Acta Agrophysica, 2003, 85, 235-243

RESPONSE OF "JONAGOLD" APPLE TREES TO FOLIAR BORON APPLICATION

P. Wójcik

Research Institute of Pomology and Floriculture
Pomologiczna 18 str., 96-100 Skierniewice, Poland; e-mail: pwojcik@insad.pl

S u m m a r y. The experiment was carried out in 2000-2001 in a commercial apple orchard in the Central Poland on mature Jonagold apple trees/M.26 planted at a spacing of 4 x 2 m on a sandy loam soil with 0.33 mg hot-water extractable B·kg^{-1}. Trees were sprayed with B (i) in spring at the stage of pink bud, beginning of flowering (when 10% of flowers were open), and at petal fall at a rate of 0.2-0.3 kg B·ha^{-1} per spray (these sprays were applied on the same trees) or (ii) in fall, 4-5 weeks before leaf drop at a rate of 0.8 kg B·ha^{-1}. Trees untreated with B served as control. The results showed that foliar B sprays had no effect on the vigour of trees, and mean fruit weight, soluble solids concentration, starch index, firmness and physiological stage of fruit at harvest. Boron-treated apple trees, regardless of the application term, had higher fruit yield as compared to control. Spring and fall B sprays increased B concentrations in flowers, fruitlets and in leaves 28 days after full bloom. Only apple fruit from the trees sprayed with B in spring had enhanced B status and were of better coloring than control. The fall B sprays caused leaf injury but had no effect on the intensity of defoliation. The results obtained indicate that fall B sprays are successful in the crop increase of B deficient apple trees.

K e y w o r d s: apple trees, boron sprays

INTRODUCTION

Boron (B) is an essential element required for the optimum growth and development of higher plants [16]. Boron deficiency causes a great loss in plant production [8]. Boron shortage occurs mostly in course-textured soils containing low levels of organic matter [20]. In such soils, plant B deficiency is particularly pronounced in the growing seasons with low precipitation levels and high air temperatures. Even though B deficiency takes place mainly in course-textured soils, its shortage may be also found in fine-textured soils in the years with cold and wet springs [20].

Researchers suggested roles of B in the plant structure and functioning however, its exact role remains unknown [6]. It has been suggested that B plays role in different processes such as tissue differentiation, metabolic control through the regulation of enzymatic reactions, membrane integrity and function, phenolic metabolism, sugar translocation, and nucleic acid synthesis [2,16]. In apple trees, poor fruit set is the first visual sign of a low B content [19]. Apples from B deficient trees are small as cell division in fruitlets is decreased together with leaf photosynthesis rate, and/or movement of carbohydrates to fruit tissues [19]. Apples with low B levels are also deformed, corked and sensitive to cracking and russeting and often have yellow skin with poor blush [21].

In Polish agriculture, sandy soils with low levels of available B prevail [7]. It is estimated that about 50% of apple orchards in the Central Poland suffer from B shortage. In this region, foliar B sprays in spring are frequently applied by apple growers. Under conditions of B deficiency, foliar B sprays at the begi-nning of flowering and at petal fall, are usually successful in increasing apple tree cropping and improving fruit quality [24]. In apple production, there is also a possibility to apply fall B sprays since foliar-applied B is phloem mobile in sorbitol-rich species [3]. However, under Polish conditions, response of apple trees to foliar B sprays in fall has not been examined. Therefore, the aim of the present experiment was to compare the efficiency of spring and fall B sprays in apple production.

MATERIALS AND METHODS

The experiment was carried out in 2000-2001 in a commercial apple orchard in the Central Poland on mature Jonagold apple (*Malus domestica* Borkh.) trees grafted on M.26 rootstock. Trees were planted in 1995 at a spacing of 4 x 2 m (1250 trees$\cdot$ha^{-1}) on a sandy loam soil (75% sand, 15% silt, 10% clay) with pH 5.7 (in 1M KCl solution), low level of organic matter (11g C kg^{-1}), medium B (0.33 mg$\cdot$kg^{-1}) and high P (61 mg$\cdot$kg^{-1}), K (135 mg$\cdot$kg^{-1}) and Mg (48 mg$\cdot$kg^{-1}). Phosphorus and K in the soil were extracted by Ca-lactate, Mg by 0.0125 M $CaCl_2$ and B by hot-water according to methods described by Ostrowska *et al.* [18]. Composite soil samples for analysis were composed of subsamples taken in the fall of 1999 (before fall B spray) from the surface of herbicide strips (1.5 m wide) along tree row from a depth of 0-20 cm. Despite the medium soil B status, no visible symptoms of plant B deficiency were observed before the study. Trees were trained as a spindle and were not irrigated. Once a year at the stage of bud break, the trees were supplied with nitrogen (N) as ammonium nitrate at a rate of 60 kg N$\cdot$ha^{-1}

