J. Elementol. 2009, 14(2): 395–404

RESPONSE OF SPRING WHEAT TO FOLIAR FERTILIZATION WITH BORON UNDER REDUCED BORON AVAILABILITY*

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Abstract

The study focused on the effects of foliar fertilization with boron applied to spring wheat grown on sandy soil, low in available boron, under the conditions of simulated drought stress and the soil pH modified by liming. The study involved pot trials set up in a greenhouse. Wagner's pots, each containing 6 kg of light soil, served as experimental units. It was demonstrated that foliar application of boron was effective in mollifying the unfavourable wheat growth and nutrients uptake conditions (drought and soil reaction change). The fertilization alleviated the results of the limited availability of boron, significantly increasing the grain and straw yield mass and enriching the yields with boron. The highest rates of boron used for foliar application (7 and 9 cm^3 0.3% $H_3BO_3 \cdot pot^{-1}$) raised the concentration of this element in wheat grain up to a level comparable to the reference data.

Key words: drought, soil liming, boron fertilization, B content, yields.

REAKCJA PSZENICY JAREJ NA NAWOŻENIE DOLISTNE BOREM W WARUNKACH OGRANICZONEJ DOSTĘPNOŚCI TEGO SKŁADNIKA

Abstrakt

W badaniach określano efekty nawożenia dolistnego borem pszenicy jarej uprawianej na glebie lekkiej o niskiej zawartości boru dostępnego, w warunkach symulacyjnego stresu suszy i zmiany odczynu gleby wskutek wapnowania. Badania przeprowadzono w doświad-

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

czeniach wazonowych, w hali wegetacyjnej. Jednostkę doświadczalną stanowiły wazony Wagnera mieszczące 6 kg gleby lekkiej. Wykazano skuteczność dolistnej aplikacji boru w łagodzeniu niesprzyjających warunków rozwoju pszenicy i pobierania składników (susza i zmiana odczynu gleby). Zastosowane nawożenie łagodziło skutki ograniczonej dostępności składnika, zwiększając istotnie masę plonów ziarna i słomy pszenicy jarej oraz wzbogacając je w bor. Najwyższe z zastosowanych w dolistnej aplikacji dawki boru (7 i 9 cm^3 0,3% $H_3BO_3 \cdot wazon^{-1}$) zwiększały zawartość tego składnika w ziarnie pszenicy do poziomu zbliżonego do porównawczego.

Słowa kluczowe: susza, wapnowanie gleby, nawożenie borem, zawartość B, plony.

INTRODUCTION

Although cereal crops, like other grasses, are less dependent on boron than dicotyledonous plants, it would be erroneous to assume that they did not need to be fertilized with this microelement. Among all major microelements, boron is the one that is most often found deficient in soil, which in turn leads to a deficit of this element in cereal crops (GOLDBACH 1997, GEMBARZEWSKI 2000). Positive response of grain plants to boron fertilization has been demonstrated in strict field experiments (WRÓBEL 2004, WRÓBEL 2006). Moreover, certain findings in physiology have abolished the notion that boron plays no role in the physiology of mammals (NIELSEN 1996). As a result, more attention is now being paid to proper boron nourishment of grain crops, one of the staple food and fodder plants in European agriculture (YAU 2000, BLEVINS, LUKASEVSKI 1998, WRÓBEL 2004, WRÓBEL 2006). Boron is taken up by plants mainly with the water transpiration stream, thus its availability for plants is worse during periods of drought, especially if the soil is low in this element. Elevated soil pH (e.g. after liming) has a similar effect on boron availability. These two factors can considerably inhibit the growth of plants, especially if they occur during critical plant growth phases.

The aim of the study has been to give scientific assessment of the effects of foliar fertilisation with boron applied to spring wheat grown under the deficit of boron in soil, which was subjected to simulated drought during a critical plant growth phase, in relationship with the soil reaction.

MATERIAL AND METHODS

The study involved pot trials set up in a greenhouse at the IUNG-PIB Experimental Station in Jelcz-Laskowice. Wagner's pots, each containing 6 kg of light soil, served as experimental units. The soil used for the trials was loamy sand, slightly acidic, rich in P, K and Zn, low in available B (0.9-1.1 mg $B \cdot kg^{-1}$ of dry soil according to the test with 1 mol $HCl \cdot dm^{-3}$)

