J. Elem. s. 449–459 DOI: 10.5601/jelem.2013.18.3.09

EFFECT OF BORON FOLIAR APPLICATION AT CRITICAL GROWTH STAGES ON SUNFLOWER (*HELIANTHUS ANNUUS* L.) YIELD AND QUALITY

Petr Škarpa

Department of Agrochemistry, Soil Science Microbiology and Plant Nutrition Mendel University in Brno

Abstract

The objective of the reported vegetation experiment, established in 2008-2011, was to explore the effect of the date of foliar boron application on the yield and quality of sunflower. Four treatments were established in the experiment: 1) control – not fertilised with boron; 2) application of 300 g B ha^{-1} in the growing stage of 4 developed leaves (V-4); 3) application of 300 g B ha^{-1} at the beginning of elongation growth (R-1); and 4) split rate of boron application of 150 g B ha^{-1} at stage V-4 (4 developed leaves) and 150 g B ha^{-1} at stage R-1 (terminal bud forms).

Foliar nutrition with boron increased the content of this element in leaves and stems, and raised the biomass production of sunflower plants. The increased uptake of nutrients by plants was essential for achene production. Application of boron fertilizer at stage V-4 increased the N content in the plant. Boron had a considerable effect on achene production. The highest increase in yields was related to the foliar boron application at stage V-4 (by 8.3% relatively). The relative increase in the oil content in response to boron application, which ranged within 1-2%, was not significant. The higher yields and a constant oil content increased oil production, most markedly after the boron foliar application at stage V-4 (by 10.2%). It was only the content of stearic acid that was increased significantly by foliar application of B at stage V-4 and split application (by 8.8% and 9.4%, respectively).

Key words: sunflower, boron, foliar application, yield, oil content.

ing. Petr Škarpa, Ph.D., Department of Agrochemistry, Soil Science, Microbiology and Plant Nutrition, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic, e-mail: petr.skarpa@mendelu.cz

WPŁYW NAWOŻENIA DOLISTNEGO BOREM W TRAKCIE KRYTYCZNYCH FAZ WZROSTU NA PLON I JAKOŚĆ PLONU SŁONECZNIKA (*HELIANTHUS ANNUUS* L.)

Celem doświadczenia wegetacyjnego, przeprowadzonego w latach 2008-2011, było zbadanie wpływu terminu nawożenia dolistnego borem na plon i jakość plonu słonecznika. Doświadczenie składało się z czterech obiektów: 1) kontrolnego – nie nawożonego borem; 2) z zastosowaniem 300 g B ha^{-1} w fazie wzrostu 4 rozwiniętych liści (V-4); 3) z zastosowaniem 300 g B ha^{-1} na początku fazy strzelania w łodygę (R-1); 4) z zastosowaniem podzielonej dawki boru: 150 g B ha^{-1} w fazie V-4 (4 rozwinięte liście) i 150 g B ha^{-1} w fazie R-1 (tworzenie pąków).

Nawożenie dolistne borem zwiększało zawartość tego pierwiastka w liściach i łodygach słonecznika oraz ilość wytworzonej biomasy. Zwiększony pobór składników odżywczych przez rośliny jest fundamentalny dla ich owocowania. Zastosowanie nawozu w postaci boru w fazie V-4 zwiększyło zawartość azotu w roślinach. Bor miał znaczny wpływ na plon słonecznika. Największy wzrost plonu odnotowano w przypadku stosowania boru w fazie V-4 (wzrost o 8,3%). Stosunkowy wzrost zawartości oleju pod wpływem zastosowania boru, który wahał się od 1 do 2%, nie był istotny. Wyższe plony i stałą zawartość oleju uzyskano najbardziej wyraźnie po zastosowaniu boru w fazie V-4 (wzrost o 10,2%). Jedynie zawartość kwasu stearynowego zwiększyła się istotnie pod wpływem dolistnej aplikacji boru w fazie V-4 (wzrost o 8,8%) lub dawki podzielonej na dwie części (wzrost o 9,4%).

Słowa kluczowe: słonecznik, bor, nawożenie dolistne, plon, zawartość oleju.

INTRODUCTION

As a certain problem in growing sunflower, the second most important oil plant in the Czech Republic, we see the stagnation of yields. From 1996 to 2011, the yields were 1.99 t/ha on average, while the genetic potential of sunflower is to produce as much as 5 tons per hectare. Implementation of new and more efficient varieties, as well as optimization of sunflower nutrition by means of rational application of fertilisers could stimulate the yields.