uniformly over the whole surface of the orchard. Because of a high concentrations of available P, K and Mg in the soil, these elements were not applied. Also, no B fertilizers were applied to the soil. During the experiment, the thinning of flowers or fruitlets was not done. Protection against pathogens and pests was carried out according to standard recommendations for commercial orchards [17]. The experimental design was a randomized complete block with three replications. Each experimental plot consisted of 10 trees. Four trees between the plots served as guard trees. Foliar B sprays were applied: (i) in spring, at the stage of pink bud, beginning of flowering (when 10% of flowers were open), and at petal fall at a rate of 0.2-0.3 kg B·ha^{-1} per spray (these sprays were applied on the same trees) or (ii) in the fall, 4-5 weeks before leaf drop at a rate of 0.8 kg B·ha^{-1}. Borvit material (8% B as boric acid, Intermag, Olkusz) was used for spray treatments. All sprays were performed by a directed air-jet sprayer with radial fan using 1000 L of water per ha. Trees untreated with B served as control. Over 2 years, the same trees were used for the treatments studied.

The following measurements and observations were made: (1) total length and number of current season shoots per tree, and their mean length were measured calculated based on 2 branches from each tree as proposed by Jolly and Holland [14]; (2) total fruit yield was measured separately for each plot and calculated per tree. Only apple fruit on the trees were considered fruit yield; (3) mean fruit weight was calculated from ca. 15-kg bulk apple sample per plot; (4) firmness, soluble solids concentration (SSC) and starch index of fruit at harvest were determined on a 20-fruit sample per plot. Firmness was measured using a Magness-Taylor firmness-tester with an 11-mm tip on the blush side and the opposite side of each apple. Soluble solids concentration was determined using an Abbe refractometer at 22 ^{o}C in the juice squeezed from fruit homogenate. Fruit starch index was estimated by the iodine test using a scale of 1 (100% of cross section area stained) to 10 (0% of area stained). Based on the data on firmness, SSC and starch index of fruit, Streif's index value [F/(RS)] was calculated according to the following formula: F/(RS) = firmness [kg] / (SSC [%] x starch index [1-10]); (5) fruit coloring was estimated on a 20-kg bulk fruit sample per plot on a scale from 1 (blush < 25% of fruit skin surface) to 5 (blush > 76% of skin surface); (6) B level in flower, fruit and leaf tissues. Flower samples were collected at full bloom. Five "king" flowers (with petals, sepals, reproductive parts, and 2-mm long peduncles) were taken from each tree. Fruit samples were collected 28 days after full bloom and at harvest; on each date three fruitlets/fruit of similar diameter were collected from each tree. Leaf samples were collected 28, 56 and 84 days after full bloom from the middle portion of current season shoots. Three leaves were taken from each tree. Fruit and leaf samples were rinsed with 0.01 M HCl and then double-deionized water to remove surface residues. Seeds and stem were removed from each apple, and two quarters of each apple were cut out from the opposite sides. Plant samples were dried in a forced-draft oven at 75°C until constant weight was reached, ground and ashed in a muffle furnace at 480°C for 12 h. Ash was dissolved in 5% nitric acid. Boron was determined by an inductively-coupled plasma spectroscopy (Thermo Jarrell Ash, Franklin, MA, USA); (7) leaf injuries were assessed visually on a scale from 1 (no damage) to 5 (severe damage). Leaf injuries were evaluated 7, 21 and 28 days after fall B spray on 200 leaves from current season shoots located in the outside zone of the canopy; (8) defoliation was evaluated on three shoots from each tree from the outside zone of the canopy at the same time as leaf injury. Defoliation was expressed as the number of leaves fallen/total number of leaves x 100.

Analysis of variance was performed on all daesa. Differences between means were evaluated separately for each season using Duncan's Multiple Range Test at P = 0.05. Data on total length and the number of current season shoots per tree, and defoliation were transformed according to y=sqr (x), y=log (x), and y=arc sin(x), respectively, as outlined by Szczepański and Rejman [22].

RESULTS

Total length of one-year-old shoots per tree did not differ among the treatments (Table 1). Also, the number of current season shoots per tree and mean shoot length were not affected by foliar B sprays averaging to 89.2 and 26.6 cm in 2000 and 96.6 and 28.6 cm in 2001, respectively.