and moderately rich in Mg, Cu, Mn and Mo (Zalecenia nawozowe 1990). A two-factor experiment with 5 replications was carried out for three years, according to the following design: first-order factor (A= 4) was boron availability: A1 – natural soil (pH = 5.7), during the whole growing season the soil moisture in the pot was maintained at 60% of the maximum water saturation (MWS); A2 – soil as above, limed with calcium carbonate according to single hydrolytic acidity (1 Hh), soil moisture at 60% MWS; A3 – natural soil, with the moisture content depressed to 40% MWS for 14 days since growth stage 61 on the Zadoks scale (onset of inflorescence emergence) (ROZDÓJ 1996); A4 – limed soil (according to 1 Hh) + soil moisture lowered to 40% MWS for 14 days. The second-order factor (B = 5) comprised boron rates in foliar fertilization treatments applied during the tillering phase (0.3% H_3BO_3 solution per pot): B1 – control treatment (without boron fertilization), B2 = 3 cm^3, B3 = 5 cm^3, B4 = 7 cm^3, B5 = 9 cm^3. The desirable moisture of soil was established on the basis of determined maximum water saturation value. Soil moisture in pots was maintained by watering with deionizated water. The adequate amount of water for each pot individually was stated by weight.

Basic fertilization (in $g \cdot kg^{-1}$ soil) was: 0.2 N, 0.1 P, 0.2 K, 0.01 Mg, + microelements (in $mg \cdot kg^{-1}$ soil): 0.750 Cu, 3.50 Mn, 0.242 Mo, 2.50 Zn. Wheat (cultivar Ismena) was harvested at the full maturity phase. Lengths of growing seasons in the successive years of experiment were 91, 93 and 88 days. Grain and straw yields were determined.

Chemical analyses of soil (before experiment) and plants (grain and straw collected after the trials had been terminated) were performed with the methods commonly used in agrochemical stations. pH of soil in 1 mole $KCl \cdot dm^{-3}$, granulometric composition of soil following Casagrande modified by Prószyński. The content of available forms of phosphorus and potassium in soil were determined with the 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 $HCl \cdot dm^{-3}$) following the instructions developed by IUNG (GEMBARZEWSKI, KORZENIOWSKA 1990). Cu, Mn and Zn were determined with the AAS method, boron and molybdenum – colorimetrically. The results of the soil analyses were estimated with the applicable threshold values (Zalecenia Nawozowe 1990). The plant material after wet mineralization was determined to define the content of calcium – with the flame photometry. The content of boron in dry mineralized plants was determined colorimeterically – using the method with curcumin (Metody badań 1980).

This paper is a synthetic presentation of the results from the three years, processed statistically. The research result analysis involved variance and correlation analyses performed with AWAR and Statgraphics programs (FILIPIAK, WILKOS 1995). The significance of cross-object differences in variance analysis were evaluated with the Tukey's test ($\alpha \leq 0.01$).

RESULTS

The soil, initially slightly acidic in reaction (pH_{KCl} 5.7), was limed in sub-blocks A2 and A4 using $CaCO_3$ in a rate calculated according to 1 Hh, after which it was made more alkaline, reaching pH_{KCl} 6.3-6.6. In sub-block A2, this did not change significantly any of the yield components tested (plant height H, ear weight EW, number of grains per ear GE). However, under these conditions, foliar application of boron improved the analysed yield parameters more effectively than in the trials with natural soil (A1), thus the highest values of the above parameters were obtained in the fertilisation variants A2B4 and A2B5. The simulated drought stress in sub-bock A3 and, even more evidently, in limed soil (A4) significantly inhibited the development of spring wheat, which was reflected by statistically significant declines in the analysed yield components. In the object A4B1 the height of plants (H) was 27.6%, ear weight (EW) – 22.2% and number of grains per ear (GE) – 30.6% lower than in the initial object A1B1 (Table 1).

Higher rates of boron significantly alleviated this unwanted effect, although when compared to the sub-blocks receiving optimum water supply during the whole growing season (A1 and A2), the differences in the yield components often remained statistically significant. The analysed components of yield produced by spring wheat showed rather close correlation, including H/EW ($r = 0.708$; $\alpha = 0.01$); H/GE ($r = 0.639$; $\alpha = 0.01$) and EW/GE ($r = 0.733$; $\alpha = 0.01$). They were also closely correlated with spring wheat grain yield, e.g. grain yield /EW ($r = 0.801$; $\alpha = 0.01$) and straw yield, e.g. straw yield/H ($r = 0.648$; $\alpha = 0.01$). Thus, modifications in the analysed yield components caused by the interaction between the experimental factors had a significant effect on the mass of yields obtained. The liming of soil with $CaCO_3$ in a rate established according to 1 Hh in sub-block A2 did not cause any significant changes in grain and straw yields compared to spring wheat grown on natural soil (A1). However, significantly depressed grain and straw yields produced by spring wheat were caused by water deficit during the flowering phase (sub-block A3), especially when the soil had been limed (sub-block A4). Foliar application of boron raised the yields significantly, both in the sub-blocks receiving optimum water supply and those which underwent water deficit and soil reaction modification (Table 2).

