J. Elementol. 2009, 14(2): 383–393

EFFECTS OF BORON FERTILIZATION OF SPRING CEREALS DEPENDING ON APPLICATION METHODS*

Stanisław Wróbel

Institute of Soil Science and Plant Cultivation National Research Institute in Pulawy
Department of Weed Science and Tillage Systems in Wroclaw

Abstract

The study is a comparison of effects produced by boron fertilization applied to spring barley and oats, grown on light soil, low in available boron, in relation to the application method (pre-sowing, top dressing, foliar applications) and rates of the element. The study was carried out as a three-year series of one-year, two-factor strict field trials (the split-plot design). It has been demonstrated that top dressing with boron applied to soil at the tillering stage as well as foliar fertilization during the stem elongation stage can significantly improve yields. Grain of both cereals from the control plots showed symptoms of insufficient boron nutrition, which were absent when boron fertilization had been applied. Presowing fertilization, although not affecting the yields, improved the supply of grain with boron. Differences between the cereal species were found in terms of boron concentrations in vegetative organs of the cereals and in their response to higher availability of this nutrient. Compared to spring barley, oats was characterised by a much higher content of boron in vegetative parts and was more responsive to increased concentrations of boron in soil.

Key words: boron deficiency, soil or foliar application of boron, boron concentration, yields.

EFEKTYWNOŚĆ NAWOŻENIA ZBÓŻ JARYCH BOREM W ZALEŻNOŚCI OD SPOSOBU APLIKACJI

Abstrakt

W badaniach porównywano efekty nawożenia borem jęczmienia jarego i owsa, uprawianych na glebie lekkiej o niskiej zawartości boru przyswajalnego, w zależności od sposo-

Stanisław Wróbel, Department of Weed Science and Tillage Systems in Wroclaw ul. Orzechowa 61, 50-540 Wrocław, Poland

* The work has been prepared as a part of task 2.4 in the IUNG-PIB long-term programme.

bu stosowania (przedsiewnie, doglebowo pogłównie, dolistnie) oraz dawki. Badania przeprowadzono w jednorocznych dwuczynnikowych doświadczeniach polowych ścisłych (metodą split-plot), powtarzanych przez trzy lata. Wykazano istotne działanie plonotwórcze nawożenia doglebowego pogłównego borem, stosowanego w stadium krzewienia oraz dolistnego w stadium strzelania w źdźbło. Ziarno obu zbóż z obiektów kontrolnych wykazywało niedostateczne zaopatrzenie w ten składnik, które ulegało poprawie pod wpływem stosowania boru, w najwyższym stopniu – pogłównie doglebowo. Nawożenie przedsiewne nie wpływało na poziom plonowania, poprawiało jednak zaopatrzenie ziarna w badany mikroelement. Stwierdzono różnice międzygatunkowe w zawartości boru w częściach wegetatywnych zbóż oraz wrażliwość na zwiększoną dostępność tego składnika. Zawartość boru w częściach wskaźnikowych owsa była istotnie wyższa w porównaniu z jęczmieniem jarym i zwiększała się w większym stopniu wraz ze wzrostem tego składnika w glebie.

Słowa kluczowe: deficyt boru, nawożenie doglebowe lub dolistne borem, zawartość boru, plony.

INTRODUCTION

In the past, the recommendations on fertilization of older generations of cereals contained an assumption that boron fertilization was useless and sometimes even harmful to these crops. The concept was derived from such traits of cereal plants as low nutritional requirements for boron and a narrow gap between the optimum and excessive amounts of this microelement in plant tissues. Another important aspect was that cereal shoots were very sensitive to increased concentrations of boron in soil (TAHTINEN 1970). Cereals grown after a forecrop of root crops fertilized with boron (e.g. beetroot) responded negatively to increased boron concentrations in soil by producing lower yields. Under the agronomic technologies currently used in cereal crop cultivation, new, high-yielding generation cultivars of cereal crops, characterised by high nutritional demands, often struggle with insufficient supply of boron. Several factors can be involved, such as the widespread deficit of boron in soils, lack of manure, use of low-ballast fertilizers, frequent spells of dry weather in spring, simplified tillage and crop rotation systems (monocultures) (BELL 2000, HUANG et al. 2000). Another independent albeit important reason why boron fertilization can be a recommended procedure is the increasing nutritional demands (Biała Księga 2000). The results of several research projects completed in the USA suggest that boron plays an important role in the metabolism of higher organisms, which casts a new light on the value of this element in diets for mammals (NIELSEN 1996). Thus, good boron supply of cereals, staple foodstuff and fodder crops, acquires a new meaning.