Cropping of control trees was relatively low (Table 1). In both growing seasons, apple trees sprayed with B had significantly higher fruit yield as compared to those of control plots (Table 1). The efficiency of spring and fall B sprays was similar.

Mean fruit weight and Streifs index value were not influenced by foliar B sprays (Table 1). Neither boron spray treatments had any effect on firmness, SSC and starch index of fruit averaging to 9.7 kg, 13.6% and 6.6 in 2000 and 9.9 kg, 13.6% and 6.1 in 2001, respectively.

In both growing seasons, flower B concentrations of the apple trees sprayed with B were higher than those of control (Table 2). Flower B concentrations of the B-sprayed trees in spring and in fall were comparable. Spring and fall B sprays increased B concentration in fruitlets (Table 2). However, only spring B sprays enhanced fruit B levels at harvest (Table 2). During the growing season, leaf B concentra-

Tabela 1.

Table 1. The effect of foliar boron sprays on vigour, cropping and "Jonagold" apple fruit quality

Treatment	Total length of one-year-old shoots [m tree^{-1}]		Yield [kg tree^{-1}]		Mean fruit weight [g]		Fruit coloring [1-5]		Streif's index	
	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001
Fall B spray	24.5a	28.4a	15.2b	18.2b	187a	175a	3.2a	3.0a	0.125a	0.121a
Spring B sprays	25.4a	27.5a	16.2b	17.8b	185a	175a	3.9b	3.8b	0.121a	0.120a
Control	27.2a	26.8a	12.3a	15.2a	186a	178a	3.3a	3.1a	0.125a	0.123a

Means with the same letter in columns are not significantly different according to Duncan's Multiple Test at $P \leq 0.05$.

Table 2. The effect of foliar B sprays on concentration of B in flowers, fruit and leaves of 'Jonagold' apple trees

Treatment	Boron concentration [mg kg^{-1} DM]											
	Flowers		Fruit				Leaves					
			28 days after full bloom		Harvest		Days after full bloom					
							28		56		84	
	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001
Fall B spray	54b	51b	82b	78b	11a	11a	32b	35b	28a	27a	25a	27a
Spring B sprays	51b	48b	88b	81b	17b	18b	31b	33b	27a	24a	26a	24a
Control	35a	32a	52a	55a	11a	12a	25a	26a	25a	26a	27a	25a

Means with the same letter in columns are not significantly different according to Duncan's Multiple Test at $P \leq 0.05$.

tion of the control trees was relatively stable, ranging from 25 to 27 mg·kg^{-1} (Table 2). Foliar B sprays in spring and in fall, increased B levels in leaves only 28 days after the full bloom (Table 2).

In both years, fall B sprays caused leaf injuries (Table 3). Leaf damage 7 days after foliar B application in fall was similar to those recorded 21 and 35 days after this treatment (Table 3). However, fall B sprays had no effect on the intensity of defoliation (Table 3).

Table 3. Effect of fall B spray on leaf injury and defoliation of "Jonagold" apple trees

Treatment	Leaf injury [1-5]						Percentage of fallen leaves					
	Days after B spray in fall											
	7		21		35		7		21		35	
	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001
Fall B spray	2.1b	2.3b	2.2b	2.3b	2.2b	2.3b	0a	0a	8.8a	15.2a	58.8a	65.3a
Control	1.0a	1.0a	1.1a	1.0a	1.0a	1.0a	0a	0a	10.5a	13.8a	53.8a	68.4a

Means with the same letter in columns are not significantly different according to Duncan's

DISCUSSION

A lot of experiments showed that foliar B applications improved vigour and/or cropping of pear (*Pyrus communis* L.), prune (*Prunus domestica* L.), apple (*Malus domestica* Borkh.), and peach (*Prunus persica* L.) trees [4,12,15,23,25]. On the other hand, Ferran *et al.* [5] and Hanson [11] did not find any response of hazelnut (*Corylus avellana* L.) and highbush blueberry (*Vaccinium corymbosum* L.) crops which exhibited no visual B deficiency signs to foliar B sprays. In our experiment, B sprays in spring or in fall increased fruit yield. The above indicated that B was a limiting factor for the cropping of apple trees. Also, low B concentrations in the summer leaves (25-27 mg·kg^{-1}) recorded in the present experiment indicated that B nutrition of "Jonagold" apple trees was not adequate to give the optimum fruit yield. According to Peryea [19], the optimum B concentration in the summer leaves ranged from 30 to 60 mg·kg^{-1}. Taking into consideration that foliar B sprays did not affect tree vigour or mean fruit weight, it seems that an increased tree yielding was due to the improved fruit set. The above may be true as it is well known that B plays an important role in the plant generative development and, especially, in the pollen germination process and growth of pollen tubes [2].

