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Boron affects the yield and quality of nonirrigated pistachio (*Pistacia vera* L.) trees

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Abstract: In Turkey, more than 95% of the pistachio (*Pistacia vera* L.) orchards are not irrigated. Therefore, a 4-year field trial was conducted to determine the effect of Tarımbor fertiliser (containing 18.5% boron [B]) on the yield, quality, and B content of two pistachio cultivars ('Uzun' and 'Siirt') planted under nonirrigated conditions. Tarımbor was applied to the pistachio trees as a soil application (0, 200, 400, and 600 g/tree) and a foliar spray (0%, 0.1%, 0.2%, and 0.3% w/v, using a tractor-mounted sprayer at the 'early bud break' stage and the 'fully leafed out' stage). Both the soil and foliar applications of Tarımbor had a significant effect on the pistachio yield, quality, and B content compared with the control. However, the foliar application resulted in greater improvements in the B content of leaves in both cultivars and the split nut ratio and kernel ratio in 'Uzun'. The greatest increases in yield were observed for the 0.3% foliar application for 'Uzun' (30%) and the 200 g/tree soil application for 'Siirt' (59%). In terms of quality, the application of Tarımbor appeared to have a greater effect on 'Uzun' than on 'Siirt'. No vegetative symptoms of B toxicity were observed in either cultivar when high concentrations of B were applied. Thus, Tarımbor could be used effectively as a foliar spray to enhance the B levels in the leaves of pistachio trees grown under nonirrigated conditions.

Key words: Boron, Tarımbor, pistachio, yield, quality

1. Introduction

The genus *Pistacia* is a member of the family Anacardiaceae and contains at least 11 species (Zohary, 1952), including *Pistacia vera* L., the cultivated pistachio. Pistachios have been grown in Turkey for over 1000 years, and the country has one of the largest pistachio germplasm collections in the world (Kaşka, 1990). Turkey is also the third highest producer of pistachios in the world, after Iran and the USA (FAO, 2015). Currently, over 95% of the pistachio orchards in Turkey are grown under rainfed (i.e. nonirrigated) conditions.

Boron (B) is an essential element for plant growth, and so must be available in sufficient quantities for optimal plant growth and productivity. In pistachio, B plays an important role in flowering and fruit set (Brown et al., 1995), with B deficiency being linked to low pollen viability, poor pollen germination, and low pollen tube growth (Nyomora et al., 1997). B also has an important function in the fertilisation of flowering plants, being involved in pollen germination and pollen tube formation.

In the soil, B is moved by passive absorption and transported via water flow (Raven, 1980; Hu and Brown, 1994; Pfeffer et al., 1997). Investigations into the distribution pattern of B in the shoots and the translocation of isotopically enriched ^{10}B in six tree species showed that B is freely mobile in sorbitol-rich species but largely immobile in sorbitol-poor species such as fig (*Ficus carica* L.), pistachio, and walnut (*Juglans regia* L.) (Brown and Hu, 1996). In tree crops, B deficiency often occurs during the reproductive phase, which can result in premature flower and fruitlet drop (Shelp et al., 1995; Brown et al., 1996). This sensitivity of the reproductive structures to B deficiency indicates that either there is restricted movement of B into the floral parts or that the B requirement for floral development is higher than that required for vegetative growth.

It has long been known that the yield of perennial tree crops can be enhanced by foliar applications of B (Nyomora et al., 1999). For example, B application has been shown to increase fruit set and yield in several fruit and nut crops, including almond, hazelnut, plum, and sour cherry, even when the trees showed no obvious symptoms of B deficiency in their vegetation. Therefore, it is evident that the reproductive process has a specific requirement for B (Perica et al., 2001). The presence of adequate B in the generative organs of fruit trees is necessary in terms

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of productivity, and the exogenous application of B has been shown to increase the yield in fruit species such as almond, olive, and apple, despite there being no sign of B deficiency (Balcı and Çağlar, 2002). B also has an effect on in vivo and in vitro pollen germination and growth (Blevins and Lukaszewski, 1998). For example, Acar et al. (2010) showed that the addition of 100 ppm boric acid to the germination medium significantly increased pollen germination in five different male pistachio cultivars.

