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Original Article

Effects of Applications of Boron with Iron and Zinc on the Contents of Pear Trees

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Abstract

Boron (B) is an essential microelement for plants, animals and humans. The present study was conducted to evaluate the effectiveness of various treatments for the correction of boron (B) with zinc (Zn) and iron (Fe) deficiencies in the pear cultivar 'Deveci' in the south eastern Marmara region of Turkey. This work consisted of 4 field experiments that primarily included control, soil and foliar applications of B alone and in combination with Zn and Fe. Soil and foliar applications of borax increased B concentrations in leaves and fruit. However, foliar treatment with B was more effective than the soil application. Foliar applications of boron four times each season appeared to be an appropriate treatment for maintaining a sufficient B level in pear trees. Foliar applications of double and triple combinations of $FeSO_4.7H_2O$ and $ZnSO_4.7H_2O$ with borax significantly increased Fe and Zn concentrations in the leaves, as well. Boron concentrations were dramatically higher in the fruit parts (flesh and peel) than in the leaves. These results clearly indicated the translocation of B from soil and treated leaves to the fruits. Therefore, the B concentration in the fruit was more useful for the evaluation of B levels in pear trees.

Keywords: application, fruit, leaf, pear, microelements, translocation

Introduction

Pears (*Pyrus communis* L.) have a very long history of cultivation in Turkey (Gerçekçioğlu *et al.*, 2008). World pear production reached 23.5 million tonnes in 2012. Turkey is the 5th largest producer in the world, annually producing 439.656 tonnes/year (FAO, 2014). The south eastern Marmara region of Turkey produces 25% of the total pear crops of Turkey (TUIK, 2014). The pear has economic and traditional importance among the crops grown in this region, which has the highest production value of pears in Turkey. Pear production in Turkey and in the Marmara region has been increasing each year with such cultivars as 'Deveci', 'Santa Maria' and 'Williams' (Öztürk, 2014).

Boron is assimilated by plants from the soil and passes through the human body via the food chain (Nielsen, 1997). Boron effects the function and composition of body systems such as brain, skeleton, and the immune system as well as energy metabolism (Velioğlu and Şimşek, 2003). Boron is an essential element for plants. It has significant roles in different metabolic functions that may impact tree yield and fruit quality (Marschner, 1995). The pear is considered to be a crop with a high requirement for B (Wojcik, 2003). If boron is not present in a sufficient amount, the flowers will die before the full bloom period. Consequently, the pear fruit are set, and the yield will be reduced (Sánchez, 2005).

Boron deficiency is one of the most common worldwide plant microelement deficiencies (Shorrocks, 1997; Freeman *et al.*, 2005; Rodrigues, 2012). Boron deficiency affects vegetative growth and reproductive processes, depending on the time and extent of the deficiency occurrence (Stellacci *et al.*, 2010). Boron deficiency can be readily prevented and corrected by both soil and foliar applications (Ganie *et al.*, 2013). A spray application of B to the leaves is more effective and economical in comparison with a soil application (Perica *et al.*, 2002; Wojcik and Wojcik, 2003; Hudina and Stampar, 2005; Yehia and Hassan, 2005). Foliar fertilization can influence nutritive competition between different metabolic sinks and control the growth and reproductive activities of fruit trees (Wojcik, 2004).

Microelements such as Fe, Zn and B are essential for different biological functions that may be responsible for tree yield and fruit quality (Shoeib, 2003; Asaad, 2014). Boron, Fe and Zn in pear groves are possibly the most important determinant elements for pears grown in calcareous or alkaline soils in the Mediterranean climate zone of Turkey (Başar, 2003; Álvarez-Fernández *et al.* 2004). Multiple microelement deficiencies are very common in the south-eastern Marmara region (Başar *et al.*, 2000; Başar, 2003; Turan *et al.*, 2013). The boron, Fe and Zn sprays are successful in combined applications and increase pear tree yields (Wojcik and Wojcik 2003; Yadav *et al.*, 2013; Mirabdulbaghı, 2014). The iron and Zn were applied in combinations with B to evaluate the effectiveness of single and combined applications of B with Fe and Zn. Therefore, this study was planned to provide a solution for other widespread

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microelement deficiencies in combination with B. The objectives of this study were to assess the comparative suitability of foliar versus soil B applications by considering dose and application frequency, to evaluate B applications, alone and in combination with other microelements, in overcoming multiple microelement deficiencies, to study the response of residual B effects from soil applied B in the following year and to determine the most descriptive plant part for the evaluation of the B level status of pear trees.