The objective of the present study has been to evaluate the effect of boron fertilization applied to highly productive cultivars of spring barley and oats, observed in a strict field experiment set up on soil low in available boron. Three fertilization methods were assessed: pre-sowing, top-dressing and foliar.

METHODS

The study was carried out over the years 2001-2003 as a three-year series of one-year, two-factor strict field trials (the split-plot design) with spring barley and oats. The trials were established on boron-deficient soils (according to a 1 mol $HCl \cdot dm^{-3}$ test) at IUNG-PIB experimental stations. The experiment involving spring barley (cultivar Brenda) was carried out on a light (heavy loamy sand), slightly acidic soil, with a high content of phosphorus, potassium and magnesium, low concentrations of boron (0.70-1.30 mg $B \cdot kg^{-1}$) molybdenum and manganese, moderate supply of copper and very high level of zinc. The soils selected for the trials on oats (cultivar Borowiak) also belonged to light, acidic soils (light loamy sand) and contained high concentrations of phosphorus, potassium, magnesium and zinc, average content of copper, iron and manganese and low amounts of boron (0.60-0.80 mg $B \cdot kg^{-1}$) and molybdenum (Zalecenia nawozowe 1990).

The design of the experiment:

Factor I (boron application methods, A = 3): A_1 – pre-sowing, H_3BO_3 in the solid form (10-15 days before sowing), A_2 – top-dressing fertilization, H_3BO_3 in the solid form applied to soil at the tillering stage, A_3 – foliar, aqueous solution of H_3BO_3 applied at the stem elongation stage. Factor II – rates of boron, B = 5, (concentrations of H_3BO_3 solutions for foliar application in brackets): B_1 – control treatment - without boron fertilization, B_2 – 0.6 kg $B \cdot ha^{-1}$ (0.1% = 0.085 kg $B \cdot ha^{-1}$), B_3 – 1.2 kg $B \cdot ha^{-1}$ (0.2% = 0.170 kg $B \cdot ha^{-1}$), B_4 – 1.8 kg $B \cdot ha^{-1}$ (0.3% = 0.255 kg $B \cdot ha^{-1}$), B_5 – 2.4 kg $B \cdot ha^{-1}$ (0.4% = 0.340 kg $B \cdot ha^{-1}$). The experimental plots measured 10.0 m x 3.0 m when establishing the trials, and 10.0 x 2.5 m for the harvest. The cereals were grown according to the principles of rational agronomy, taking into account the soil and climatic conditions, stand, forecrop, soil fertility, etc. The weather conditions did not much differed over subsequent research years. Winter throughout the three years showed mild temperatures, higher that the multi-year norms, at lower precipitation. In 2001 March and July recorded heavier precipitation (about 35 and 70 mm above the multi-year mean, respectively). The two successive years kept mostly near-normal temperatures and precipitation with more considerable water deficits in June 2003 or in July 2002. Full chemical control of the experimental plots was performed. Grain yields were measured. For chemical analyses, the following were sampled: aerial parts of plants at the early heading stage (barley) or the early booting stage (oats) – the indicator parts according to BERGMANN & NEUBERT (1976), grain and straw at the harvest and soil from the arable layer (0-20 cm deep) after the termination of the trials. Chemical analyses of soil and plants were performed with the methods commonly used in agrochemical stations.The plant material after wet mineralization was determined to define the content of nitrogen with Kjeldahl method, phosphorus with the vanadium-molybdenum method, potassium and calcium – with the flame photometry and magnesium – with the AAS method. The content of microelements in dry mineralized plants was determined with the AAS method (Cu, Mn and Zn) except for colorimetrically determined boron – the method with curcumin and molybdenum – the thiocyanate method (Metody badań 1980). pH of soil in 1 mole KCl·dm^{-3}, granulometric composition of soil following Casagrande modified by Prószyński. The content of available forms of phosphorus and potassium in soil were determined with Egner and Riehm method, magnesium following Schachtschabel (Metody badań 1980). To determine the microelements (B, Cu, Mn, Mo, Zn), the soil was extracted with the so-called common extractant (1 mole HCl·dm^{-3}) following the instructions developed by IUNG (GEMBARZEWSKI, KORZENIOWSKA 1990). Cu, Mn and Zn were determined with the AAS method, boron and molybdenum – calorimetrically. The results of the soil analyses were estimated with the applicable threshold values (Zalecenia Nawozowe 1990).