The uptake of B by the plant in the soil solution is affected by the pH, texture, moisture content, temperature, and organic matter content of the soil (Güneş et al., 2002). Over the last 60 years, B deficiency has been reported in over 80 countries and for 132 different crop species (Shorrocks, 1997). Turkey has the largest B reserves in the world, with 66% of the total reserves being found here, and Tarımbor fertiliser, which contains 18.5% B, was developed by the National Boron Research Institute (BOREN) in Turkey.

Pistachio has a deep and strong root system. It can be grown in all types of soils, but prefers relatively deep, light soils with a high lime content (pH 7.0–8.0), and it is sensitive to soil salinity (Tekin et al., 1985). Approximately 85.5% of Turkey's soils have a high pH, 56.4% contain excess lime, 61.9% have a heavy structure (clay loam–clay) and 94% contain insufficient organic matter. The presence of free calcium (Ca) ions in soils that are alkaline and have a high lime content and low levels of B in the growth environment, the application of high-dose nitrogen (N) fertilisers, and drought stress have a greater effect on the availability of B than other microelements, and thus reduce the intake of B by plants. The availability of B in the soil is also coupled with the amount of organic matter, with soils containing more organic matter usually also containing more B (Kacar and Katkat, 2007).

The application of supplemental B during the late dormant stage increases germination, reduces blanking and nonsplits, and increases the yield in pistachio trees (Brown et al., 1995). Foliar applications are the most effective method to ensure that the flowers receive adequate amounts of B. Soil applications of B are also effective for increasing the levels of B in the leaves, but are not as effective as foliar sprays at increasing yield under irrigated conditions (Brown, 1995). The aim of the present study was to investigate the effect of soil and foliar applications of B on the yield and quality characteristics of pistachio under rainfed (nonirrigated) conditions.

2. Materials and methods

2.1. Experimental location

A 4-year field trial was conducted at the Pistachio Research Institute in Gaziantep Province, Turkey. This site is 840 m above sea level and receives a long-term average rainfall of 550 mm, a large portion of which falls in winter and early spring, with no rainfall during the summer. The experimental orchard was located at Dr. Ahmet Münir Bilgen Research Station, 25 km away from the Research Institute. The soil characteristics of the experimental orchard are as follows: clay soil, slightly alkaline, unsalted, lime-rich, low in organic matter; available B content is low; K, Ca, and Mg are high; available P, Fe, Zn, Mn, and Cu contents are satisfactory.

2.2. Plant materials, treatments and sampling

An experiment was conducted from 2008 to 2011 using two cultivars of 30-year-old pistachio trees: 'Uzun' and 'Siirt'. These trees were grown under nonirrigated conditions at a planting density of 208 trees/ha. Trees were selected on the basis of their uniformity of growth and fruit yield.

Tarımbor fertiliser, containing 18.5% B, was applied to the pistachio trees as a soil or foliar application during the 4-year period. The soil application of Tarımbor was conducted in January of each year at four doses (0, 200, 400, and 600 g/tree), alongside the addition of macro- and micronutrient fertilisers, and farmyard manure to a soil depth of 20 cm beneath the edge of the canopy. In contrast, the foliar application of B (0%, 0.1%, 0.2%, and 0.3% w/v Tarımbor in water) was conducted twice per year (once in February at the 'early bud break' stage and again in May at the 'fully leafed out' stage) using a tractor-mounted sprayer. Treatments were completely randomised, with three replicates per treatment.

Soil samples were taken from a depth of 0–30 cm and 30–60 cm beneath the canopy, and leaf samples were collected at the beginning of maturity (Tekin et al., 1986). Samples from each cultivar were analysed for the B concentration in the leaves, yield, and nut quality characteristics in the Pistachio Research Institute laboratory.

2.3. Yield measurements

Mature nuts of the 'Uzun' and 'Siirt' cultivars were hand-harvested in mid-September and late September, respectively, and fresh yield was measured in the orchard using a scale. A 1-kg sample of fresh nuts from each tree was left to dry for 5–6 days, allowing the fresh yield of each tree to be converted to dry yield (kg dry nut weight per tree) using the dry/fresh weight ratio of the nut samples.

2.4. Nut quality measurements

The following nut quality characteristics were analysed: 100 dry fruit weight (g), split nut ratio (%), and kernel ratio (%, kernel dry weight/nut dry weight × 100).

