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EVALUATING THE APPLICABILITY OF THE SOIL TEST WITH 1 mole HCl·dm^{-3} TO DEFINE THE BORON FERTILISATION REQUIREMENTS OF OAT

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ABSTRACT

Over 1999-2001 three two-factorial strict field experiments were carried out to evaluate the applicability of soil boron test (1 mole HCl·dm^{-3}) to determine boron fertilisation requirements of oat. Three boron application methods (pre-sowing, top-dressing and foliar fertilisation) were the variants of the first factor while four doses of boron constituted the second factor. The optimal oat boron supply in B-deficient soil is noted in the study. Despite an over-optimal boron concentration in plants, fertilisation with the microelement brings statistically significant increases in oat grain yield and a continuous increase in B content in plant tissues. The results call for a verification of the tests of boron concentration in soil (1 mole HCl·dm^{-3}) and oat plants and reveal the advantage of boron top-dressing and foliar methods in yield-enhancement. Considering the impact of boron application on yield and its chemical composition as well as the level of nutrient uptake by yield, the doses of 1.8-2.4 kg of B·ha^{-1} applied as top-dressing can be considered most effective.

Key words: oat, boron, fertilisation, soil test, plant test

INTRODUCTION

Cereals, similarly to other *Poaceae* family plants, show considerably lower boron requirements than dicotyledonous plants, which, however, should not be identified with a lack of demand for fertilisation with this microelement. The literature reports more and more frequently on negative effects of boron deficits and positive effects of its application in cereal cultivation [1,2,3,6,14,20,21,26,27,28]. It is related to genetic conditions, greater needs of new high-yielding cereal cultivars, as well as a gradual exhaustion of soil resources of available boron forms, increased by a drastic slump in manure consumption. Boron shortage symptoms in cereals can occur both as a deteriorated grain quality and a slump in yielding. Due to physiological functions of boron in plant, related to the growth and development of generative organ, its shortage results in a deteriorated seeding value of cereal grain. According to Szukalski [22] and Benedycka and Kozikowski [2,3], an increased content of boron in grain is strictly related to an enhanced energy and germination capacity. Da Silva [6] reports on the application of 0.65 kg $B \cdot ha^{-1}$ which significantly increased wheat yield by a reduction in male sterility, both directly and as an after-effect.

Lower-yielding cultivars of older-generation cereals rarely showed boron deficits, however it was easier to obtain the effect of its excessive amount, especially when it was applied inadequately. The degree of tolerance to the amount of boron in soil depends on the genetic biological barriers produced by plants [19]. Some research show that the tolerance is controlled by single recessive genes, and so a considerable genetic variation can occur across cultivars of the same species [25]. According to Tahtinen [24], a negative reaction of cereals to boron is mainly related to the tolerance of cereal sprouts, and so boron phytotoxicity can depend on the application method. Therefore it is neither acceptable to apply boron on seeds nor to combine applying boron fertiliser with grain. Replacing pre-sowing with top-dressing or foliar fertilisation and avoiding stands after preceding crops intensively fertilised with boron, it is possible to obtain considerably better results. According to the author, obeying the said rules made it possible to increase barley, oat and wheat yielding due to boron fertilisation by about 20%. The information quoted suggested a need for defining the most effective method of oat fertilisation with boron under domestic conditions, which constituted the objective of the present research. Realising the objective, however, requires the application of adequately precise chemical tests, which would allow for defining the degree of a given microelement content in soil and plant.

In earlier research reported by the author, carried out in the network of 75 domestic oat production fields, boron deficits in soil occurred in as many as 90.7%, and in plants – 62.1% of the fields researched [26]. So in the research the plant analysis confirmed only partially the results of soil analysis, which can suggest specific doubts on the diagnostic applicability of the soil test used (1 mole $HCl \cdot dm^{-3}$), showing such a great range of boron deficits. It was therefore decided to test to what extent the boron deficits were a result of its actual shortage in soil or whether they could have been a result of too strict calibration of the soil test. The task was yet another objective of the present research.

MATERIAL AND METHODS

Over 1999-2001 three one-year two-factor strict field experiments were carried out at the Osiny Experiment Station of the Puławy Institute of Soil Science and Plant Cultivation (IUNG) with the split-plot method, including the K control with four replications. The experiments included only soils of low boron content (following the group test with 1 mole $HCl \cdot dm^{-3}$). The soils selected were light, of acid reaction, high and very high content of phosphorus, average and high of potassium, low and average of magnesium, high of zinc, average of copper, iron and manganese and a low of boron and molybdenum [29] (Table 1).