Sunflower is a plant with high demand for boron (B) and, depending on specific soil conditions, for other trace elements. To some extent, the uptake of nutrients by plant roots depends on soil properties (particularly soil pH) and supply of micronutrients in the soil. The critical content of boron at the time of sunflower emergence is 20 mg kg^{-1} of soil (Asad 2002). That is the reason why farmers prefer foliar nutrition when applying micronutrients. Some authors (Asad et al. 2003, Zerrari, Moustaoui 2005) have described the effects of foliar application of boron on the growth and development of sunflower. Zerrari and Moustaoui (2005) stated that the boron content corresponding to its deficit is 32.5 mg B kg^{-1} of dry matter. The demand of sunflower for boron is varied, depending on the stage of plant growth. The critical content of boron in sunflower at the age of 4 weeks is 46.0-63.0 mg B kg^{-1} of dry matter, while 8-week old plants need just 36.0 mg B kg^{-1} (Rashid, Rafique 2005). Sunflower plants with the tissue content of boron ranging between 16.5 and 23.0 mg kg^{-1} of dry matter require 300 g B ha^{-1}, and for plants containing between 23.0 and 32.5 mg B kg^{-1} of dry matter, the rate of 150 g B ha^{-1} is sufficient Boron application significantly increases not only its content in the plant, but also the dry matter production and achene yields (Sharma et al. 1999, Rashid, Rafique 2005, Zerrari, Moustaoui 2005). Boron is an important element, which affects yields of sunflower, cotton (Dordas 2006a), rape (Asad et al. 2002), alfalfa (Dordas 2006b) and maize (Hosseini et al. 2007).

The objective of this study was to determine the critical stage of boron foliar applications in sunflower, assuming its positive effects on the biomass production, content of nutrients in dry matter, achene yield, oil content, oil production and content of fatty acid in sunflower oil.

MATERIAL AND METHODS

In 2008-2011, a field trial with sunflower (*Helianthus annuus*) was established at the School Farm of the Mendel University in Brno in Žabčice (49°00'45"N, 16°37'50"E) and the Ivaň Farm Cooperative in the district of Vranovice (48°57'26"N, 16°36'18"E). In the experiment, we explored the effect of the date of boron application on sunflower production and achene quality.

The content of nutrients in the soil analysed prior to the establishment of the experiment (Table 1) was on an adequate to very high level. The soil reaction (pH/$CaCl_2$) was slightly acid (2010, 2011) to neutral (2008, 2009). The content of available B in soil (Berger and Truog) is given in Table 1.

In all the years of the experiment, we used the hybrid Orasole (early hybrid with high achene yields, high oil content and a higher proportion of oleic acid, i.e. a high oleic plant). Prior to sowing, the plot was fertilized to a rate of 100 kg N ha^{-1} (this rate included the content of N_{min} determined before sowing – Table 1). On sowing, the inter-row distance was 75 cm, the seeds in the row were spaced 20 cm apart and planted to a depth of 4-6 cm. After sowing, the plot was compacted and a pre-emergence application of herbicides followed.

After the emergence of the plants, a micro-plot experiment was established (4.5 m x 15 m plot area; 450 plants on plot). Application of B was performed in the form of foliar nutrition during the developmental stages V-4 (4 developed leaves and stage) and R-1 (terminal bud forms a miniature floral head rather than a cluster of leaves), in combinations and rates given in Table 2. Boron was applied in the form of ethanolamine as sodium pentaborate. Each treatment was repeated 4 times.

The content of dry matter and the levels of nutrients (N, P, K, Ca, Mg and B) were determined in plant mass in developmental stages V-4, R-1 and

Table 1

Agrochemical characteristics of the soil

Year	pH/$CaCl_2$	Nmin (kg ha^{-1})	Content of nutrients in (mg kg^{-1} DM) soil (Mehlich 3)				Available B (mg kg^{-1})
			P	K	Ca	Mg	
2008	6.2	15.0	91	254	2672	244	0.83
2009	6.2	5.0	66	179	4477	313	0.80
2010	6.7	8.6	63	111	2321	164	0.71
2011	6.8	12.6	78	206	2864	262	0.75

Table 2

Treatments of the experiment

Treatments of fertilization	Dose of B (g ha^{-1})	Time of application*
Control	0	–
Boron 1	300	V-4
Boron 2	300	R-1
Boron 3	150	V-4
	150	R-1