Materials and methods

The study was conducted from 2011 to 2015, in the south-eastern Marmara region, which is situated in northwest Turkey. The experiments were conducted individually in 4 commercial groves, including the towns of Gürsu (3) and Osmangazi (1) in Bursa, Turkey (Fig. 1). The geographical locations of the experimental sites are presented in Table 1. The study areas were evaluated in alluvial great soil groups according to the soil map of the Bursa province (Anonymous, 1995). The results of the soil chemical analysis are presented in Table 1. The experiments were set up in very uniform orchards with cv. 'Deveci' pear trees, the main cultivar in the region. Twenty-one healthy; uniform and regular pear bearing trees in the each grove were used in the experiments. The trees were treated with nearly the same fertilizer program and irrigation scheduling, with adjustment for tree size. The experiments were conducted in a completely randomized design with three replications. A minimum of two or three trees were placed between the experimental trees to prevent interaction of the applications during the spraying of the compounds. Each time the spray treatments were applied with an engine sprayer, until the complete moistening of the upper and lower leaf epidermis was achieved. The treatments were applied just before night fall.

For the treatment of foliar nutrition, the trees were sprayed with boron ($Na_2B_4O_7.10H_2O$), zinc ($ZnSO_4.7H_2O$) and iron ($FeSO_4.7H2O$). The experiments including the different B treatments were set up separately in 4 pear groves. Boron was applied alone and in combinations with Zn and Fe. For this purpose, a survey study was performed to individually evaluate the most appropriate pear grove for the experiments. The experiments were as follows: experiment I: borax single, experiment II: borax + Zn sulfate, experiment III: borax + Fe sulfate and experiment IV: borax + Zn sulfate + Fe sulfate deficiencies. The rest of the nutrients in the trees were adequate according to the sufficiency ranges indicated for pear trees.

The soil and foliar treatments were separately applied to the nutrient deficient trees to estimate the most effective application method for pears. The treatments mainly consisted of control, soil and foliar applications in each grove. In soil applications, 2 doses of compound(s) containing the deficient nutrient were only applied in the early spring of the first year of the experiment to estimate the residual effect in the following year. Foliar applications were sprayed onto the leaves twice and four times at two rates in the consecutive years. Treatments and application rates for each experiment are presented in Table 2.

In each orchard, the soil samples from 0-30 cm and 30-60 cm deep were collected to form a compound sample (Kacar, 2009) in the dormancy period of the trees in winter, and prepared for subsequent analyses (Chapman and Pratt, 1961). The leaf samples that were expanded to full size and had petioles were taken from the mid-part of annual shoots located on different sides of the middle section of the canopy in each grove (Kacar and Inal, 2008), after the foliar applied nutrients were assimilated by the leaves in July. The fruit samples were collected at maturity in September. After collection, leaf and fruit samples were immediately transported to the laboratory in closed polyethylene bags and washed thoroughly with tap water, acidified (0.1 *M* HCl) water and then distilled water (Wallinga *et al.*, 1989). Analyses were also conducted on the fruit flesh and peel. Pear fruit peels were removed by a stainless steel knife before they were dried in an oven. The fruit and leaf samples were oven-dried at 65 °C for 72 h and finely ground in a stainless steel mill to pass through a 0.5 mm sieve. Care was taken to prevent contamination at all steps in the process.

Soil pH was measured in a 1:2.5 soil-to-water ratio. Electrical conductivity was measured in saturation extracts of soils using an EC meter. Particle size analysis was determined using a hydrometer method (Bouyoucus, 1955) and the soils were identified using the U.S. Department of Agriculture soil taxonomy (USDA, 2013). Soil organic carbon was determined by the wet oxidation method of Walkley and Black (1934). Exchangeable cations (Ca, Mg, and K) were determined after extraction with 1 *M* NH_4OAc at pH 7.0 (Kacar, 2009). The extracts were analyzed for Ca, Mg, and K by a flame photometer. Available phosphorus was extracted by $NaHCO_3$ (Olsen and Dean, 1965) and the concentration was measured colorimetrically after developing the blue color with ascorbic acid as described by Kacar and Kovancı (1982). The available Fe, Mn, Zn and Cu, contents of the soils were extracted with 0.005 *M* DTPA (Lindsay and Norvell, 1978). Available B was assayed according to Wolf (1971).

