plant salt contents

Different boron concentrations of irrigation water resulted in significant changes in plant calcium and magnesium contents at $p<0.05$ level. The highest Ca (0.87%) and Mg (0.68%) contents were observed in 1 ppm boron treatment. However, decreases were observed in both element contents after 1 ppm dose. Over 1 ppm, while the Ca content of treatments was higher than the control treatment, the case was relatively different for Mg. Following 1 ppm treatment dose, Mg content of the plants started to decrease and ultimately reached to 0.12% in 8 ppm treatment.

Different boron concentrations increased nitrogen, potassium and phosphorus concentrations of the plants. While the increases in nitrogen and potassium contents were not found to be significant at $p<0.05$ level, the increase in phosphorus content was found to be significant. While the lowest nitrogen content was observed in control treatment with 0.21%, the highest value was observed in 8 ppm treatment with 0.27%. Similarly, while the lowest potassium content was observed in control treatment with 2.65%, the highest value was observed in 8 ppm treatment with 3.10%. Again, the lowest phosphorus content was observed in control treatment with 0.44%, the highest value was observed in 8 ppm treatment with 0.75%. However, phosphorus contents of 4 and 8 ppm treatments were relatively close to each other (Table 3). Such a finding indicated that the synergic effect decreased after 4 ppm threshold level and toxic effect might be seen after 8 ppm level.

There were non-distinctive changes in Na and Cl contents which were not found to be significant at $p<0.05$ level. However, the case is relatively different for boron. Significant increases were observed in plant boron concentrations with increasing boron concentrations of irrigation water ($p<0.05$). While the control treatment had boron concentration of 0.93%, 8 ppm treatment had a boron concentration of 5.8%. The relationship between B and Na contents of soils indicated a trend for B accumulation with increasing soil alkalinity (Aydın et al. 2012). As B adsorption of soils is pH-dependent (Keren and Bingham 1985), liming some soils to increase the pH and thus promoting adsorption of B from soil solution may provide a short term solution (Bartlett and Picarelli 1973).

Table 3. Salts in plants
Tablo 3. *Bitki bünyesinde bulunan tuz mineralleri*

Element (%)	Control	Boron Levels (ppm)			
		1	2	4	8
Ca	0.40 e	0.87 a	0.80 b	0.73 c	0.60 d
Mg	0.40 b	0.68 a	0.48 b	0.21 c	0.12 d
Na	0.04	0.03	0.03	0.03	0.04
K	2.65	2.98	3.02	3.07	3.10
N	0.21	0.22	0.23	0.24	0.27
P	0.44 d	0.48 c	0.58 b	0.74 a	0.75 a
B	0.93 e	1.31 d	2.17 c	3.25 b	5.80 a
Cl	0.21	0.23	0.21	0.20	0.23

Ca content of soil directly affects boron uptake of plants. In alkaline soils, the B hazard can be ameliorated by the addition of gypsum, which improves water infiltration and converts readily soluble Na-metaborate to less soluble Ca-metaborate (Bhumbla and Ckhabra 1982). Heavy applications of $Ca(H_2PO_4)^2$ also lower plant available B, especially in acid soils (Nable et al. 1997).

There is a synergic relationship between boron and potassium (Sakal 1988). Therefore, potassium contents of soils were influenced by boron treatments.

Boron is also an essential micro nutrient for plants. Worldwide, boron deficiency is more extensive than the deficiency of any other plant micro nutrients (Gupta 1979; Reisenauer et al. 1973). Adequate boron nutrition is critical not only for high yields but also for high quality of crops. Boron deficiency causes many anatomic, physiologic, and biochemical changes, most of which represent secondary effects. Because of rapid and variety of symptoms for boron deprivation, determining the primary function of boron in plants has been one of the greatest challenges in plant nutrition (Blevins and Lukaszewski 1998).

Despite 8 pmm boron concentration of irrigation water, clear boron toxicity was not observed in plants because of well-buffering of soil and leaching water added to irrigation water.

Boron concentrations of the present study did not result in toxicity in plants. In other words, current decreases in plant heights and fresh weights were not because of boron toxicity. The case is similar to plant responses under normal conditions. Telci et al. (2005) reported plant heights of some basic genotypes of Turkey as between 22.9 and 57.0 cm. Current plant heights comply with the values reported by Ceylan (1997); Erşahin (2006); Ekren et al. (2009).

Although boron is a highly mobile in soils, its mobility is relatively low in plants like Ca. Boron plays a role in plant tissue differentiation, root growth, carbohydrate mechanism and pollen germination. Plant available B in a specific soil is controlled by the physical and chemical properties of soils, such as pH, soil texture, clay mineralogy, organic matter, etc. (Goldberg 1993).

As it is well known, Ca and Mg play crucial roles in plants. While Ca provides supports in improving cell membrane and mechanical strength against various diseases, Mg mostly plays a role in photosynthesis and carbohydrate mechanism.

The present results revealed an antagonistic relationship between boron and Ca-Mg contents. Similar outcomes were also reported by Singh and Singh (1983); Fox (1968) and Chauhan and Power (1978). Lime stone treatments over soils rich in boron increased boron loss in soils through the synthesis of calcium boron complexes and increased soil permeability and resulted in a decrease in boron toxicity symptoms (Golakia and Patel 1988).

Nitrogen, phosphorus and potassium are macro nutrients and play significant roles in plant basic functions. There is a synergic relationship between boron and these three elements (Singh and Singh 1990; Patel and Golakia 1986; Gezgin and Hamurcu 2006). It was also previously reported that increased boron concentrations of irrigation waters increase plant boron concentrations (Smith et al. 2010).

4. Conclusion

Water-born boron problems are probably more frequent than soil-born boron problems. Boron exists in environment as borates and borosilicate minerals, such as borax associated with salt deposits in saline lakes, borate and aluminum borosilicate. Boron is commonly associated with saline hydrogeological conditions. Boron toxicity can affect nearly all crops but, like salinity, there is a wide range of tolerance among crops.

Recommended boron threshold values are the accumulation limits in soils and it is highly erroneous to associate them with irrigation water. The most remarkable issue in literature is the perception of such limit values as the limit values for irrigation waters.

In regions with irrigation waters containing high boron concentrations, boron-resistant species and genotypes should definitely be cultivated and boron up taking plants should be preferred. However, boron accumulation in soils should be monitored and relevant measures should be taken in case of long duration use of high-boron containing irrigation waters. The present results revealed that there was more than 3 ppm boron accumulation around the root region of plants irrigated with 8 ppm boron-containing irrigation water. Boron damage will be inevitable through the increase of such accumulation. Toxicity may not be observed in short-run. Therefore, irrigation waters up to 8 ppm boron concentrations may be used in basil irrigation together with sufficient leaching water for short durations. In long-run, cotton, asparagus, alfalfa, sun flower and sun choke-like boron resistant/up taking plants may be incorporated into crop rotation plans for sustainable culture. With such rotation plans, some of accumulated boron may also be removed from the soil.

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