In the present experiment, fall B sprays increased concentration of the subject element in flowers and also in leaf and fruit tissues in the spring. This indicates that fall foliar application of B was retranslocated from leaves to wood and remobilized in the following season to the growing tissues. These results are in agreement with the findings of Baron [1], Hanson [10], Hanson and Breen [12] and Hanson *et al.* [13] in other fruit and nut crops rich in sorbitol and/or mannitol, where it was observed that B foliar application in the previous fall or dormant period could influence B concentration in tissues in the subsequent spring. However, in our experiment, foliar B sprays had no effect on B levels the in the summer leaves and fruit at harvest. Also, Hanson [11] observed no increase in the B concentration in the summer leaves of prune trees following foliar B application in fall. Thus, it seems that foliar B sprays in fall can increase B levels in plant tissues (mainly in the reproductive organs) only in spring.

In our study, spring B sprays increased not only fruit yield but also coloring of apple fruit. Also, Yogaratnam and Johnson [26] found better coloring of apple fruit as a result of foliar B sprays. Better coloring of apple fruit sprayed with B in spring might result from a higher accumulation of carbohydrates in fruit. This may be true because it is known that B complexes with carbohydrates facilitate their transport in the phloem [6].

CONCLUSION

Foliar application of B in fall is a valid method of enhancing B levels in the tissues of reproductive organs in the subsequent spring which can increase fruit set and consequently yielding of B deficient apple trees. This conclusion is probably true for any species for which B is freely phloem mobile including all *Malus*, *Pyrus*, *Prunus* and *Oleaceae*. Spring B sprays should be recommended for increasing not only fruit yield of B deficient apple trees but also for the improvement of fruit quality, particularly fruit coloring.

REFERENCES

1. **Baron L.C.:** The value of boron sprays on filberts. Nut Growers Assn. Oregon and Washington. Proc. 58[th] Annu. Mtg., Portland, Ore., 58, 43-44, 1973.
2. **Blevins D.G., Lukaszewski K.M.:** Boron in plant structure and function. Annu. Rev. Plant Physiol. Plant Mol. Biol., 49, 481-500, 1998.
3. **Brown P.H., Hu H.:** Phloem mobility of boron is species dependent: Evidence for phloem mobility in sorbitol-rich species. Annals of Botany 77, 497-505, 1996.