2.5. Boron analysis

Leaf samples from the mid-shoot of each tree were collected at the end of July (the beginning of maturation) in each year. The leaves were washed for 1 min in deionised water, dried at 65 °C for 48 h, and analysed for B concentration using the azomethine-H method with spectrophotometry (Wolf, 1971).

2.6. Statistical analyses

Statistical analyses were performed using Minitab, release 11.12 (Minitab Inc.). Duncan's multiple range test was used to test for significant differences between the means, using a significance level of $P \leq 0.05$.

3. Results

3.1. Concentration of boron in the leaf tissues

The concentrations of B in the leaves of the two pistachio cultivars 'Uzun' and 'Siirt' in response to different levels of soil and foliar Tarımbor fertiliser are provided in Table 1. Trees that were treated with Tarımbor had significantly higher concentrations of B in their leaves than control trees that received no fertiliser, with the foliar spray being more effective than the soil application. The lowest average B contents of the leaves in control trees were 77.03 and 90.72 mg kg^{-1} for 'Uzun' and 'Siirt', respectively, which increased to 127.40 and 134.39 mg kg^{-1} following 0.3% and 0.2% foliar Tarımbor applications, respectively (Table 1).

Previous studies have also shown that the concentrations of B in the leaves of pistachio, almond, and walnut trees are higher following the foliar application of B (Brown et al., 1995, 1996; Keshavarz et al., 2011). Similarly, based on a 2-year field experiment investigating the effects of foliar B on two almond varieties, Kızıldemir et al. (2013) reported an increased concentration of B in the leaves of both cultivars in both years. In our study, both soil and foliar applications increased the concentration of B in the leaves above the critical value (100–150 ppm) in 'Siirt', while 0.2% and 0.3% foliar applications increased the concentration of B in the leaves above 100 ppm in 'Uzun'. A significant correlation was also determined between the concentration of B in the leaves and the concentration of the Tarımbor application for both cultivars (r = 0.9931 for 'Uzun' and r = 0.9226 for 'Siirt').

3.2. Pistachio yield

Pistachio yield was significantly enhanced by the addition of Tarımbor during each year (Table 2), with the foliar application having a significant effect on the yield of 'Uzun' and the soil application having a significant effect on the yield of 'Siirt'. For 'Uzun', the 0.3% foliar application of Tarımbor achieved the highest mean pistachio yield (10.87 kg/tree), which was 30% higher than untreated control trees (8.36 kg/tree). By contrast, for 'Siirt', the 200 g/tree soil application of Tarımbor achieved the highest mean pistachio yield (10.97 kg/tree), which was 59% higher than untreated trees (6.93 kg/tree).

In our study, the cultivar 'Uzun' had a higher yield than 'Siirt', which contrasts with the findings of several other studies that have shown that 'Siirt' has a higher yield than 'Uzun' (Arpacı et al., 1995; Açar et al., 2005, 2011). The yield of 'Uzun' was correlated with the concentration of the Tarımbor application (r = 0.9257), but no such correlation was observed for 'Siirt' (r = 0.0490).

3.3. Nut quality characteristics

The quality of the pistachio nuts was determined by measuring the 100 nut weight, split nut ratio, and kernel ratio. The two pistachio cultivars used in our study had different responses to the Tarımbor applications, with 'Uzun' being more responsive than 'Siirt' in terms of both yield and quality characteristics. The application of Tarımbor had no significant effect on any of the quality characteristics of 'Siirt' or the 100 nut weight of 'Uzun' (Table 3). However, larger nuts were obtained from 'Uzun' following a soil application of 600 g/tree and from 'Siirt' following a foliar application of 0.3%. The split nut ratio is an important quality characteristic for pistachio. For 'Uzun', a 0.3% foliar application of Tarımbor produced the highest split nut ratio (64.9%) and kernel ratio (44.5%). These findings match those previously recorded in cultivars of sweet cherry (Usenik and Stampar, 2007), almond (Nyomora et al., 1997, 2000), Brussels sprout (Turan et al., 2009), lucerne (Turan et al., 2010), tomato (Dursun et al., 2010), and strawberry (Esringü et al., 2011).