The results underwent statistical processing with analysis of variance, correlation and multiple regression with Statgraphics package and AWAR program (FILIPIAK, WILKOS 1995, FILIPIAK, WILKOS 1998). The significance of cross-object differences in variance analysis were evaluated with Tukey's test (a Ł 0.05).

RESULTS AND DISCUSSION

Similar tendencies in the response of grain yields of both cereals to boron fertilization were observed depending on the method of boron application and its rate. As a result of this interaction, statistically the highest yields were obtained in the sub-blocks which had received base top dressing fertilization and foliar fertilization, with the latter treatment method producing substantially better results, especially with respect to oats (Table 1). The fact that the cereals did not respond to pre-sowing boron application with improved grain yields can be attributed to the negative effect of boron on germinating cereal plants (TAHTINEN 1970). Another factor which comes to play is the time lapse between the introduction of the fertilizer to soil and the moment when the plants' demand for this nutrient was the highest. In contrast, boron applied in a top-dressing treatment during the tillering stage was a good source of this element for the crops, which was reflected by the positive response to boron fertilization with both improved grain yields and higher boron concentration in grain. The highest rates of boron applied with this method caused non-significant decrease in yields, which confirmed the assumption that cereals are responsive to elevated availability of boron (NABLE et al. 1997). Boron used for foliar treatments applied during the critical stage of the crop development proved to be most effective in stimulating higher yields. As the data set in table 1 indicate, this method of boron appli-

Table 1

Response of spring cereal grain yield to boron fertilization (three-year average)

Treatment			Spring barley	Oats	Mean
			$Mg \cdot ha^{-1}$		cereal units$\cdot ha^{-1}$
Fertilization	pre-sowing	A_1B_1	4.19	4.58	43.85
		A_1B_2	4.17	4.72	44.45
		A_1B3	4.21	4.70	44.55
		A_1B_4	4.20	4.65	44.25
		A_1B_5	4.22	4.49	43.55
	top-dressing	A_2B_1	4.17	4.58	43.75
		A_2B_2	4.38	4.74	45.60
		A_2B_3	4.40	5.12	47.60
		A_2B_4	4.37	5.15	47.60
		A_2B_5	4.35	4.94	46.45
	foliar	A_3B_1	4.16	4.57	43.65
		A_3B_2	4.50	5.21	48.55
		A_3B_3	4.50	5.22	48.60
		A_3B_4	4.40	5.26	48.30
		A_3B_5	4.45	5.32	48.85
Average		A_1	4.20	4.63	44.13
		A_2	4.33	4.91	46.20
		A_3	4.40	5.12	47.59
LSD $\alpha \leq 0.05$			0.19	0.23	2.08
Average		B_1	4.17	4.58	43.75
		B_2	4.35	4.89	46.20
		B_3	4.37	5.01	46.92
		B_4	4.32	5.02	46.72
		B_5	4.34	4.92	46.28
LSD $\alpha \leq 0.05$			n.s.*	n.s.	n.s.
LSD $\alpha \leq 0.05$		II/I	0.20	0.33	2.62
		I/II	0.18	0.39	2.77

* n.s. – non-significant differences

cation raised an average yield of cereal units within the range of 4.65-5.20 per ha. For oats, the three-year average grain yield increment ranged from 14.0 to 16.4% versus the control.