The dried plant (leaf, fruit flesh and fruit peel) samples were digested with 8 ml HNO_3 (65%) and 2 ml H_2O_2 (30%) in closed pressurized vessels in a microwave oven according to U.S. Environmental Protection Agency (EPA, 1994). To dissolve the dried plant samples for total elemental analysis, microwave-assisted acid decomposition was performed at high pressure and

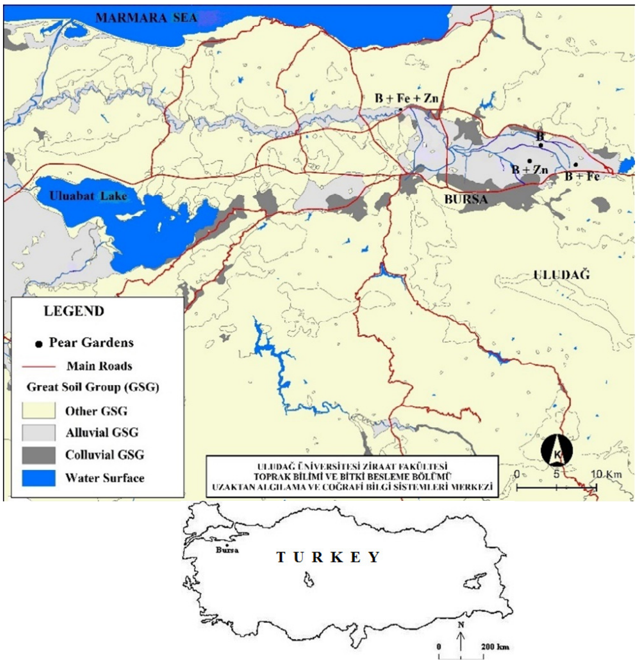

Fig. 1. The location of experimental groves in the map

Table 1. Selected soil characteristics of the experiments

Experiment	Elements	Soil layer (cm)	pH	EC µS cm^{-1}	$CaCO_3$ %	O.M %	Particle size, % S	Si	C	Total N, %	Available P, mg kg^{-1}	Extractable cations (mg kg^{-1}) K	Ca	Mg	Fe	Available micro nutrients, (mg kg^{-1}) Zn	Mn	Cu	B	Geographical location X coordinates	Y coordinates	Great soil group
1	B	0-30	8.03	211	6.53	3.03	40.62	36.98	22.40	0.13	59.80	192	3617	209.00	6.53	1.25	6.29	7.60	0.78	684268	4458002	Alluvial
		30-60	8.45	165	8.07	0.91	52.33	30.55	17.12	0.06	5.80	104	3555	259.50	4.63	0.29	4.60	3.18	0.61			
2	B+Zn	0-30	7.57	159	5.76	2.00	59.11	29.41	11.49	1.11	34.80	124	2498	148.40	5.87	1.42	9.49	10.30	0.72	684798	4457929	Alluvial
		30-60	8.09	75	5.57	1.48	86.68	7.73	5.59	0.02	12.00	32	1979	97.97	4.23	0.43	4.46	2.06	0.31			
3	B+Fe	0-30	8.03	164	5.38	2.22	55.39	28.71	15.89	0.08	31.80	231	3222	168.60	11.94	0.69	7.02	19.48	0.74	688689	4454895	Alluvial
		30-60	8.45	152	8.84	1.70	53.27	24.71	14.13	0.04	4.00	53	4116	259.50	4.00	0.15	6.76	2.56	0.34			
4	B+Zn+Fe	0-30	7.64	171	6.53	3.11	70.39	8.01	21.60	0.10	13.80	358	3453	501.90	3.79	0.54	21.12	6.76	0.62	668569	4461477	Alluvial
		30-60	7.76	184	10.38	2.37	60.70	16.07	23.23	0.06	11.80	163	4035	350.40	2.17	1.04	10.93	1.44	0.39			

Table 2. Treatments applied in the present experiments

Treatments***	Application Stage*	Frequency of application	Rate of Compounds** in Experiments****							
			Experiment 1		Experiment 2		Experiment 3		Experiment 4	
			B	B	ZnS	B	FeS	B	ZnS	FeS
Control	-	0	0	0	0	0	0	0	0	0
Soil 1	Early spring	1	250	250	250	250	500	250	250	500
Soil 2	Early spring	1	500	500	500	500	1000	500	500	1000
Foliar 1	1st, 2nd	2	0.25 %	0.25 %	0.10 %	0.25 %	0.10 %	0.25 %	0.10 %	0.10 %
Foliar 2	1st,2nd,3rd,4th	4	0.25 %	0.25 %	0.10 %	0.25 %	0.10 %	0.25 %	0.10 %	0.10 %
Foliar 3	1st, 2nd	2	0.50 %	0.50 %	0.20 %	0.50 %	0.20 %	0.50 %	0.20 %	0.20 %
Foliar 4	1st, 2nd,3rd,4th	4	0.50 %	0.50 %	0.20 %	0.50 %	0.20 %	0.50 %	0.20 %	0.20 %

*Application stage: 1st : 3 weeks after full bloom.
2nd: 5 weeks after full bloom.
3rd: 7 weeks after full bloom.
4th: 9 weeks after full bloom.