The grain obtained on boron-deficient soil, irrespective of water supply or soil reaction, was characterised by a low concentration of this element versus the comparison data. Foliar application of boron increased its content in grain, with the actual improvement dependent on the water supply and soil reaction modification. The most positive changes in the boron content occurred in the control sub-block (A1) and limed sub-block (A2), in which higher boron fertilisation rates resulted in the boron content in grain exceeding the reference data. The least positive results were obtained from sub-block A4 (drought stress + liming), in which the supply of boron for

Table 1

Effect of boron foliar application on some components of the spring wheat yield (three-year average)

Treatment		Plant height cm (H)	Weight of ear g (EW)	Weight of ear in g (EW)	Number of grain per ear (GE)
A1	B1	88.0	1.35	37.6
	B2	91.2	1.56	43.7
	B3	92.1	1.67	44.0
	B4	93.5	1.62	45.9
	B5	90.7	1.70	44.6
A2	B1	86.4	1.30	36.6
	B2	90.0	1.52	44.7
	B3	90.9	1.58	44.0
	B4	92.4	1.75	47.0
	B5	92.3	1.78	47.2
A3	B1	67.7	1.15	30.2
	B2	70.4	1.33	30.9
	B3	71.3	1.35	31.4
	B4	78.3	1.43	32.5
	B5	78.4	1.51	34.8
A4	B1	63.7	1.05	26.1
	B2	67.7	1.03	25.9
	B3	67.5	1.13	27.9
	B4	69.9	1.33	30.5
	B5	72.8	1.48	32.3
Average	A1	91.1	1.58	43.2
	A2	90.4	1.59	43.9
	A3	73.2	1.35	32.0
	A4	68.3	1.20	28.5
LSD $_{\alpha \leq 0.01}$		9.14	0.29	6.08
Average	B1	76.5	1.21	32.6
	B2	79.8	1.36	36.3
	B3	80.5	1.43	36.8
	B4	83.5	1.53	39.0
	B5	83.6	1.62	39.7
LSD $_{\alpha \leq 0.01}$		6.18	0.31	5.95
LSD $_{\alpha \leq 0.01}$	II/I	5.66	0.34	3.90
	I/II	7.85	0.28	4.49

Table 2

Yields of spring wheat grain and straw under boron treatment (three-year average)

Treatment		Grain	Straw
		g · pot^{-1}	
A1	B1	27.1	33.9
	B2	30.0	34.6
	B3	30.5	36.6
	B4	31.0	36.7
	B5	31.4	34.2
A2	B1	27.0	34.1
	B2	28.8	36.0
	B3	30.9	36.5
	B4	32.0	37.3
	B5	30.3	35.9
A3	B1	24.9	30.3
	B2	25.5	32.5
	B3	26.9	34.0
	B4	28.1	35.6
	B5	29.2	35.9
A4	B1	23.8	29.5
	B2	24.4	30.7
	B3	25.6	32.2
	B4	27.3	34.2
	B5	28.3	34.5
Average	A1	30.0	35.2
	A2	29.8	36.0
	A3	26.9	33.7
	A4	25.9	32.2
LSD $_{\alpha \leq 0.01}$		2.58	2.87
Average	B1	25.7	32.0
	B2	27.2	33.5
	B3	28.5	34.8
	B4	29.6	36.0
	B5	29.8	35.1
LSD $_{\alpha \leq 0.01}$		2.57	2.66
LSD $_{\alpha \leq 0.01}$	II/I I/II	3.55 3.03	2.75 n.s.*

*n.s. – non-significant differences

Table 3

Content of boron and Ca:B quantitative ratio in the spring wheat grain and straw (three-year average)