The initial boron concentration (in B1 objects without boron fertilization) in the indicator plant parts of both cereal crops was within the optimum range as established by BERGMANN & NEUBERT (1976). Nonetheless, it rose significantly in response to the fertilization. The highest increase in the boron levels in plant tissues occurred under the highest rate of boron, 2.4 kg B·ha^{-1}, applied to soil as a top-dressing treatment. The foliar application of boron to oats proved only slightly less effective. Both absolute values of boron concentrations in vegetative parts and increased boron levels caused by the fertilization were higher in the case of oats, which results mainly from the genetic traits of the two cereal species (RERKASEM, JAMOD 1997). For both cereals, the pre-sowing boron fertilization did not affect the yields but increased the concentration of boron in the indicator parts in a way that was similar to the effects produced by the top-dressing fertilization, which in turn caused an evident stimulating effect on the grain yields (Tables 1 and 2).

Boron supply of cereal grains showed somewhat different tendencies. By referring to the analogous data available from literature, it was discovered that the initial boron concentration in grains of both cereal crops was lower than the norm, but the boron fertilization treatments successfully improved the supply of this element, with the best results obtained when top-dressing applications were used. This finding is confirmed by the correlations: B soil/B barley grain $r = 0.77$; B soil/B oats grain $r = 0.82$; $\alpha = 0.01$. In the case of foliar application, boron concentration levels similar to the comparative data were obtained only when the highest boron rates had been applied. Top-dressing of oats with the highest boron rates proved to be less effective, both in terms of the resulting grain yield mass and the concentration of boron in grain (Tables 1 and 2). The results suggesting high effectiveness of boron top-dressing soil treatments in improving boron concentration in cereal grains are supported by earlier studies (RERKASEM et al. 1997, HUANG et al. 2001, WRÓBEL, SIENKIEWICZ-CHOLEWA 2004). Although foliar application is relatively less expensive, this method cannot compete with the classical soil fertilization, which guarantees ionic balance in soil and continuous dynamics in the uptake of this nutrient, which in turn ensures proper supply of grains with boron. This is also a result of the fact that boron is not reutilized in plants.

The next stage in the evaluation of the effect of a given boron fertilization treatment was the computation of quantitative relations between the content of boron and calcium in tissues of the index parts of barley and oats. As the two elements are antagonistic to each other, the ratio of their quantities in new plants is better at establishing the boron supply than the absolute concentration of boron in plants (SIMOJOKI 1991). The Ca:B values were narrower as the rates of boron increased, which proved that the boron supply of plants improved. The highest doses of boron depressed the mean Ca:B ratios for both cereal indicator parts (Table 2).

The results of the chemical analysis of soil samples after the termination of the trials showed that top-dressing application of boron significantly rose the content of its forms soluble in 1 mol HCl·dm^{-3}, considered to be available forms (GEMBARZEWSKI, KORZENIOWSKA 1990). In both series of the tri-

Table 2

Changes of B concentration and Ca:B quantitative ratio in cereals under boron fertilization (average effect)