* Stages of sunflower development (Schneiter, Miller 1981)

R-2 (immature bud elongates 0.5 to 2.0 cm above the nearest leaf attached to the stem). The samples of plant mass were dried at a temperature of 60°C, then crushed in a grinder and homogenized. The resultant crushed plant mass was mineralized using a mixture of H_2SO_4 and H_2O_2 (Zbíral 2005). The amount of N in the mineralized sample was determined using the Kjeldahl's method. The content of P in the extract was determined colorimetrically on an ATI Unicam 8625 UV/VIS spectrophotometer. The levels of K, Ca, and Mg were determined in mineralized samples using Atomic Absorption Spectrophotometry (AAS) with a Carl Zeiss Jena AAS-30 instrument. The content of B was determined by ICP-AES.

Sunflower was harvested when it reached physiological ripeness. The yield of achenes, oil content, oil production and levels of fatty acids (palmitic, stearic, oleic and linoleic) in the achenes were evaluated after harvest. The oil content was determined using the Soxhlet method based on the extraction of sunflower achenes in a continuous flow extractor. The levels of fatty acids (FA) were determined as methyl esters using Gas Chromatography (Hougen, Bodo 1973).

The Statistica 9 programme was used for the determination of overall characteristics. Arithmetic means were calculated when evaluating the results of experiments from 2008-2011. In order to elaborate the significance of differences among the arithmetic means of each characteristic, we used one- and two-factor analyses of variance followed by testing at 95% ($p < 0.05$), 99% ($p < 0.01$) and 99.9% ($p < 0.001$) levels of significance using the Fischer's LSD test.

RESULTS AND DISCUSSION

According to Cerkal et al. (2011), the nutrient content determined in stage V-4 (Table 3) showed that sunflower was well nourished. However, the soil had a low content of B and was therefore unable to provide the plant with an amount sufficient according to the plant material analyses (the optimal B content ranges between 35 and 100 mg kg^{-1}).

Table 3

Dry weight (g per plant) and nutrients concentration (% DM, mg kg^{-1} DM) of plant in the V-4 stage of sunflower development

Dry weight of plant (g per plant)	Content of nutrients					
	(% DM)					(mg kg^{-1} DM)
	N	P	K	Ca	Mg	B
3.01±0.33	4.27±0.33	0.40±0.04	5.04±0.30	1.94±0.43	0.77±0.11	35.60±3.07

Values show means of experiments in 2008-2011± SEM

Foliar application of boron in stage V-4 increased the boron content in the plant biomass; in plant leaves the increase was significant ($p < 0.05$). Asad et al. (2003) also discovered that foliar application of boron increased the concentration of B in all parts of the sunflower plant. The rate of 150 g B ha^{-1} (Boron 3) increased the concentration of B in leaves comparably to the treatment with 300 g B ha^{-1}. The relative increase in the boron content thus ranged between 37.6 and 52.6 mg kg^{-1}. Foliar nutrition did not significantly affect its content in the stem. Boron application increased the uptake of macro biogenic nutrients (especially N), as can be seen in analyses of plants taken in stage R-1 (Table 4). Foliar nutrition with boron at V-4 also increased the dry matter yield of the plants (Table 4), both in leaves (by 21.0-22.5%) and in stems (by 18.6-36.0%). Boron deficiency in sunflower inhibits plant growth and reduces dry matter production (Bonacin et al. 2008).

The positive effect of boron fertilization in stage R-1 on dry matter production (Boron 2) is obvious from the results of analyses of plants in stage R-2 (Table 5). The dry matter yield of leaves and stems increased by 21.1%

Table 4

Dry weight (g per plant) and concentration of nutrients concentration (% DM, mg kg^{-1} DM) of plants in the R-1 stage of sunflower development

