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Effect of soil application and foliar boron (Etidot-67) on hazelnut yield and kernel ratio

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ABSTRACT

In this study, the effect of boron fertilizations of foliar and soil was investigated on the quality of hazelnuts (*Corylus avellana* L.) in two provinces in Turkey between 2013 and 2014. The experimental trials were carried out in soil application (0.0, 3.0 and 6.0 g per Ocak) and foliar spraying (0 and 300 mg B L^{-1}). Results show that compared with the control, soil and foliar application of boron increased hazelnut yield and quality. Due to the two-year average, the highest yield of the hazelnut in Samsun-Çarşamba was obtained from the application and dose of 36.70% increase in hazelnut yield was achieved by applying B (3g $Ocak^{-1}$) from the soil in comparison with the control application. It was a 20% increase in Ordu-Ulubey district. The highest kernel ratio of hazelnut was obtained from F1S2 applications for the two districts. Increases were observed at Samsun-Çarşamba (10%) and Ordu-Ulubey (7%). Results showed that there was also a positive association between the B leaf concentration and hazelnut yield and kernel ratio and no significant differences between foliar and soil applications on hazelnut quality. As a result of this study, and with increasing yield, foliar applications of B are an effective method of supplying sufficient B for the flowers. In addition, B leaf applications are more appropriate than soil B application.

1. Introduction

The hazelnut (Corylus avellana L.) is a hard-shelled fruit that has been known to man for about 5000 years. It originated in the Black Sea area and spread to the world from there. The main nut producers in the world are Turkiye, Italy, the United States, and Spain. Turkiye's hazelnut production is still on going in 705,445 hectares of cultivable land, especially on the Black Sea Coast [1]. Although Turkiye is the largest producer of hazelnuts in the world and accounting for about 70% of the world's supply, its production performance is quite low compared to other countries. Low lime content of the soil, slope, shallow soil depth, low water holding capacity, and high clay content are the main reasons for low hazelnut yield. In addition, the lack of macro and micro-nutrients in the soil is another cause.

Boron is an essential micronutrient for plant growth and fruit production. It affects pollen germination and pollen tube growth [2]. Boron deficiency in soils has been reported in 80 countries and 132 plant species [3]. It was also reported that 85% of areas in hazelnut orchards are insufficiently supplied with boron [4]. In 2019, deficiency of boron (B) has been identified as a current problem for plant growth in the Black Sea region of Turkiye, as well. On the other hand, many researchers reported that the application of B increased fruit quality and yield in hazelnuts [5, 6, 7].

The main aim of the study was to research the effect of soil and foliar applications of boron on the yield and quality of hazelnuts and give information about B fertilization to hazelnut producers.

2. Materials and Methods

2.1. Experimental Location and Treatments

Experiments were conducted in two different locations, Samsun-Carsamba and Ordu-Ulubey in the eastern Black Sea region of Turkiye (31°64'98''N and 45°77'44.08''E, height: 5m and 39°77'78''N and 45°27'50.09''E height: 397 m) in 2013 and 2014. The experiments were established in the "Tombul" (Corylus avellana L.) hazelnut orchard, which consists of four stemmed 25-year-old bushes called "Ocak" (a multi-rooted planting system specific to Turkiye) and conducted in a completely randomized block with a factorial combination of 3, 2 treatments (soil and foliar doses),

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of which 5 were repeated. (N=b*s*l*r=3*3*2*5=90; b=number of blocks; s=number of soil borings; number of leaf borings; r=number of replicates).

Basal fertilization (nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O)) was performed according to the results of soil analysis and 20 kg N da^{-1} as calcium ammonium nitrate (26% N), 10 kg da^{-1} P_2O_5 as triple superphosphate ($3Ca(H_2PO_4)2$-H_2O (42-44% P_2O_5)), and 10 kg K_2O da^{-1} as potassium sulfate (K_2SO_4 (48-50% K_2O)) in two consecutive years.