4. Discussion

Foliar and soil applications of B have been shown to benefit pistachio trees under nonirrigated conditions (present study) and irrigated conditions (Weinbaum et al., 1994 Brown, 1995; Brown et al., 1995). B has a unique role in pistachio trees, and foliar applications of B have been shown to increase pollen viability, pollen germination, fruit

Table 1. Leaf B concentration of 'Uzun' and 'Siirt' pistachio in response to Tarımbor application averaged over 4 years (mg kg^{-1}).

Cultivar	Foliar application				Soil application			$LSD_{5\%}$
	0	0.1%	0.2%	0.3%	200 g	400 g	600 g	
Uzun	77.03 d*	89.88 c	105.80b	127.40 a	77.81 d	86.28 cd	81.73 cd	10.98
Siirt	90.72 d	100.08 cd	134.39 a	132.29 a	111.59 b	107.80 bc	107.96 bc	10.12

*The letters following the numbers indicate different groups determined by Duncan's test ($P \leq 0.05$).

Table 2. Effects of Tarımbor fertilizer on yield of 'Uzun' and 'Siirt' pistachio cultivars.

Cultivar	Application	Boron rate (per tree)	Yield kg/tree				
			2008	2009	2010	2011	Mean
Uzun	Control	0	16.23 abc*	6.90 b	9.63 d	0.66 ab	8.36 b
	Foliar application	0.1%	17.03 abc	2.23 d	14.97 ab	0.56 abc	8.70 b
		0.2%	19.00 a	2.97 cd	13.80 bc	0.88 a	9.16 b
		0.3%	19.13 a	8.53 a	15.80 a	0.00 d	10.87 a
	Soil application	200 g	18.03 ab	1.33 e	12.67 c	0.44 bc	8.12 b
		400 g	14.00 c	6.20 b	10.33 d	0.28 cd	7.70 b
		600 g	14.67 bc	3.43 c	12.53 c	0.68 ab	7.83 b
$LSD_{5\%}$			3.37	0.77	1.33	0.32	1.32
Siirt	Control	0	2.73 cd	11.37 ab	6.48 c	7.14 b	6.93 b
	Foliar application	0.1%	3.93 c	10.70 bc	4.42 d	6.65 b	6.43 b
		0.2%	2.23 d	10.17 c	3.03 e	6.77 b	5.55 b
		0.3%	6.57 b	8.33 d	9.91 b	4.47 c	7.32 b
	Soil application	200 g	10.77 a	10.33 bc	13.84 a	8.95 a	10.97 a
		400 g	2.10 d	11.90 a	4.14 de	6.56 b	6.18 b
		600 g	6.67 b	11.17 abc	5.45 cd	6.77 b	7.52 b
$LSD_{5\%}$			1.22	1.08	1.34	1.73	1.79

*The letters following the numbers indicate different groups determined by Duncan's test (P ≤ 0.05).

Table 3. Effects of Tarımbor fertilizer on nut characteristics of 'Uzun' and 'Siirt' pistachio cultivars averaged over 4 years.

Cultivar	Application	Boron rate (per tree)	Nut quality characteristics		
			100 nut weight (g)	Split nut ratio (%)	Kernel ratio (%)
Uzun	Control	0	104.03	52.7 bc	42.6 abc
	Foliar application	0.1%	104.99	41.2 d	42.8 ab
		0.2%	109.00	58.6 ab	41.7 bc
		0.3%	106.68	64.9 a	44.5 a
	Soil application	200 g	101.37	44.2 d	41.3 bc
		400 g	105.85	47.5 cd	40.5 c
		600 g	109.55	53.4 bc	41.9 bc
$LSD_{5\%}$			NS	7.12	1.90
Siirt	Control	0	122.74	82.8	43.1
	Foliar application	0.1%	126.67	79.7	42.5
		0.2%	127.99	78.0	43.3
		0.3%	129.29	79.8	42.5
	Soil application	200 g	126.85	79.7	42.2
		400 g	123.91	80.4	43.4
		600 g	124.70	81.1	43.4
$LSD_{5\%}$			NS	NS	NS

*The letters following the numbers indicate different groups determined by Duncan's test (P ≤ 0.05).