** Compounds: B: Borax (sodium tetra borate decahydrate; Na2B4O7.10H2O), 12 B %
ZnS: Zinc sulphate heptahydrate; ZnSO4.7H2O, 22 Zn %
FeS: Iron sulphate heptahydrate; FeSO4.7H2O, 17 Fe %

***Treatments:
Soil treatments: g tree-1
Foliar treatments: 30 ml of glutechin (alkyl-poliglucoside) as surfactant was added to 100 l of spray solution.

****Experiments: The experiment was consisted of 7 treatments with 3 replications.

temperature (Model Start D, Milestone S.r.l, Sorisole, Italy). The iron and zinc contents in the digest were analyzed with an atomic absorption spectrometer (Model A Analist 400, Perkin Elmer, Waltham, Massachusetts, USA). Leaf and fruit B concentrations were determined colorimetrically using the Azomethin-H method after dry combustion (Kacar and Inal, 2008).

All of the analyses were carried out in duplicate and the results were subjected to statistical analysis. Simple correlations were made among the data, which were obtained from the soil, leaf and fruit (flesh and peel) samples (SAS, 2005).

Selected chemical and physical properties of the soils and the concentrations of some elements in the soils are given in Table 2.

Results and Discussion

Experiment I. Effects of soil and foliar applied B on B concentrations in the leaves and in the fruit

Soil and foliar applications of B in the form of borax increased the B concentrations in both plant parts compared with the control (Table 3). However, the leaf B concentration was not statistically significantly influenced. Nevertheless, the treatments resulted in dramatically higher B concentrations in the fruits than in the leaves. In fact the B content in the fruit was significantly influenced by the soil and foliar applications in each year of the experiment.

The results showed that the soil application of borax at the rate of 500 g per tree was the most effective soil treatment compared with the control and the 250 g $tree^{-1}$ treatments. In contrast, the results of LSD (Least Significant Difference) test also showed that the 4 application of borax 4 times at the rate of 0.5% was the most effective treatment to increase B concentrations in the fruit. The existence of the highest B concentrations in the fruit samples indicated that the majority of B absorbed by the roots and the leaves were transferred to and accumulated in the fruit. However, the effect of the soil-applied B was more evident on the fruit, especially on the fruit flesh. The fruit B concentration decreased in the first year of the experiment. The reason might be that B was not applied into soil in the second year of the experiment to observe if a residual effect of the soil-applied B existed. Wojcik (2003) indicates that pre-bloom and post harvest B sprays are successful in increasing pear tree yield and improving fruit storability under low B availability conditions in the soil.

Experiment II. Effect of combined soil and foliar application of B and Zn on the B and Zn concentrations in the leaves and the fruit

Soil and foliar-applied borax increased the leaf B contents in both years of the experiment (Table 4). The highest B concentration in the leaves was obtained with the application of B in combination with Zn compared with the other 3 foliar treatment experiments. With soil and foliar applications, the B concentrations in the fruit samples were dramatically and statistically higher than for the control treatment in the first year of the experiment. The highest B concentration was obtained with the treatment of foliar application of borax 4 times at a rate of

Table 3. Effects of soil and foliar applied B on B concentrations in leaves and fruits (flesh and peel)

B		mg kg^{-1}					
		Leaf		Fruit Flesh		Fruit Peel	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Control	0	21.47	21.44	18.41c	19.58c	18.53 c	13.99 c
Soil 1 (250 g borax tree^{-1})	1	25.92	21.45	18.03c	18.82c	26.97 bc	11.70 c
Soil 2 (500 g borax tree^{-1})	1	30.36	21.62	42.84ab	28.23c	30.05 b	20.00 bc
Foliar 1 (Spraying 0.25% borax)	2	24.51	24.84	21.16 c	25.35c	22.19 c	19.58 bc
Foliar 2 (Spraying 0.25% borax)	4	29.06	24.84	37.63b	49.08ab	35.17 b	31.79 a
Foliar 3 (Spraying 0.50 % borax)	2	23.97	21.53	44.92ab	45.60b	25.70 bc	28.82 ab
Foliar 4 (Spraying 0.50 % borax)	4	28.74	26.79	64.04a	62.39a	64.23 a	34.92 a
F		NS	NS	**	**	**	**
LSD (0.05)				23.29	14.72	17.41	10.12