In the experiments, Etidot-67 ($Na_2B_8O_{13}.4H_2O$) was used as the B source, containing 20.96% B, and was applied as soil and foliar additives to the hazelnut Ocaks during the two-year period. Soil application of B was made in February of each year at three doses (Control, S1=3.0, S2=6.0 B g ocak^{-1}) and foliar application of B (F1=300 mg B L^{-1}) was made three times per year (i: after harvest in October, ii: at the "before flowering" stage in March, and iii: during fruit set in May) using a sprayer. Treatments were randomized, with five replicates per treatment. Foliar applications were made early in the morning or before sunset, and foliar applications of the drone fertilizer were sprayed with more than 0.25% nonionic wetting agent (Tween-20).

Technical and cultural practices such as pruning, weed control, disease and pest control were carried out in hazelnut orchards in both locations where the trials were held.

2.2. Preparation of Leaf Samples

After boron application, leaf samples were taken every other year from the third or fourth branch of each tree at the onset of maturity. Leaves were washed in deionized water for 1 minute and stored in air for 24 hours. They were then dried at 65°C for 48 hours. And then, boron concentrations of the leaves were analyzed.

2.3. Analysis of Soils and Plants

Before the experiments were established, some physical and chemical analyzes of the orchard soils were determined. Soil texture analysis was performed according to the hydrometer method [8]. pH and EC values of the soil were measured in saturated extracts as described by Jackson [9], and $CaCO_3$ content of the soil was determined as described by Hızalan [10]. Soil organic matter was determined by the Walkley-Black method of Schlichting and Blume [11]. Available phosphorus (P) was determined according to the method of Bray and Kurtz [12]. Available potassium (K) was determined by AAS; Pratt [13]. Available concentrations of Fe, Cu, Zn, Mn, and were determined by DTPA extraction according to metod of Lindsay and Norvell [14]. B available in soil was extracted with hot water 0.01 M $CaCl_2$ for 5 min (1:2) in water bath (95ºC) and then filtered with Whatman No. 42 filter paper Measured by ICP-OES (Bingham F T; Boss and Fredeen) [15, 16]. The dried plant samples were then crushed and approximately 0.2 g of the samples was digested at 550ºC for 12 h to determined B concentration. The concentration of boron and other mineral elements in the leaves was determined by optical spectroscopy with inductively coupled plasma (ICP-OES - Perkin Elmer 2100V).

2.4. Measurements of the Yield

The hazelnut cultivation in the garden is carried out as an Ocak system and as a single body. The ocak system is a high bush cultivation system and is divided into single-rooted ocak and multi-rooted ocak. Multi-rooted ocak system is widely used in Turkiye and each ocak contains between 4-8 plants (branches) [17].

The planting system of the gardens selected for the experiment is 4x4m. Since there are 60 ocaks per decare area, the hazelnut yield (kg da^{-1}) in one ocak was calculated by multiplying the ... by 60. and expressed in kg da^{-1}. To ensure homogeneity in the experimental gardens, 4 branches were left in each ocak. Yield was calculated as kg da^{-1} over 4 branches in the ocaks.

Fruits were harvested by hand from four branches and fresh weights were determined. Then the nuts were separated from the husk by hand, dried at natural conditions (under sunlight) and the yield of the dried hazelnuts was determined.

2.5. Determination of Hazelnut Kernel Ratio (Quality)

Hazelnut quality characteristic (kernel ratio) were determined by analysing 100 randomly selected nuts. Three replicates of 100 nuts per treatment were used to calculate the percentage of empty and damaged nuts. And then kernel ratio percentages were calculated were calculated (See Eq. 1) [18, 19, 20]:

$$\text{kernel ratio (\%)} = \frac{\text{kernel weight (g)}}{\text{total nut weight (g)}} \times 100 \quad (1)$$

The Duncan multiple range test was used to determine further differences between groups. Significance was estimated at p<0.05 for all tests. Statistical analyses were performed using SPSS 22.0. (SPSS, Inc., Chicago, Ill.).

3. Results

Statistically significant increases in the amount of B usable in the soil were obtained based on the amounts of B applied in both years compared to the initial B concentration in the soil (Table 1).