Treatment		Grain mg·kg^{-1} dry matter		Ca:B	Straw mg·kg^{-1} dry matter		Ca:B
A1	B1	1.35	441	327	4.35	1720	395
	B2	1.47	464	316	4.97	1914	385
	B3	1.64	506	308	5.64	1963	348
	B4	1.74	496	285	5.74	1847	321
	B5	1.69	485	287	5.69	1809	318
A2	B1	1.00	388	388	3.91	1810	463
	B2	1.38	523	379	4.79	2060	430
	B3	1.45	536	370	4.88	2060	422
	B4	1.68	588	350	5.71	2146	376
	B5	1.67	576	345	5.85	2135	365
A3	B1	1.09	363	333	3.09	1225	396
	B2	1.08	352	326	3.27	1276	390
	B3	1.35	443	328	3.65	1340	367
	B4	1.48	458	310	4.21	1390	330
	B5	1.56	490	314	4.33	1380	319
A4	B1	1.00	392	392	2.97	1340	451
	B2	1.08	410	379	3.08	1340	435
	B3	1.15	443	385	3.22	1295	402
	B4	1.33	478	360	3.73	1436	385
	B5	1.37	485	354	3.88	1478	381
Average	A1	1.58	478	305	5.28	1851	353
	A2	1.44	522	366	5.03	2042	411
	A3	1.31	421	322	3.71	1322	360
	A4	1.19	442	374	3.38	1378	411
LSD $_{\alpha \leq 0.01}$		0.20	72.4	58.1	0.97	189.5	46.7
Average	B1	1.11	396	360	3.58	1524	426
	B2	1.25	437	350	4.03	1648	410
	B3	1.40	482	348	4.35	1665	385
	B4	1.56	505	326	4.85	1705	353
	B5	1.57	509	325	4.81	1701	346
LSD $_{\alpha \leq 0.01}$		0.22	77.0	33.1	0.69	176.3	38.9
LSD $_{\alpha \leq 0.01}$	II/I I/II	0.27 0.24	49.4 45.2	36.5 55.0	0.72 1.18	164.8 283.5	44.2 56.6
Reference B content after FOTYMA and MERCIK (1995)							
		1.52	800	-	3.25	2700	-

wheat grain did not reach the reference data (Table 3). The initial content of boron in wheat straw was high, surpassing the reference data. However, the straw of wheat plants grown under drought conditions was clearly inferior in the amounts of this microelement and satisfactory improvement was obtained only in the objects fertilised with the highest rates of boron (Table 3).

These observations are confirmed by the values of the Ca:B quantitative ratio in spring wheat grain and straw, which characterises plants' nutrition with boron more fully than the absolute content of boron in plant dry matter. Even when plants receive quite a good supply of boron, excessive amounts of calcium in plant tissues may create boron deficiency conditions (Gupta 1972, Kopeć, Michalec 2007). It is so because of antagonism between these two elements. Any narrowing of the Ca:B ratio suggests improved supply of plants with boron. The comparison of the Ca:B ratios from particular experimental objects proves the effectiveness of boron application as a means of improving plants' supply with boron. Changes in the Ca:B ratio occurring in the experimental objects depended mainly on changes in the content of boron in plant tissues, thus they were more evident in straw rather than in grain. Both in grain and in straw of spring wheat, the Ca:B quantitative ratio was broader in limed sub-blocks (A2 and A4), which was due to the increased supply of calcium. Under such conditions, the demand of wheat plants for boron also increased. As a result of foliar application of boron, the Ca:B ratio changed in a reversely proportional correlation to the volume of the boron rate applied (Table 3).

DISCUSSION

The interaction between the experimental factors (availability of boron x foliar fertilisation with boron) caused significant changes in the analysed yield structure of spring wheat. These changes affected the yields of grain and straw. Water deficit during the inflorescence phase (from growth stage 61 according to the Zadoks scale) may create a considerable threat to spring wheat yields (Mouhouche et al. 1998, Huang et al. 2000). One of the reason could be the deficit of boron in plants resulting from the fact that the uptake of this element by plants is largely limited under drought conditions (plants take up boron with the water transpiration stream) as well as the lack of reutilisation of boron in plants (Goldbach 1997, Blevins, Lukasewski 1998, Thellier et al. 2001). Another cause why the availability of boron was limited might have been increased soil pH. At $pH_{KCl} > 6.0$, boron occurs in soil solution as anions of boron hydrides $B(OH)_4^-$, which can easily be absorbed by loamy minerals, aluminium hydroxides and organic substances.

The physiological functions of boron in a plant, including the effect of this element on the development of generative parts, are decisive for the proper development and maturation of cereal grains (GOLDBACH 1997, HUANG et al. 2000, YAU 2000) thus by supplying additional amounts of boron in the form of foliar application during the critical growth phases can be perceived as a factor which mollifies the results of unfavourable boron deficits. Foliar fertilization with boron in the experiments leads to a statistically significant improvement of yield structure parameters and spring wheat yield volumes. This type of a relationship is further verified by relatively high coefficients of B in straw/plant height ($r = 0.667$; $\alpha = 0.01$), B in straw/weight of ear ($r = 0.511$; $\alpha = 0.01$), B in grain/grain yield ($r = 0.562$; $\alpha = 0.01$), B in straw/straw yield ($r = 0.622$; $\alpha = 0.01$).