Treatment			Barley		Oats		Barley	Oats
			indicator parts	grain	indicator parts	grain	Ca:B (indicator parts)	
			mg B · kg^{-1} of dry matter					
Fertilization	pre-sowing	A_1B_1	8.4	1.2	17.8	1.2	157	475
		A_1B_2	13.3	1.7	29.9	1.2	124	220
		A_1B3	15.4	1.8	31.3	1.3	97	172
		A_1B_4	15.1	1.8	36.3	1.4	107	153
		A_1B_5	18.3	1.7	45.5	1.3	82	120
	top-dressing	A_2B_1	8.2	1.1	18.2	1.2	160	436
		A_2B_2	9.3	1.2	40.3	1.3	133	128
		A_2B_3	13.2	1.8	49.1	1.4	108	113
		A_2B_4	15.7	1.8	50.4	1.8	101	93
		A_2B_5	19.0	2.3	52.1	1.7	77	81
	foliar	A_3B_1	7.8	0.8	17.9	1.1	168	481
		A_3B_2	8.2	1.0	29.2	1.1	154	315
		A_3B_3	8.1	1.0	35.3	1.3	157	237
		A_3B_4	8.9	1.1	38.4	1.3	144	205
		A_3B_5	9.1	1.3	44.0	1.5	146	188
Average		A_1	14.1	1.6	32.2	1.3	113	228
		A_2	13.1	1.6	42.0	1.5	114	202
		A_3	8.4	1.0	33.0	1.3	165	296
LSD $\alpha \leq 0.05$			3.89	0.42	n.s.*	n.s.	33.94	n.s.
Average		B_1	8.1	1.0	18.0	1.2	161.7	464
		B_2	10.3	1.3	33.1	1.2	137.0	221
		B_3	12.2	1.5	38.6	1.3	91.3	174
		B_4	13.2	1.6	41.7	1.5	117.3	150
		B_5	15.5	1.8	47.2	1.5	101.7	130
LSD $\alpha \leq 0.05$			4.74	0.44	19.33	0.17	34.40	139.94
LSD $\alpha \leq 0.05$		II/I	4.33	0.58	17.51	0.31	29.21	155.09
		I/II	4.09	0.54	n.s.	n.s.	23.16	n.s.
Reference levels								
			5-12**	1.34***	15 - 20**	1.44*-**		

* n.s. – non-significant differences
**after Bergmann and Neubert (1976), ***after Fotyma and Mercik (1995)

als, with barley and with oats, this meant that the available boron concentration in soil changed from class III (low) to II (moderate) (Zalecenia nawozowe 1990), Table 3.

By performing step-wise the multiple regression calculations, the effect of boron on higher grain yields was demonstrated in the form of functions. Assuming that grain yield was a dependent variable and the content of nutrients in plants and soil were independent variables, the following equations were obtained:

$$y_{barley} = 0.5009 + 0.2029\ B_{straw} + 0.0473\ P_{soil} + 0.0777\ K_{soil} \qquad R^2 = 0.871;\ \alpha \leq 0.05$$

$$y_{oats} = 0.8718 + 0.0412\ B_{straw} + 0.0842\ Mn_{grain} + 0.4536\ K_{i.p.} \qquad R^2 = 0.73;\ \alpha \leq 0.05$$

where:

- y – grain yield, in t per ha;
- B_{straw} – content of boron in straw of cereal crops, in mg $B \cdot kg^{-1}$ d.m.;
- Mn_{grain} – content of manganese in oats grain in mg $Mn \cdot kg^{-1}$ d.m.
- $K_{i.p.}$ – content of potassium in the indicator parts of oats plants, in mg $K \cdot kg^{-1}$ d.m.;
- P_{soil} K_{soil} – content of available forms of phosphorus and potassium in soil, in $mg \cdot kg^{-1}$ d.m. of soil.

High determination coefficients suggest that the above equations describe large part of the analysed variability of yields, which are significantly affected by a series of factors including the supply of vegetative plant parts (straw) with boron.