After soil and foliar application, hazelnut leaves were highly statistically significant in the B concentration in both years compared to controls. B concentration in hazelnut leaves was (75, 69.0±14.0 mg kg^{-1}) in Samsun-Çarşamba location, (48.0±7.2, 50.1±7.0 mg kg^{-1}) in Ordu-Ulubey location in both years, when F1 dosage

Table 1. Physical and chemical properties of soil in hazelnut orchards.

Soil Properties	Location	
	Samsun-Çarşamba	Ordu-Ulubey
Texture	Clay	Clay
Soil PH	6.79	6.73
Salinity (dS.m^{-1})	0.02	0.08
$CaCO_3$ (%)	1.11	0.89
Orcanic matter (%)	1.13	2.71
Available phosporus (mg.kg^{-1})	2.0	5.0
Available potassium (mg.kg^{-1})	85	141
Available boron (mg.kg^{-1})	0.02	0.22

was applied. The B concentration of hazelnut leaf was 82.0±8.2, 99.0±14.0 mg kg^{-1} in Samsun-Çarşamba, and 37.0+5.1, 61.0+10.2 mg kg^{-1} in Ordu-Ulubey district when S1 was applied. In Samsun-Çarşamba (103.0±10.1, 119.0±19.7 mg kg^{-1}) and Ordu-Ulubey (54.0±8.0, 67.0±5.0 mg kg^{-1}) the results were obtained by applying F1+S1. After the application of S2, the B concentrations in hazelnut leaves were determined in Samsun-Çarşamba (84±7.1, 109.0±16.4 mg kg^{-1}) and Ordu-Ulubey (54.0±4.3, 95.0±15.1 mg kg^{-1}). Boron concentrations in hazelnut leaves were measured in Samsun-Çarşamba (149.0±9.1, 158.0±20.1 mg kg^{-1}) and Ordu-Ulubey (69.0±8.3, 90.0±9.1 mg kg^{-1}), after the treatment of soil by F1+S2 (Table 2).

There were statistically significant differences between B applications and hazelnut yield for both years and the two locations ($p<0.05$) (Table 3).

In the first year, hazelnut yield (94.5±7.8, 75.1±4.3, 79.9±2.7 kg da^{-1}) was observed in Samsun-Çarşamba by the applications of S1, F1, F1+S1. Hazelnut yield (76.5±2.1, 54.5±1.8 kg da^{-1}) was determined by the applications of S2, F1+S2. The lowest hazelnut yield was obtained with the control dose (67.1±5.1 kg da^{-1}). In the second year, hazelnut yields determined in Samsun-Çarşamba by the applications of S1, F1, F1+S1, S2 and F1+S2 were 124.9±6.3, 113.7±2.6, 117.8±5.3, 111.1±03.0, 94.9±2.0 kg da^{-1}, respectively. The lowest hazelnut yield was measured in control samples (92.5±4.2 kg da^{-1}).

In the first year, hazelnut yields determined in Ordu-Ulubey by the applications of S1, F1, F1+S1, S2 and F1+S2 were 20.3±1.9, 19.9±1.8, 17.5 ±1.5, 19.3±1.6 and 19.2±2.6 kg da^{-1}, respectively.The lowest hazelnut yield was obtained with the control dose (18.6±1.6 kg da^{-1}). In the second year, hazelnut yield in Ordu-Ulubey district (41.0±1.9, 35.5±1.8, 38.3±2.3 kg da^{-1}) was determined by applying S1, F1, and F1+S1. Hazelnut yield (36.1±1.8, 39.4±1.9 kg da^{-1}) was determined by the application of S2 and F1+S2. The lowest hazelnut yield was obtained with the control dose (32.5±2.7 kg da^{-1}).