The deficit of available boron in the soil used for our trials, made more severe due to the drought stress or when the soil reaction was more alkaline, may have implied that plants received insufficient amounts of boron as a nutrient. As one could have expected, the content of boron in plants from the control objects (B1 – without boron fertilization) was too low versus the data supplied by the references (FOTYMA, MERCIK 1995). The highest rates of boron applied for foliar treatments increased the content of boron in grains to a level comparable to the standard, in which case the fertilisation treatment played a double role: it increased the grain yield and improved its nutritional quality (Tables 2, 3). In sub-block A4 (periodic drought + soil liming), such a level of boron concentration was not achieved. Insufficient content of boron in wheat grain can raise some anxiety in terms of nutritional quality of grain for human consumption or animal fodder (BIAŁA KSIĘGA 2000). As some research seems to suggest, boron deficit in food or fodder can be responsible for health disorders in man and animals (NIELSEN 1997).

CONCLUSIONS

1. The deficit of boron available in soil had a negative effect on the spring wheat yield structure parameters and yield level as well as the concentration of boron in grain and straw. This correlation was stronger when boron availability was depressed (periodic drought, soil liming).

2. Foliar fertilization with boron has a favourable effect on the major wheat yield components, significantly improving grain and straw yields.

3. The highest rates of boron used for foliar application (7 and 9 ml 0.3% H_3BO_3/pot) raised the concentration of this component in wheat grain up to a level comparable to the reference data.

4. In the light of such positive effects of foliar fertilization with boron as presented in this paper, it can be stated that boron fertilisation is a treatment which can mollify results of less favourable conditions for boron uptake by plants.

REFERENCES

Biała księga bezpieczeństwa żywności. [The White Book of Food Safety]. 2000. Żywność Żywienie Prawo a Zdrowie. Wyd. I.ŻiŻ, Warszawa, 9 (1): 5-74.

BLEVINS D.G., LUKASEWSKI K.M. 1998. *Boron in plant structure and functions.* An. Rev. Plant Physiol. Plant Mol. Biol., 49, 481-500.

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

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

GEMBARZEWSKI H. 2000. *Stan i tendencje zmian zawartości mikroelementów w glebach i roślinach z pól produkcyjnych w Polsce.* Zesz. Probl. Post. Nauk. Rol., 471(1): 171-177.

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.

GOLDBACH H. E. 1997. *A critical review on current hypotheses concerning the role of boron in higher plants: suggestion for further research and methodological requirements.* J. Trace Microprobe Tech., 15(1): 51-91.

GUPTA U.C. 1972. *Interaction effects of boron and lime on barley.* Soil Sci. Soc. Am. Proc., 36 (2): 332-334.

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.

KOPEĆ M., MICHALEC M. 2007. *Study of correlation between contents of calcium and boron in the sward of long-term fertilizing experiments.* Ecolog. Chem. Ing. 14(3-4): 335-342.

Metody badań laboratoryjnych w stacjach chemiczno-rolniczych. [Laboratory Research Methdos at Chemical and Agrikultural Stations]. 1980. I, II. IUNG Puławy.

MOUHOUCHE B., RUGET F., DELECOLLE R. 1998. *Effect of water stress applied at different phenological phases on yield components of dwarf bean.* Agronomie. 18: 197-205.

NIELSEN F.H. 1996. *Evidence for the nutritional essenciality 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.

ROZDÓJ J. 1996. *Wzrost i rozwój rośliny zbożowej – badania botaniczne a praktyka rolnicza.* Biul. Inst. Hod. Roś., 192(97): 3-21.

THELLIER M., CHEVALLIER A., HIS I., JARVIS C., LOVELL M., RIPOLL C., ROBERTSON D., SAUERWEIN W., VERDUS M.C. 2001. *Methodological developments for application to the study of physiological boron and to boron neutron capture therapy.* J. Trace Microprobe Tech., 19 (4): 623-657.

WRÓBEL S. *2004. Reakcja pszenżyta ozimego na nawożenie borem w zależności od sposobu stosowania i dawki.* Pam. Puł., 138: 153-165.

WRÓBEL S. 2006. *Reakcja owsa na nawożenie borem.* Biul. IHAR. 239: 155-163.

YAU S. K. 2000. *Soil-boron affects straw quality and other agronomic traits in two cultivars of barley.* Commun. Soil Sci. Plant Anal., 31(5&6): 591-604.

Zalecenia nawozowe. [Fertilization recommendations]. 1990. *Liczby graniczne do wyceny zawartości w glebach makro- i mikroelementów.* IUNG Puławy, P (44): 1-34.