The results reported in this paper imply that the issue of boron fertilization of spring cereal crops is a complex one. The effectiveness of foliar application of boron in raising grain yield volumes does not coincide with the situation in which an appropriate level of this nutrient is guaranteed to occur in cereal grains. Plants grown on soils which are low in available boron will have an optimum amount of this element, and then boron fertilization causes substantial increments in the content of boron in the vegetative parts of the plants and in the grain. Certain differences between the two cereal species seem to occur, both in terms of their nutritional demands and sensitivities of the highest rates of boron tested in our study. Thus, it seems worth continuing the present research. The next steps should consist of verification of the criteria applied for assessment of the supply of plants with boron. The ranges of optimum supply suggested by BERGMANN and NEUBERT (1976) concerned older generation of cereals and could be an inadequate reference for contemporary, high-yielding genotypes. Lack of proper criteria makes it impossible to assess precisely how cereal grain is supplied with boron. And such an evaluation will become a necessity under the new EU regulations which follow the principle 'from field to table'. This

Table 3

Available boron content in soil after harvest (three-year average)

Treatment			mg B · kg^{-1}		
			spring barley	oats	average
Fertilization	pre-sowing	A_1B_1	0.88	0.50	0.69
		A_1B_2	1.21	0.33	0.77
		A_1B3	1.18	0.37	0.78
		A_1B_4	1.18	0.72	0.95
		A_1B_5	1.28	0.82	1.05
	top-dressing	A_2B_1	0.86	0.50	0.68
		A_2B_2	1.21	0.54	0.88
		A_2B_3	1.28	0.60	0.94
		A_2B_4	1.41	0.82	1.12
		A_2B_5	1.44	1.12	1.28
	foliar	A_3B_1	0.90	0.52	0.71
		A_3B_2	0.89	0.51	0.70
		A_3B_3	0.93	0.56	0.75
		A_3B_4	1.00	0.50	0.75
		A_3B_5	1.08	0.49	0.79
Average		A_1	1.15	0.55	0.85
		A_2	1.24	0.72	0.98
		A_3	0.96	0.52	0.74
LSD $\alpha \leq 0.05$			0.11	0.13	0.12
Average		B_1	0.88	0.51	0.69
		B_2	1.10	0.46	0.78
		B_3	1.13	0.51	0.82
		B_4	1.20	0.68	0.94
		B_5	1.27	0.81	1.04
LSD $\alpha \leq 0.05$			0.25	0.20	0.23
LSD $\alpha \leq 0.05$		II/I	0.22	0.19	0.21
		I/II	0.28	0.25	0.26

* n.s. – non-significant differences

principle sets forth certain requirements on the chemical composition of foodstuffs, particularly such important agricultural products as grains of cereal plants (Biała Księga 2000). The redefined nutritional recommendations regarding boron are a consequence of the latest global studies which clearly underline the important functions this element plays in the metabolism of calcium and fluorine in bodies of mammals (NIELSEN 1996, NIELSEN 1997). The suggested future studies should focus on nutritional demands of species and cultivars of various crops as well as their response to boron fertilization. The results of the studies conducted until now point to a disturbing fact that soil fertilization with boron is almost a non-existent procedure whereas sporadic fulfilment of plants' nutritional demands via foliar application of multi-component preparations can lead to producing grain that is insufficiently supplied with this important microelement, and such grain is of inferior biological and consumption quality.

CONCLUSIONS

1. Boron fertilization, and particularly soil top-dressing and foliar application of this element, caused significant increase in the grain yields produced by spring barley and oats, grown on soil low in available boron. Presowing fertilization, while not affecting the grain yields, improved the grain supply with boron.

2. Compared to spring barley, oats was characterised by a much higher content of boron in vegetative parts and was more responsive to increased concentrations of boron in soil.

3. Grain of both cereal crops grown under boron deficit in soil contained less than average amounts of this nutrient. Boron fertilization improved boron concentrations in grains. The best results in improving the supply of grain with boron were obtained under top-dressing soil application of this nutrient.

4. The results obtained in the present study suggest that grains produced on soils low in available boron by high yielding cultivars of spring barley and oats, which have high nutritional demands, might contain insufficient amounts of this element even if foliar fertilization had been applied, such as some of popular multi-component micronutrient preparations.