The first year, kernel ratio in Samsun-Çarşamba district, was determined respectively (53.6, 51.7, and 52.5%) by applications of S1, F1, and F1+S1. It was hazelnut kernel ratio (51.2- 52.4%) determined by both applications of S2, and F1+S2. The lowest hazelnut kernel ratio was obtained with the control dose (48.0%). In the second year, the kernel quotient in Samsun-Çarşamba district was determined by the application of S1, F1, and F1+S1 (49.6-48.3-49.6%). The kernel ratio of hazelnuts was determined by the application of S2 and F1+S2 (51.4-51.8%). The lowest kernel ratio was obtained with the control dose (46.3%) (Table 4).

In 2013, with the applied dosages of S1, F1, F1+S1, S2 and F1+S2 the kernel ratios in Ordu-Ulubey district

Table 2. Effect of B (Etidot-67) fertilizer application on leaf B concentration (mg kg^{-1}).

Location		Control	F1	S1	F1+S1	S2	F1+S2
Samsun Çarşamba	Leaf $B_{(2013)}$	33.0 ±4.2d	75.0±10.2c	82.0±8.3c	103.0±10.1b	84.0±7.1c	149.0±9.1a
	Leaf $B_{(2014)}$	29.0±2.0d	69.0±14.0c	99.0±14.0b	119.0±19.7b	109.0±16.4b	158.0±20.1a
	Leaf B_{avg}	31.0±3.7d	72.0±12.1b	90.5±14.1c	111.0±18.0b	96.5±17.6c	153.5±15.5a
Ordu Ulubey	Leaf $B_{(2013)}$	25.0±4.2d	48.0±7.2b	37.0±5.1c	54.0±8.0b	54.0±15.1b	69.0±8.3a
	Leaf $B_{(2014)}$	23.0±2.1d	50.1±7.0c	61.0±10.2c	67.0±5.0b	95.0±15.1a	90.0±9.1a
	Leaf B_{avg}	24.0±3.3c	49.5±6.9b	49.0±14.7b	60.7±9.2b	74.5±24.0a	79.5±13.8a

Table 3. Effect of B (Etidot-67) fertilizer application on nut yield (kg da^{-1}).

Location		Control	F1	S1	F1+S1	S2	F1+S2
Samsun Çarşamba	$Yield_{(2013)}$	67.1±5.1c	75.1±4.3b	94.5±7.8a	79.9±2.7b	76.5±2.1b	54.5±1.8d
	$Yield_{(2014)}$	92.5±4.2d	113.7±2.6bc	124.9±6.3a	117.8±5.3b	111.1±3.0c	94.9±2.0d
	$Yield_{avg}$	80.2±13.7bc	94.8±20.2ab	109.7±16.9a	98.9±20.3a	93.8±18.4ab	74.7±21.42c
Ordu Ulubey	$Yield_{(2013)}$	18.6±1.6ab	19.9±1.8ab	20.3±1.9a	17.5±1.5b	19.3±1.6ab	19.2±2.6ab
	$Yield_{(2014)}$	32.5±2.7c	35.5±1.8b	41.0±1.9a	38.3±2.3ab	36.1±1.8b	39.4±1.9a
	$Yield_{avg}$	25.6±7.7	27.7±8.4	30.6±11.1	27.9±11.1	27.7±9.1	29.3±10.8

Table 4. Effect of B (Etidot-67) fertilizer application on Kernel ratio (%).

Location		Control	F1	S1	F1+S1	S2	F1+S2
Samsun Çarşamba	Kernel ratio$_{(2013)}$	48.5±4.8	51.7±2.8	53.6±6.1	52.5±2.3	51.2±2.2	52.4±3.3
	Kernel ratio$_{(2014)}$	46.3±3.2	48.3±5.5	49.6±3.1	49.6±7.9	51.4±5.9	51.8±1.2
	Kernel ratio$_{avg}$	47.4±4.0b	50.0±4.5a	51.7±5.0ab	51.0±5.7ab	51.3±4.2ab	52.1±2.4a
Ordu Ulubey	Kernel ratio$_{(2013)}$	49.5±2.1	51.6±2.8	51.9±2.9	51.4±3.1	51.8±1.9	51.2±2.6
	Kernel ratio$_{(2014)}$	47.6±1.6b	52.0±4.2a	51.9±3.5a	52.3±1.9a	52.0±2.9a	52.8±2.5a
	Kernel ratio$_{avg}$	48.5±2.0b	51.8±3.3a	51.9±3.1a	51.8±2.5a	51.9±2.4a	51.9±2.5a