* p < 0.05, ** p < 0.01, NS: not significant

Table 4. Effects of soil and foliar applied B and Zn on B and Zn concentrations in leaves and fruit samples

B		mg kg^{-1}					
		Leaf		Fruit Flesh		Fruit Peel	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Control	0	20.82d	28.48	21.36	13.06c	18.13 d	15.09c
Soil 1 (250 g borax tree^{-1})	1	24.51 cd	31.87	19.85	13.05c	20.39 d	17.72c
Soil 2 (500 g borax tree^{-1})	1	27.33 bc	27.04	45.55	23.82bc	21.65 cd	20.68bc
Foliar 1 (Spraying 0.25% borax)	2	29.50 bc	31.96	26.56	22.46c	19.40 d	19.24 c
Foliar 2 (Spraying 0.25% borax)	4	30.47b	36.20	24.29	43.99a	24.19 bc	22.04 bc
Foliar 3 (Spraying 0.50 % borax)	2	31.45b	25.01	36.76	35.69ab	25.75 b	30.09 b
Foliar 4 (Spraying 0.50 % borax)	4	39.58a	35.26	41.53	45.86a	43.59 a	41.62a
F		*	NS	NS	*	**	**
LSD (0.05)		5.97			12.85	17.41	10.48
Zn		Leaf		Fruit Flesh		Fruit Peel	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Control	0	37.83b	28.14d	5.70 bc	4.73	10.53	7.80
Soil 1 (250 g $ZnSO_4.7H_2O$ tree^{-1})	1	42.35 b	25.34d	4.89c	5.98	7.16	6.24
Soil 2 (500 g $ZnSO_4.7H_2O$ tree^{-1})	1	42.75b	27.51d	4.76c	4.14	8.23	6.57
Foliar 1 (Spraying 0.10% $ZnSO_4.7H_2O$)	2	92.38ab	94.22c	7.03ab	5.44	11.30	10.42
Foliar 2 (Spraying 0.10% $ZnSO_4.7H_2O$)	4	90.40ab	136.40b	6.19abc	5.04	10.36	5.44
Foliar 3 (Spraying 0.20 % $ZnSO_4.7H_2O$)	2	131.14a	101.80c	6.75ab	6.30	10.93	7.74
Foliar 4 (Spraying 0.20 % $ZnSO_4.7H_2O$)	4	157.16a	239.26a	7.89a	3.80	16.53	10.17
F		*	**	*	NS	NS	NS
LSD (0.05)		75.03	26.70	1.78			

* p < 0.05, ** p < 0.01, NS: not significant

0.5%. In addition, the residual effect of soil-applied B in the fruit flesh samples at the rate of 500 g tree^{-1} was more evident. These results are also consistent with the results of experiment I, in which the fruits contained more B than the leaves and verify the translocation of B into the tree.

The combined application of B and Zn-containing compounds did not exhibit contrary trends to the single application of B. Regarding Zn treatments, the foliar application of Zn increased Zn contents in the leaves and the fruit. However, these increases were not statistically significant in the fruits. In contrast to the partitioning of B between the leaves and the fruits, the Zn concentration in fruit was lower than in the leaves. Additionally in contrast to the partitioning of B between the fruit flesh and the fruit peel, the Zn concentration in the fruit flesh was lower than in the fruit peel. This different behavior of B and Zn could be attributed to the poor mobility of foliar-applied Zn in the tree (Ferrandon and Chamel, 1988; Zhang and Brown, 1999). The results of the B + Zn experiment also indicated that there was no adverse relationship between B and Zn in absorbtion by the roots and the leaves. Therefore, when B and Zn deficiencies occur at the same time, this problem could be handled by the application of those compounds together in pear trees. Taheri and Talaie (2001) indicated that a B and Zn spray had a significant effect on the concentration of these elements in the leaves and fruits of olive trees. The application of foliar Zn and B significantly promoted the qualitative and quantitative characteristics of pear trees (Canesin and Buzetti, 2007; Canesin *et al.*, 2010). The combined foliar application of B and Zn maximizes the yield and extends the bearing life of citrus fruit plants, while significantly reducing the dieback, chlorosis and rosette tree in citrus plants (Sajid *et al.*, 2010).