Treatments of fertilization	Part of plant	Dry weight of plant (g per plant)	Content of nutrients					
			(% DM)					(mg kg^{-1} DM)
			N	P	K	Ca	Mg	B
Control	leaves	8.68±1.51	4.13±0.42	0.40±0.04	4.23±0.39	2.05±0.63	0.89±0.20	66.44 ^{a}±1.58
Boron 1	leaves	10.63±1.62	4.51±0.14	0.47±0.02	4.05±0.44	2.07±0.64	0.85±0.20	101.38 ^{b}±2.17
Boron 3	leaves	10.50±1.84	4.56±0.22	0.45±0.03	4.24±0.44	2.07±0.70	0.83±018	91.45 ^{b}±1.58
Control	stems	3.77±1.41	2.09±0.38	0.28±0.02	5.87±1.05	1.18±0.22	0.81±0.17	49.07 ^{a}±1.85
Boron 1	stems	4.47±0.86	2.39±0.18	0.36±0.05	5.83±0.85	1.23±0.30	0.91±0.25	44.96 ^{a}±1.39
Boron 3	stems	5.13±1.36	2.18±0.10	0.34±0.05	5.96±0.71	1.19±0.31	0.86±0.24	43.75 ^{a}±1.30

$P < 0.05$ – statistical significance at a 95% level of significance.
Variants with identical letters express statistically insignificant differences. Values show means of experiments in 2008-2011 ± SEM

Table 5

Dry weight (g per plant) and nutrients concentration (% DM, mg kg^{-1} DM) of plant in the R-2 stage of sunflower development

Treatments of fertilization	Part of plant	Dry weight of plant (g per plant)	Content of nutrients					
			(% DM)					(mg kg^{-1} DM)
			N	P	K	Ca	Mg	B
Control	leaves	27.55±4.20	3.02±0.28	0.36±0.02	3.35±0.65	1.74±0.53	0.83±0.16	61.99 ^{a}±1.51
Boron 1	leaves	28.92±1.01	3.05±0.38	0.38±0.03	3.52±0.50	1.63±0.45	0.82±0.16	72.23 ^{b}±2.12
Boron 2	leaves	33.34±3.87	3.17±0.22	0.38±0.02	3.65±0.39	1.63±0.47	0.73±0.17	76.47 ^{b}±2.31
Boron 3	leaves	28.39±4.09	3.06±0.33	0.40±0.03	3.53±0.51	1.63±0.49	0.75±0.16	78.41 ^{b}±2.34
Control	stems	26.15±2.46	1.10±0.38	0.25±0.02	4.49±1.07	0.83±0.20	0.71±0.19	24.02 ^{a}±1.82
Boron 1	stems	29.56±3.23	1.11±0.28	0.23±0.01	4.02±0.75	0.68±0.13	0.68±0.24	23.68 ^{a}±0.67
Boron 2	stems	30.87±4.85	1.16±0.37	0.24±0.01	4.42±0.84	0.73±0.18	0.64±0.25	23.35 ^{a}±2.21
Boron 3	stems	27.10±3.49	1.08±0.40	0.26±0.02	4.59±1.33	0.77±0.15	0.70±0.20	26.43 ^{b}±0.12

$p < 0.05$ – statistical significance at a 95% level of significance. Variants with identical letters express statistically insignificant differences. Values show means of experiments in 2008-2011 ± SEM.

and 18.0%, respectively. Foliar boron application increased the boron content in the sunflower plant biomass statistically significantly ($p < 0.05$) versus the unfertilised treatment (in leaves by 23.4%). Likewise, in the treatment where a split rate of boron was applied, the biomass yield increased and its content in the plant increased significantly ($p < 0.05$).

Boron applications had a positive effect on achene production in all fertilisation treatments (Figure 1). BLAMEY et al. (1997), ZERRARI and MOUSTAOUI (2005) and SUMATHI et al. (2005) also reported elevated achene yields after fertilisation with boron. Achene yields increased statistically significantly ($p < 0.05$) after boron application at V-4 (Boron 1) by 8.3%. SOUZA et al. (2004) and MARTIN et al. (2010) reported 15 to 40% reduction in yields due to boron deficiency. Additional B nutrition in treatments Boron 2 and Boron 3 increased yields, although not statistically significantly ($p < 0.05$).