5. Owing to the complex nature of cereal fertilization with boron as well as growing nutritional demands of consumers, studies focusing on this question need to be continued.

REFERENCES

BELL R. W. 2000. *Temporary nutrient deficiency – a difficult case for diagnosis and prognosis by plant analysis.* Commun. Soil Sci. Plant Anal., 31: 1847-1861.

BERGMANN W., NEUBERT P. 1976. *Pflanzendiagnose und Pflanzenanalyse.* VEB Gustaw Fischer Verlag, Jena, 497: 1-711.

Biała księga bezpieczeństwa żywności [The white book of food safety]. 2000. Żywność Żywienie Prawo a Zdrowie. Wyd. I.ŻiŻ, Warszawa, 9 (1): 5-74.

FILIPIAK K., WILKOS S. 1995. *Obliczenia statystyczne. Opis systemu AWAR [Statistical calculations. Description of the AWAR system].* IUNG, Puławy, R (324): 1-52.

FILIPIAK K., WILKOS S. 1998. *Wybrane metody analizy wielozmiennej i ich zastosowanie w badaniach przestrzennych [Selected methods of multivariate analysis and their application to spatial studies].* IUNG, Puławy, R (349): 1-59.

FOTYMA M., MERCIK S. 1995. *Chemia rolna [Agricultural Chemistry].* PWN. Warszawa: 1-244.

GEMBARZEWSKI, H., KORZENIOWSKA, J. 1990. *Simultaneous extraction of B, Cu, Fe, Mn, Mo and Zn from mineral soils and an estimation of the results.* Agribiol. Res., 43 (2): 115-127.

HUANG L., BELL R.W., DELL B. 2001. *Boron supply to wheat (Triticum aestivum L. cv. Wilgoyne) ear during early growth phase.* J. Exp. Bot., 52: 1731-1738.

HUANG L., PANT J., DELL B., BELL R.W. 2000. *Effects of boron deficiency on anther development and floret fertility in wheat (Triticum aestivum L. cv. Wilgoyne).* Ann. Bot., 85: 493-500.

Metody badań laboratoryjnych w stacjach chemiczno-rolniczych [*Laboratory research methdos at chemical and agricultural stations*]. 1980. I-IV. IUNG Puławy,

NABLE R.O., BANUELOS G.S., PAULL J.G. 1997. *Boron toxicity.* Ann. Bot., 66. 83-90.

NIELSEN F.H. 1996. *Evidence for the nutritional essentiality of boron.* J. Trace Elem. Exp. Med., 9: 215-229.

NIELSEN F.H. 1997. *Boron in human and animal nutrition*. Plant Soil., 193: 199-208.

RERKASEM B., Jamod S. 1997. *Genotypic variation in crop response to low boron and implication for plant breeding.* Plant Soil., 193: 169-180.

RERKASEM B., Lordkaew S., Dell B. 1997. *Boron requirements for reproductive development in wheat.* Soil Sci. Plant Nutr., 43: 953-957.

SIMOJOKI, P. 1991. *Boron deficiency in barley*. Ann. Agric. Fenn., 30: 389-405.

TAHTINEN H. 1970. *Residual effect of boron fertilization.* Ann. Agric. Fenn., 9: 331-335.

WRÓBEL S., SIENKIEWICZ-CHOLEWA U. 2004. *Określenie potrzeb nawożenia pszenicy ozimej borem [Determination of boron fertilization needs of winter wheat].* Zesz. Probl. Post. Nauk Rol., 502 (1): 459-466.

XU J.M., WANG K., BELL R.W., YANG Y.A., HUANG L.B. 2001. *Soil boron fractions and their relationship to soil properties. S*oil Sci. Soc. Am J., 65: 133-138.

Zalecenia nawozowe. 1990. *Liczby graniczne do wyceny zawartości w glebach makro- i mikroelementów*. [Fertilization recommendations.1990. *Threshold values for evaluation of soil content of macro- and micronutrients]*] IUNG Puławy, P (44): 1-34.