set, yield, and the concentration of B in the leaves, and to reduce the number of blank nuts. However, the timing of the foliar application is critical, with late dormancy being the most effective time for treatment. In contrast, later treatments still effectively increase the concentration of B in the plant tissues, but may not increase the fruit yield or quality for the current year (Brown, 1995). This difference is due to the uptake of passively absorbed nutrients such as B being influenced not only by their concentration in the soil solution, but also by the transpirational flux rate of the plant (Barber, 1984; Güneş et al., 2002; Marschner, 2011). Recently absorbed B is sequestered in the plant roots and then redistributed to other parts of the tree at a later date. The transpiration rate is greater in off-year pistachio trees than in on-year trees due to off-year trees having a 43% larger transpiring leaf surface area than on-year trees (Weinbaum et al., 1994).

In pistachio, a B concentration of 100–150 ppm in the leaves in mid-summer (July) is critical for seed yield (Tekin et al., 1985; Brown et al., 1992). In our study, the average concentration of B in the leaves of untreated (control) trees was 77 ppm in 'Uzun' and 91 ppm in 'Siirt', which was below the critical B level. However, these levels increased in proportion to the amount of Tarımbor applied (for both foliar and soil applications) for both cultivars. According to Brown et al. (1995), foliar application is the most effective method for providing sufficient B for flowers and is also more effective than soil application for increasing the concentration of B in the leaves. However, in our study, both applications increased the concentration of B in the leaves above the critical level.

The yield of our cultivars was also affected by foliar application in 'Uzun' and by soil application in 'Siirt'. Tarimbor applications increased yield significantly, with the increase about 30% with 0.3% foliar application for 'Uzun' and 59% with 200 g/tree soil application for 'Siirt' as the highest value (Table 2). Nyomora et al. (1999) found that crops have a variable response to B, with no clear relationship between the concentration of B in the plant tissues and the yield response. B is an essential element for the growth and development of healthy plants, but the way in which B is applied is also important. Several previous studies have shown that a soil application of B is not as effective for increasing the yield as a foliar treatment (Brown et al., 1995; Wojcik et al., 1998; Ganie et al., 2013). By contrast, our study showed that both soil and foliar applications of B were equally important for improving the pistachio yield across the two cultivars investigated.

The increase in yield that was experienced as a result of the foliar application of B likely results from increased pollen viability and germination (Lee et al., 2009; Keshavarz et al., 2011), which increase fruit set and the final marketable yield (Perica et al., 2001; Usenik and Stampar, 2002; Silva et al., 2003; Wojcik and Wojcik, 2006). Kızıldemir et al. (2013) documented increased pollen viability and pollen germination, and improved fruit set following the foliar application of B to almond trees, and, similarly, Keshavarz et al. (2011) reported a significant increase in walnut yield when a foliar spray of B was applied either alone or in combination with zinc. Fruit set and yield increases following the application of B have also been reported for several other fruit and nut crops, including almond (Nyomora et al., 1997, 1999), hazelnut (Baron, 1973), Italian plum (Chaplin et al., 1977), pistachio (Brown et al., 1995), and sour cherry (Hanson, 1991).

Nut size, splitting ratio, and kernel ratio are very important quality characteristics for pistachio nuts. In terms of nut quality, the two cultivars differed in their responses to Tarımbor, with 'Uzun' being more responsive than 'Siirt' for all characteristics. The application of Tarımbor did not have a significant effect on nut size in either cultivar. However, in 'Uzun', the 0.3% foliar application was found to have the greatest effect on the split nut and kernel ratios, while this was not effective in 'Siirt' (Table 3). Nyomora et al. (1997) similarly reported that the 'Butte' cultivar of almond had a more significant yield response to the application of B than the 'Mono' cultivar, with applications of 245 or 490 ppm B increasing the yield of these cultivars by 53% and 4%, respectively. Thus, the response of trees to the application of B is affected by the timing of the application, plant species and variety, ecological conditions, yield, fruit size, and the interaction between B and other nutrients.

In the present study, we did not observe any vegetative symptoms of B toxicity in either pistachio cultivar following the application of high concentrations of B. Therefore, it can be concluded that foliar applications of Tarımbor can be used effectively to enhance the concentrations of B in the leaves of pistachio trees under nonirrigated conditions. However, adequate B nutrition is required to improve the yield, as well as some quality characteristics.

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