Experiment III. Effect of combined soil and foliar application of B and Fe on the B and Fe concentrations in the leaves and the fruit

The results of the amount of B detected in the fruit flesh and fruit peel samples changed meaningfully in relation to the treatments (Table 5). The effects of the treatments were observed more clearly in the second year of the experiment than in the first year in almost each treatment. Although the soil application of borax was performed only in the first year of the experiment, the highest concentrations were observed in the fruit flesh and peel samples of the second year. Similar to the other 3 experiments, the B contents of the fruit samples were clearly higher than that of the leaf samples. The most effective foliar rate of borax for increasing the B content of different plant parts appeared to be 4 times at a 0.5% concentration.

Table 5. Effects of soil and foliar applied B and Fe on B and Fe concentrations in leaves and fruit samples

B		mg kg^{-1}					
		Leaf		Fruit Flesh		Fruit Peel	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Control	0	14.53	20.09	4.12c	9.75 d	9.91c	11.95c
Soil 1 (250 g borax tree^{-1})	1	19.63	24.33	12.94c	17.72cd	11.05c	16.44bc
Soil 2 (500 g borax tree^{-1})	1	18.22	29.16	18.60bc	28.99bc	20.78 b	19.16bc
Foliar 1 (Spraying 0.25% borax)	2	17.56	25.60	16.25bc	24.07bc	17.20bc	25.68bc
Foliar 2 (Spraying 0.25% borax)	4	19.74	29.33	25.04 b	24.58bc	22.10b	27.29 b
Foliar 3 (Spraying 0.50 % borax)	2	20.27	28.91	26.27 b	33.48b	22.95 b	42.04a
Foliar 4 (Spraying 0.50 % borax)	4	20.05	27.38	53.34a	51.62a	40.85a	49.84a
F		NS	NS	*	**	**	*
LSD (0.05)				20.15	12.10	13.32	14.37

Fe		Leaf		Fruit Flesh		Fruit Peel	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Control	0	68.56cd	98.88de	10.69c	6.19	9.15d	23.15bc
Soil 1 (500 g $FeSO_4.7H_2O$ tree^{-1})	1	69.42cd	101.72de	13.12bc	7.03	9.54cd	14.64c
Soil 2 (1000 g $FeSO_4.7H_2O$ tree^{-1})	1	64.41 d	98.48 e	11.93bc	5.61	8.50d	19.59c
Foliar 1 (Spraying 0.10% $FeSO_4.7H_2O$)	2	98.83c	164.71cd	13.55bc	7.40	10.32cd	23.34bc
Foliar 2 (Spraying 0.10% $FeSO_4.7H_2O$)	4	153.38b	240.67ab	14.96bc	7.37	15.67b	34.13ab
Foliar 3 (Spraying 0.20 % $FeSO_4.7H_2O$)	2	136.04b	182.07bc	15.75ab	6.87	14.05bc	31.71ab
Foliar 4 (Spraying 0.20 % $FeSO_4.7H_2O$)	4	261.53a	300.50a	19.72a	6.20	22.96a	42.07a
F		**	**	*	NS	**	*
LSD (0.05)		32.39	65.84	4.32		4.87	10.97

* $p < 0.05$, ** $p < 0.01$, NS: not significant

The iron contents, determined in both plant parts, were considerably higher than the control and the sufficiency ranges proposed for pears in all foliar-applied trees. It is already known that, the soil application of Fe(II) sulfate does not increase the Fe concentrations in the plant tissues. In fact, soil-applied Fe(II) sulfate is of little or no agronomic value in calcareous soils where the Fe^{+2} is subjected to rapid oxidation and insolubilisation as a hydroxide (Tagliavini and Rombolá, 2001). However, the foliar application of Fe raised the Fe concentrations in the leaf samples more than the same concentrations in the fruit tissues. Therefore, the results of experiment III highlighted that the combined application of borax and iron sulfate could be readily performed in cases where B and Fe deficiencies appeared together. Jin *et al.* (2008) indicated that compared with the control, the contents of Fe, Zn, protein and 16 amino acids increased significantly with the application of combination of foliar Fe + boron complex.