was calculated as 51.9%, 51.6%, 51.4%, 51.8%, and 51.2%, respectively. The kernel ratio percentage was obtained with the control dose (49.5%). In 2014, with the applied dosages of S1, F1, F1+S1, S2 and F1+S2 the kernel ratios in Ordu-Ulubey district was calculated as 51.9%, 52.0%, 52.2%, 52.0%, and 52.8%, respectively. The lowest kernel ratio was obtained with the control dose (47.6%) (Table 4).

4. Discussion

Boron deficiency is the most common nutritional disorder and is easily washed out as $B(OH)_3$ in places with heavy rainfall. In regions with high annual precipitation, B deficiency occurs in sandy and highly decomposed, acidic soils by leaching. It has been reported that there is a decrease in flower formation in plants grown under B deficiency and metabolic damage in plants during vegetative growth [21]. Insufficient B supply in hard-shelled fruit production, may have a negative impact on yield and quality. A number of researchers have found that boron fertilization has a positive effect on yield by reducing cavity formation in nuts, almonds, and pistachios. For example, in walnut [22], almond [23, 24], and pistachio [25], B fertilization increased fruit set and more fruits were reported accordingly.

There are several studies on the positive effects of boron fertilizer applications on the yield and quality of hazelnuts. There are studies that find that fertilization with B generally reduces empty formation in hazelnuts and increases fruit set, leading to an increase in yield. For example, in one of the first studies on this topic by Okay et al. [26], vacant fruit formation was found to decrease by 41.5% when leaves were sprayed with 0.1% boric acid; Korkmaz et al. [27] found that dosage across leaves increased in the garden dominated by Palaz hazelnut cultivars. In the application of 0, 0.2 and 0.4% B, 0.2% dose increased the hazelnut yield and yield, and in Samsun Terme, 0-6-12-18-24 g B ocak^{-1} and 0.2% solubor application from the leaf, 12 g B ocak^{-1} application increased the hazelnut yield by 55.5%, and the application of 600 mg B L^{-1} over two years in the orchard with the hazelnut cultivar Barcelona by Shrestha et al. [28] increased the fruit set by 23% in the first year and 17% in the second year, respectively.

In the study conducted by Erdogan and Aygun [29], 300 and 600 mg kg^{-1} B were applied over the leaves to the hazelnut cultivar "Tombul" in the third week from January to May 1 over a period of two years. It was reported that leaf B content increased with increasing B application and fruit set was higher with 300 mg kg^{-1} B application than with 600 mg kg^{-1} B application in both years. In the study conducted by Tarakcıoglu et al. [30], 0-6-12 g B from Ocak^{-1} soil and 0-250-500-750 mg B L^{-1} were applied to leaves. According to the results, 6 g B ocak^{-1} from soil increased total wet weight, shell yield, kernel weight, and kernel weight compared to the control, and 500 mg L^{-1} B from leaves; it was found that total fresh weight, shell yield, shell weight, and kernel weight increased, and foliar application of B increased hazelnut yield and leaf B content.

The highest boron concentration in hazelnut leaves in Samsun-Çarşamba district was achieved by the application and dosage of F1+S2 in two-year average. According to the observations made during the trials, no toxic damage caused by boron to the leaves was observed. The boron concentration of hazelnut leaves was increased by 390% by the application of F1+S2 compared to the control application. In Ordu-Ulubey district, the highest boron concentration in hazelnut leaves was determined by the application and dose of F1+S2. Boron concentration in hazelnut leaves was increased by 231% by the application of F1+S2 compared to the control.