4. **Callan N.W., Thompson M.M., Westwood M.N.:** Effects on fruit set of Italian prune following fall foliar and spring B sprays. J. Amer. Soc. Hort. Sci., 103, 253-257, 1978.
5. **Ferran X., Tous J., Romero A., Lloveras J., Pericon J. R.:** Boron does not increase hazelnut fruit set and production. HortScience 32, 1053-1055, 1997.
6. **Gauch H.G., Dugger W.M.:** The physiological action of boron in higher plants: review and interpretation. University Maryland AES Techn. Bull. 80, 1-43, 1954.
7. **Grześkowiak A.:** Mineral fertilizers in modern agriculture (in Polish). In: Mineral Fertilization of Plants (Eds R. Czuba). Zakłady Chemiczne "Police" S.A, Police, 17-56, 1996.
8. **Gupta U.C.:** Boron deficiency and toxicity symptoms for several crops as related to tissue boron levels. J. Plant Nutr. 6, 387-395, 1983.
9. **Hanson E.J.:** Movement of boron out of tree leaves. HortScience, 26, 271-273, 1991.
10. **Hanson E.J.:** Boron requirement and mobility in tree fruit species. Current Topic Plant Biochem. Physiol. 10, 240-246, 1991.
11. **Hanson E.J.:** Foliar boron sprays do not affect highbush blueberry production. Small Fruit Rev. 1, 35-41, 2000.
12. **Hanson E.J., Breen P.J.:** Effects of fall boron sprays and environmental factors on fruit set and boron accumulation in Italian prune flowers. J. Amer. Soc. Hort. Sci. 110, 389-392, 1985.
13. **Hanson E.J., Chaplin M.H., Breen P.J.:** Movement of foliar applied boron out of leaves and accumulation in flower buds and flower parts of Italian prune. HortScience, 20, 747-748, 1985.
14. **Jolly G.M., Holland D.A.:** Sampling methods for the measurement of extension growth of apple trees. A.R.E. Malling Res. Stat., 87-90, 1958.
15. **Kamali A., Childers N.F.:** Growth and fruiting of peach in sand culture as affected by boron and a fritted form of trace elements. J. Amer. Soc. Hort. Sci. 95, 652-656, 1970.
16. Marschner H.: Mineral Nutrition of Higher Plants. Academic Press, London, 1995.
17. **Olszak R., Bielenin A.:** Program of Fruit Crop Protection (in Polish). Agrosan, Sandomierz, 1999.
18. **Ostrowska A., Gawliński S., Szczubiałka Z.:** Analysis of Soils and Plants (in Polish). Instytut Ochrony Środowiska, Warsaw, 1991.
19. **Peryea F.J.:** Boron nutrition in deciduous tree fruit. In: Tree Fruit Nutrition (Eds A.B. Peterson, R.G. Stevens). Good Fruit Grower, Yakima, Washington, 95-99,1994.
20. **Shorrocks V.M.:** The occurrence and correction of boron deficiency. Plant Soil 193, 121-148, 1997.
21. **Svagzdys S.:** Use of boron fertilizers in apple orchards of Lithuania. Acta Hort. 383, 487-490, 1995.
22. **Szczepański K., Rejman S.:** Statistical Analysis in Pomology (in Polish). PWRiL, Warsaw, 1987.
23. **Woodbridge C.G., Carney A., McClarty H.R.:** A boron deficiency in pears growing in soil having an adequate boron content. Sci. Agric. 32, 440-442, 1952.
24. **Wójcik P., Mika A., Cieśliński G.:** Wpływ nawożenia borem na plonowanie jabłoni oraz jakość owoców. Acta Agrobotanica 50, 111-124, 1997.
25. **Wójcik P., Cieslinski G., Mika A.:** Apple yield and fruit quality as influenced by boron applications. J. Plant Nutr. 9, 1365-1378, 1999.
26. **Yogaratnam N., Johnson D.S.:** The application of foliar sprays containing nitrogen, magnesium, zinc and boron to apple trees. II. Effect on the mineral composition and quality of the fruit. J. Hort. Sci. 57, 159-164, 1982.

REAKCJA JABŁONI ODMIANY "JONAGOLD" NA NAWOŻENIE DOLISTNE BOREM

P. Wójcik

Instytut Sadownictwa i Kwiaciarstwa
Pomologiczna 18 str., 96-100 Skierniewice, Polska; e-mail: pwojcik@insad.pl

S t r e s z c z e n i e. Doświadczenie przeprowadzono w latach 2000-2001 w prywatnym sadzie jabłoniowym w Centralnej Polsce. Obiektem doświadczalnym były jabłonie odmiany Jonagold/M.26 posadzone w rozstawie 4 x 2 m na glebie piaszczysto gliniastej zawierającej średnią zawartość przyswajalnego boru (0,33 mg $B \cdot kg^{-1}$). Drzewa opryskiwane były borem (i) na wiosnę, w fazie różowego pąka, na początku kwitnienia (10% kwiatów w pełni kwitnienia) oraz w czasie opadania płatków kwiatowych w dawce 0.2-0.3 kg $B \cdot ha^{-1}$ w każdym zabiegu (wiosenne opryski wykonywane były na tych samych drzewach) oraz (ii) jesienią, 4-5 tygodnie przed opadaniem liści w dawce 0.8 kg $B \cdot ha^{-1}$. Drzewa nie traktowane borem stanowiły kontrolę. Wyniki badań wykazały, że dolistne nawożenie borem nie miało wpływu na wzrost drzew, średnią masę owocu, ekstrakt, indeks skrobiowy, jędrność oraz stan dojrzałości owoców w czasie zbioru. Niezależnie od terminu nawożenia dolistnego borem, zabieg ten powodował wzrost plonowania drzew. Zarówno wiosenne jak i jesienne nawożenie dolistne borem zwiększało koncentrację boru w kwiatach, zawiązkach owocowych oraz w liściach 28 dni po kwitnieniu. Jedynie jabłka z drzew opryskiwanych wiosną borem miały podwyższony poziom boru oraz były bardziej wybarwione niż owoce z drzew kontrolnych. Jesienne nawożenie dolistne spowodowało uszkodzenie liści co nie miało jednak wpływu na intensywność defoliacji. Uzyskane wyniki wskazują, że jesienne nawożenie dolistne borem jest skutecznym zabiegiem zwiększającym plonowanie jabłoni w warunkach niedostatecznego odżywienia tym składnikiem.

S ł o w a k l u c z o w e: jabłoń, nawożenie dolistne borem