Experiment IV. Effect of combined soil and foliar application of B, Zn and Fe on the B, Zn and Fe concentrations in the leaves and the fruit

Soil and foliar applied borax combined with Fe and Zn enhanced the B concentrations in the plant samples (Table 6). There were statistically significant differences between B concentrations in the untreated trees and the soil applied trees. Soil applied borax showed higher B concentrations in the leaves and the fruit flesh samples in the second year compared with the first year. However, the fruit peel B concentrations decreased in the second year. In addition, the soil-applied B concentrations in the fruit flesh were slightly higher than in the fruit peel. In contrast, the soil application of B in combination with Fe and Zn did not have significant effects on the B concentrations in the fruits compared with the B+Zn (experiment II) and B alone (experiment I) application experiments.

Repeated foliar applications of borax resulted in higher B concentrations in the fruit flesh compared with the leaves. These differences produced statistically meaningful relationships in both years of the experiment. Boron in the fruit of foliar-applied trees accumulated significantly compared with control and soil treatments. The findings of this two year experiment indicated that the highest B concentrations in the fruit were obtained with the repeated application of borax 4 times at the rate 0.5%. In addition, the Fe and Zn concentrations significantly increased in only the foliar-applied leaves. The iron and zinc concentrations in the leaves and fruit did not demonstrate significantly meaningful differences with control trees by the soil application of Fe and Zn-containing compounds. The iron and Zn contents of fruits only indicated significant increases in the 4 times repeated foliar applications. Based on the aforementioned results, pear trees are well able to take up a combination of B, Zn and Fe in some solution without any hazardous effect.

The iron and zinc concentrations increased significantly in only foliar applied leaves. The iron and Zn concentrations in the leaves and fruit did not demonstrate statistically meaningful differences with the control trees by the soil application of Fe and Zn containing compounds. Regarding the Fe and Zn concentrations in the fruit of the foliar-treated trees, the concentrations of those 2 elements changed accordingly in relation to the treatments. For example, the Fe contents of the fruit peels and the Zn contents of the edible parts showed significant increases in the second year. These results are generally consistent with the other 2 experiments mentioned above. Based on the aforementioned results, the above ground parts of the pear are well able to take up the combination of B, Zn and Fe in the same solution without any hazardous effect. In contrast, foliar application treatments of a B+Fe+Zn combination can produce the highest values for harvest, yield and quality (Anees *et al.*, 2011; Abdel-Latif and El Haggan, 2014).

The B contents in the fruit parts and leaves were influenced by the soil and foliar applications of boron. Apparently, the fruit B contents evidently appeared in higher amounts than in the leaves in each experiment, as well. This could be due to translocation of the boron from the treated leaves to the developing tissues. In other words, higher B concentrations in

Table 6. Effects of soil and foliar applied B, Zn and Fe on B, Zn and Fe concentrations in leaves and fruit samples

B		mg kg^{-1}					
		Leaf		Fruit Flesh		Fruit Peel	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Control	0	19.52b	23.90	16.44c	18.22b	15.66d	15.00
Soil 1 (250 g borax tree^{-1})	1	20.61b	21.45	16.04c	21.95ab	19.83cd	18.48
Soil 2 (500 g borax tree^{-1})	1	22.66b	29.58	21.63bc	27.72ab	21.73bcd	20.34
Foliar 1 (Spraying 0.25% borax)	2	19.08b	23.57	19.26c	17.63 b	19.07d	18.22
Foliar 2 (Spraying 0.25% borax)	4	21.36b	27.38	28.45b	32.72a	27.59b	26.36
Foliar 3 (Spraying 0.50 % borax)	2	20.49b	23.48	23.43bc	23.14ab	25.32bc	17.89
Foliar 4 (Spraying 0.50 % borax)	4	28.52a	26.53	52.30a	33.06a	47.95a	25.43
F		*	NS	**	*	**	NS
LSD (0.05)		5.65		8.72	11.28	6.08	
Zn		Leaf		Fruit Flesh		Fruit Peel	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Control	0	24.69c	22.43d	2.83b	3.85	5.80d	5.78bc
Soil 1 (250 g $ZnSO_4.7H_2O$ tree^{-1})	1	23.41c	21.43d	3.49b	3.32	5.40d	4.07c
Soil 2 (500 g $ZnSO_4.7H_2O$ tree^{-1})	1	21.70c	17.68d	2.30b	3.68	5.90d	4.31c
Foliar 1 (Spraying 0.10%$ZnSO_4.7H_2O$)	2	36.38c	58.47 c	3.69b	4.28	7.06cd	9.01b
Foliar 2 (Spraying 0.10%$ZnSO_4.7H_2O$)	4	77.53b	121.60b	3.74b	5.60	12.40b	21.94a
Foliar 3 (Spraying 0.20%$ZnSO_4.7H_2O$)	2	74.07b	97.57b	2.80b	4.47	10.41bc	10.60b
Foliar 4 (Spraying 0.20%$ZnSO_4.7H_2O$)	4	161.78a	191.03a	6.71a	5.11	18.66a	16.74a
F		**	**	*	NS	**	**
LSD (0.05)		27.31	34.35	1.81		4.40	5.39
Fe		Leaf		Fruit Flesh		Fruit Peel	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Control	0	47.33c	51.88d	3.76c	3.98	3.59c	15.60bc
Soil 1 (500 g $FeSO_4.7H_2O$ tree^{-1})	1	43.44c	49.96d	3.92c	2.40	2.65c	11.65c
Soil 2 (1000 g $FeSO_4.7H_2O$ tree^{-1})	1	45.39c	57.23cd	6.11ab	4.97	2.21c	11.09c
Foliar 1 (Spraying 0.10%$FeSO_4.7H_2O$)	2	82.23bc	94.26c	4.38bc	3.62	3.00c	23.70ab
Foliar 2 (Spraying 0.10%$FeSO_4.7H_2O$)	4	144.06b	152.40b	4.48bc	3.68	11.61 b	32.01a
Foliar 3 (Spraying 0.20%$FeSO_4.7H_2O$)	2	131.46b	135.83b	5.25bc	4.67	6.55bc	18.41bc
Foliar 4 (Spraying 0.20%$FeSO_4.7H_2O$)	4	309.89a	249.45a	7.30a	4.40	30.22a	31.45a
F		**	**	*	N.S	**	*
LSD (0.05)		67.62	39.19	2.01		5.29	11.65