The study found that the yield and kernel ratio of hazelnuts were positively affected by the application of fertilizer B in hazelnuts from the soil and leaves compared to controls. According to the two-year average, the highest yield of hazelnut in Samsun-Çarşamba was obtained by the application and dosage of S1. Hazelnut yield was increased by 36.70% by the application of S1 compared to the control application. However, there were no significant differences between the doses of S1 and F1, F1+S1, S2 with yield. In Ordu-Ulubey district, also had not occurred a significant difference between the application and doses in the yield of hazelnut. However, the application of B increased the hazelnut yield by 20% compared to the control. Some authors indicated that fruit yield and quality of hazelnuts could be improved by the application of boron, while others found no effect [31, 32]. The application of boron had no significant effect in certain trials under Mediterranean conditions [31, 33, 34]. In contrast, foliar and soil application of B in hazelnuts has been shown to favour fruit quality and fruit set [32]. It was also reported that although 300 and 600 ppm B were sprayed only once on trees in Ocak, positive effects of B application on fruit set in Tombul were obtained and an annual increase was observed [6]. However, one study found that B-based treatments had significant effects on fruit set when tested in cooler spring climates such as Oregon. These results suggest that climatic conditions may be related on the translocation of boron [32]. As a result, cooler spring conditions should promote better utilization of this mineral and higher fruit production to support higher metabolic rates [35]. The beneficial effect depends on the average air temperature during flowering (June-July) and increases as temperatures drop. As a result of increased fruiting, nut yield increases [36]. According to TUIK [37], average hazelnut yields in Turkiye in 2013 and 2014 were 78 and 64 kg da^{-1}, respectively. These yield values correspond to an average of 8 to 10 branches of hazelnut ocaks in growers' orchards. Considering the fact that the yield values in our trials were determined on four branches, it was found that fertilization with B has a positive effect on yield.

This experiment with different boron applications on hazelnuts showed that there was a positive and very significant correlation ($p<0.001$, $r=0.433$) between leaf B concentration and yield in Ordu-Ulubey district ($p<0.001$). On the other hand, in Samsun-Çarşamba district, there was no significant correlation between leaf B concentration and yield.It is possible that climatic differences are responsible for this significance, and this result was also confirmed in other studies.

The two-year average hazelnut kernel ratio was statistically significant between the B applications and the control ($p<0.05$). The highest proportion of hazelnut kernels was obtained in F1+S2 applications in the two districts. These increases were found in Samsun-Çarşamba (10%) and Ordu-Ulubey (7%). There was also a positive correlation in Samsun ($p<0.05$, $r=0.296$), Ordu ($p<0.05$, $r=0.305$) between B leaf concentration and hazelnut kernel ratio. These correlations occurred at both district levels ($p<0.05$). The technical reports stated that the optimal B-leaf concentration for good fruit and hazelnut yield was between 25 and 30 mg kg^{-1} DW [38]. Soil and foliar applications were reported to have a considerable effect on yield, quality, and peanut content compared to controls, and foliar applications were reported to have significant increases in leaf B concentration and kernel to nut ratio [39]. Similar to our results, the kernel size of hazelnut cultivar 'Negret' was also reported to increase with boron application [7]. Similar results were reported in the literature [40, 41, 42, 43].

5. Conclusion

Foliar-B fertilization generally increases fruit set and yield in various fruit varieties. For this reason, foliar fertilization is usually applied to plants such as walnut, almond, hazelnut, etc. Our study showed that foliar fertilization statistically increased the yield and quality of hazelnut. Depending on the yield increase, foliar fertilization with B is an efficient method to provide sufficient B for the flowers. In addition, foliar fertilization of B is a more suitable method because it reduces the toxicity of boron as it does not mix with groundwater and does not enter the environment. It also shows that there are differences in yield and quality at two different locations where the study was conducted, and that the application of B to increase B concentration in leaves is related to different factors. Therefore, the timing and weather conditions are also important for foliar application. As a result, fertilization of crop products with B is necessary for high yield when the plant-available B concentration in the soil determined by hot water extraction is <0.5 mg B kg^{-1}. When hazelnut yield is in the range of 0.5-1.0 mg B kg^{-1}, fertilization with B may be recommended.

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