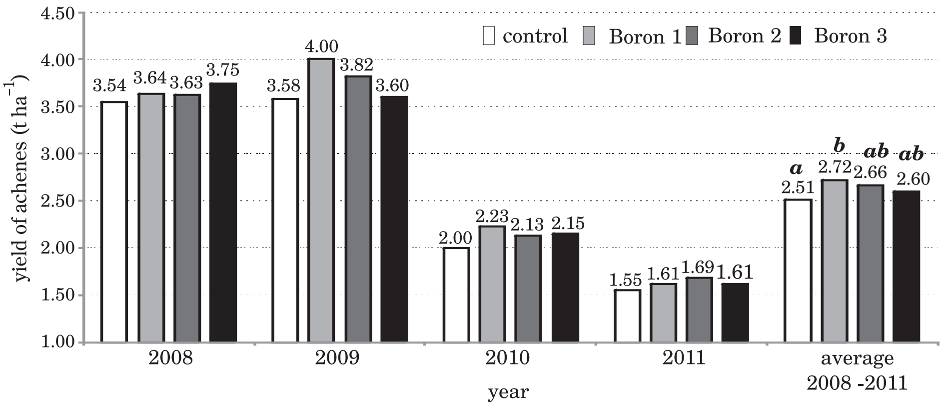

Fig. 1. Effect of different foliar boron application on yield of achenes
Means followed by different letters are significantly different (yield of achenes – $P < 0.05$).
Values show means of experiments in 2008-2011

Foliar boron nutrition increased the oil content in treatments with single boron application (Boron 1 and Boron 2), with an increase ranging between 1.2 and 1.8% (Table 6), which was not statistically significant ($p < 0.05$). In all the treatments, the oil content ranged between 44.47 and 45.65%. Also CEYHAN et al. (2008) reported lower oil content due to B application.

Owing to higher yields and a stabile oil content, the resulting effect of fertiliser application was higher oil production (in t ha^{-1}); the fertilisation combinations statistically significantly ($p < 0.05$) exceeded the control treatment, most highly the one with boron application at the beginning of vegetation (Boron 1; an increase by 10.2%).

Table 6

Effect of different foliar boron fertilization on oil content (%) and oil production (t ha^{-1})

Treatments of fertilization	Oil content (%)	Oil production (t ha^{-1})
Control	44.83 ^{a} ± 0.61	1.191 ^{a} ± 0.083
Boron 1	45.65 ^{a} ± 0.56	1.313 ^{b} ± 0.026
Boron 2	45.37 ^{a} ± 0.50	1.258 ^{ab} ± 0.024
Boron 3	44.47 ^{a} ± 0.77	1.258 ^{ab} ± 0.025

Means followed by the different letters are significantly different ($p < 0.05$).
Values show means of experiments in 2008-2011 ± SEM

In terms of the qualitative parameters of sunflower yield, we evaluated the share of fatty acids in sunflower oil; their composition is given in Table 7. Oleic acid is claimed to be among the most important fatty acids (the proportion of oleic acid in sunflower of the high oleic type should be at least 82%). The results of our analysis showed that the content of oleic acid ranged between 86.51 and 88.42%, and foliar nutrition with boron did not have a significant ($p < 0.05$) effect on its amount. Application of B increased significantly ($p < 0.05$) only the content of stearic acid, which ranged between 1.5 and 9.4%, and was the highest in the treatment with split rates of boron.

Table 7

The content of fatty acid (%) in sunflower oil

Treatments of fertilization	C 16:0	C 18:0	C 18:1	C 18:2
Control	3.39 ^{a}±0.10	3.20 ^{a}±0.08	87.01 ^{a}±1.24	6.28 ^{a}±1.26
Boron 1	3.41 ^{a}±0.08	3.48 ^{b}±0.09	86.51 ^{a}±0.95	6.50 ^{a}±0.96
Boron 2	3.45 ^{a}±0.17	3.25 ^{ab}±0.10	88.06 ^{a}±0.86	5.13 ^{a}±0.82
Boron 3	3.24 ^{a}±0.08	3.50 ^{b}±0.11	88.42 ^{a}±0.64	4.72 ^{a}±0.65

Palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2).
Means followed by the different letters are significantly different ($p < 0.05$). Values show means of experiments in 2008-2011 ± SEM.

CONCLUSIONS

Foliar application of boron increased the biomass production of sunflower plants and raised its content in leaf and stem dry matter. Early application of boron (stage V-4) also increased the uptake of macro biogenic nutrients (particularly N). Similarly to the year of cultivation, the application of boron had a statistically significant effect on sunflower yields. The achene yield increased significantly (by 8.3%) after the application of 300 g B ha^{-1} at the beginning of vegetation (stage V-4). Owing to the increased yields and stabile oil content, the oil production increased and was the highest after the application of boron fertilisation at the beginning of vegetation (by 10.2% relatively).

ACKNOWLEDGEMENTS

This study was supported by the National Agency for Agriculture Research of the Czech Republic No. QH 81271 called Optimization of the nutrition and fertilization of the sunflower with the aim of increasing the yield and quality of production.