* $p < 0.05$, ** $p < 0.01$, NS: not significant

the fruit samples of the soil-applied treatments clearly exhibited the movement of B from the soil to the fruit. This may be accepted as a proof of translocation of the B treatment to the fruit in pear trees. Either pear is a boron remobilizing plant or boron is phloem mobile in pear and/or pome fruits (Hanson, 1991; Sánchez *et al*., 1998; Sánchez and Righetti, 2005). As a result, it can be stated that the determination of the leaf B contents is not a useful tool for estimating the level of B in pear trees. From the current results, it seems justified that the fruit B content is a suitable tool to indicate the B level status of pear trees.

Soil and foliar applications of borax resulted in significant increases in the B contents in different parts of the trees except for the soil application in experiment IV. Effects of the treatments were more obvious in the first year. This suggests that the regular application of borax is necessary to maintain sufficient B levels in the tree by soil or foliar applications. These results are consistent with the earlier research findings of Sánchez *et al*. (1998), who showed that soil and foliar applications of boron had effects on the B content in the flower parts in pear. There are also other studies that have reported effects of B compounds on pear trees (Yehia and Hassan, 2005; Jordão *et al*. 2008; Canesin *et al*., 2010).

Different combinations of B with Zn and Fe appeared to be effective and increased the leaf and fruit B concentrations with the application of B alone. This relationship may be accepted as an example of the synergistic interaction of these nutrients. Similar results were reported by Canesin *et al*. (2010) who sprayed pears with boric acid and $ZnSO_4$ at 110 g ha^{-1} and 250 g ha^{-1} concentrations, respectively, in combination with chelating agents. This application caused a significant increase in the leaf Zn content. However, the final fruit set and the number of fruit were not influenced by the foliar spray with B and Zn.

Conclusions

The results of this research indicated that the applications of borax (sodium tetra borate decahydrate) via the soil and leaves, increased the B concentrations in all plant parts. Boron in the component plant organs indicated the superiority of the foliar B application compared with the soil application. As conducted in these experiments, the foliar spraying should be performed 4 times to induce an adequate B content in the tissues of the pear trees. It was clearly observed that the fruit tissues had more B than did the leaf tissues. Therefore, the fruit B concentration should be fundamentally considered in evaluation of the B level status of pear trees. Double and triple combinations of B, Zn and Fe in one spray solution could be successfully applied in case of multiple nutrient deficiencies observed in pear trees. These results obviously indicated that the leaf B concentration is not acceptable as a reliable criterion for the determination of the B level in pear trees. The fruit B content was found to be a better and more consistent predictor of sufficient B content in pear trees. Nevertheless, there is a need to have precise preliminary universal critical values for B in fruit. Thus, the seasonal variations of boron in fruit and a procedure for representative fruit sampling should be determined for a suitable sampling method.

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