REFERENCES

ASAD, A. 2002. *Boron requirements for sunflower and beet*. J. Plant Nutr., 25: 885-899.

ASAD, A., BLAMEY, F.P.C., EDWARDS, D.G. 2002. *Dry matter production and boron concentrations of vegetative and reproductive tissues of canola and sunflower plants grown in nutrient solution*. Plant Soil, 243: 243-252.

ASAD, A., BLAMEY, F.P.C., EDWARDS, D.G. 2003. *Effects of boron foliar applications on vegetative and reproductive growth of sunflower.* Ann. Bot., 92: 565-570.

BLAMEY, F.P.C., ZOLLINGER, R.K., SCHNEITER, A.A. 1997. *Sunflower production and culture*. In: *Sunflower science and tehnology*. Ed. Schneiter, A.A., ASA, Madison, 595-670.

BONACIN, G.A., RODRIGUES, T.J.D., CRUZ, M.C.P., BANZATTO, D.A. 2008 *Características morfofisiológicas de sementes e produção de girassol em função de boro no solo*. Revista Brasileira de Engenharia Agrícola e Ambiental, 13: 111-116.

CERKAL, R., KAMLER, J., ŠKARPA, P., POKORNÝ, R., MAREČEK, V., FAJMAN, M., MUŠKA, F. 2011. *Methods of cultivation and important factors affecting the yield and quality of sunflower.* In: *Sunflowers: cultivation, nutrition, and biodiesel uses*. Nova Science Publishers, Inc., New York, 47-98.

CEYHAN, E., ONDER, M., OZTURK, O., HARMANKAYA, M., HAMURCU, M., GEZGIN S. 2008. *Effects of application boron on yields, yield component and oil content of sunflower in boron-deficient calcareous soils.* Afr. J. Biotechnol., 7: 2854-2861.

DORDAS, C. 2006a. *Foliar boron application affects lint and seed yield and improves seed quality of cotton grown on calcareous soils*. Nutr. Cycl. Agroecosyst., 76: 19-28.

DORDAS, C. 2006b. *Foliar boron application improves seed set, seed yield, and seed quality of alfalfa*. Agron. J., 98: 907-913.

HOSSEINI, S.M., MAFTOUN, M., KARIMIAN, N., RONAGHI, A., EMAM, Y. 2007. *Effect of zinc x boron interaction on plant growth and tissue nutrient concentration of corn.* J. Plant Nutr., 30: 773-781.

HOUGEN, F.W., BODO, V. 1973. *Extraction and methanolysis of oil from whole or crushed rapeseed for fatty-acid analysis*. J. Am. Oil Chem. Soc., 50: 230-234.

MARTIN, T.N., PAVINATO, P.S., GLASENAPP DE MENEZES, L.F., BERTONCELLI, P., ORTIZ, S. 2010 *Phytomass partition of sunflower silage, under boron and calcium fertilization*. 19th World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane, Australia, 191-194.

RASHID, A., RAFIQUE, E. 2005. *Internal boron requirement of young sunflower plants: Proposed diagnostic criteria.* Commun. Soil Sci. Plant Anal., 36: 2113-2119.

SHARMA, K.R., SRIVASTAVA, P.C., GHOSH, D., GANGWAR, M.S. 1999. *Effect of boron and farmyard manure application on growth, yields, and boron nutrition of sunflower.* J. Plant Nutr., 22: 633-640.

SCHNEITER, A.A., MILLER, J.F. 1981. *Description of sunflower growth stages*. Crop Sci., 21: 901-903.

SOUZA, A., OLIVEIRA, M.F., CASTIGLIONI, V.B.R. 2004. *The effect of boron on sunflower crop*. Semin.-Cienc. Agrar., 25: 27-34.

SUMATHI, P., NIRMALAKUMARI, A., MURALIDHARAN, V. 2005. *Pollen use effýcýency of sunflower (Helianthus annuus* L.*) lýnes cms 234 A and RHA 6D-1.* Helia, 28: 99-106.

ZBÍRAL, J. 2005. *Plant analysis*. Central Institute for Supervising and Testing in Agriculture, Brno, Czech Republic. (in Czech)

ZERRARI, N., MOUSTAOUI, D. 2005. *The fertilisation of the sunflower (Helianthus annuus* L.*) in boron*. I. *Field calibration trials of plant analyses and recommendations for foliar fertilisation*. Agrochimica, 49: 182-189.