Table 1. Agrochemical characteristics of soils used in the experiments

Year	pH_{KCl}	F_F	O_M	P	K	Mg	B	Cu	Fe	Mn	Mo	Zn
		%		$mg \cdot kg^{-1}$								
1999	4.8	16	2.34	75.4	131.1	38.0	0.60	9.90	787	40.8	0.021	11.4
2000	4.2	13	1.87	104.1	109.2	39.0	0.20	2.06	870	42.0	0.020	10.1
2001	5.3	19	1.72	82.0	110.0	25.0	0.80	2.20	775	48.5	0.019	12.8

F_F – floatable fraction (clay) < 0.02 mm
O_M – organic matter

Nutrients content in soil: low | medium | high | very high

Experiment scheme:

- K – control (non-fertilised with boron)
- – factor I (boron application methods, n = 3)

  A_1 – pre-sowing, H_3BO_3 in a solid form (10-15 days before seed sowing),
  A_2 – top-dressing, H_3BO_3 in a solid form (tillering),
  A_3 – foliar fertilisation, water solution H_3BO_3 (shooting)

– factor II (boron doses, n = 4)

  B_1 – 0.6 kg B·ha^{-1} (0.1 %* = 0.085 kg B·ha^{-1}),
  B_2 – 1.2 kg B·ha^{-1} (0.2 %* = 0.170 kg B·ha^{-1}),
  B_3 – 1.8 kg B·ha^{-1} (0.3 %* = 0.255 kg B·ha^{-1}),
  B_4 – 2.4 kg B·ha^{-1} (0.4 %* = 0.340 kg B·ha^{-1});

* H_3BO_3 solution concentrations for foliar-application, consuming 500 l of solution per 1 ha.

Experimental plots area – 30 m^2; harvest area – 25 m^2.

The experiment investigated oat, 'Borowiak' cultivar, cultivated following the principles of reasonable agronomic practices. The sowing date in respective years ranged from April 4 to 8, and the sowing norm of qualified grain ranged from 180 to 200 kg·ha^{-1}. The row spacing was 12.0 cm. The fertilisation plan was established annually with the computer fertilisation-counselling program, NAW-3 [11]. NPK-fertiliser was applied pre-sowing: 8N:24P:24K and 60% potassium salt. The fertilisation was supplemented by top-dressing with 34% ammonium nitrate and magnesium sulphate (16% MgO). Also full chemical control of the experimental plantations was applied. The grain yield and 1000 grain weight were defined. The chemical analysis involved sampling over-ground oat parts at the beginning of panicle occurring, test parts according to Bergmann and Neubert [4], grain and straw at the harvest and soil from the topsoil of post-harvest fields.

The control objects (K) involved determining pH of soil in 1 mole KCl·dm^{-3}, content of organic carbon with the Tiurin method, granulometric composition following Casagrande modified by Prószyński and the content of available P, K, Mg, B, Cu, Mn, Mo and Zn forms. The soil samples from the other objects – the content of available forms of B, P, K and Mg as well as pH_{KCl}. The content of available forms of phosphorus and potassium were determined with the Egner and Riehm method, magnesium following Schachtschabel [16]. To determine the microelements (B, Cu, Mn, Mo, Zn), the soil was extracted with the so called common exhauster (1 mole HCl·dm^{-3}) following the instructions developed by IUNG [17]. Cu, Mn and Zn were determined with the AAS method, boron and molybdenum – colorimeterically. The results of the soil analyses were estimated with the applicable threshold values [29].

The chemical analysis of the plant material involved determining the content of dry matter, B, N, P, K, Ca and Mg. The plant samples from control objects were also analysed to determine the contents of Cu, Mo, Zn and Mn. The plant material after wet mineralisation was determined to define the content of nitrogen with the 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 mineralised plants was determined with the AAS method (Cu, Mn and Zn) except for colorimeterically determined boron – the method with curcumin and molybdenum – the thiocyanate method. Also plant dry matter was determined (at 105°C) [16]. To evaluate the content of microelements in dry matter of test oat parts, threshold ranges were applied developed by Bergmann and Neubert [4].

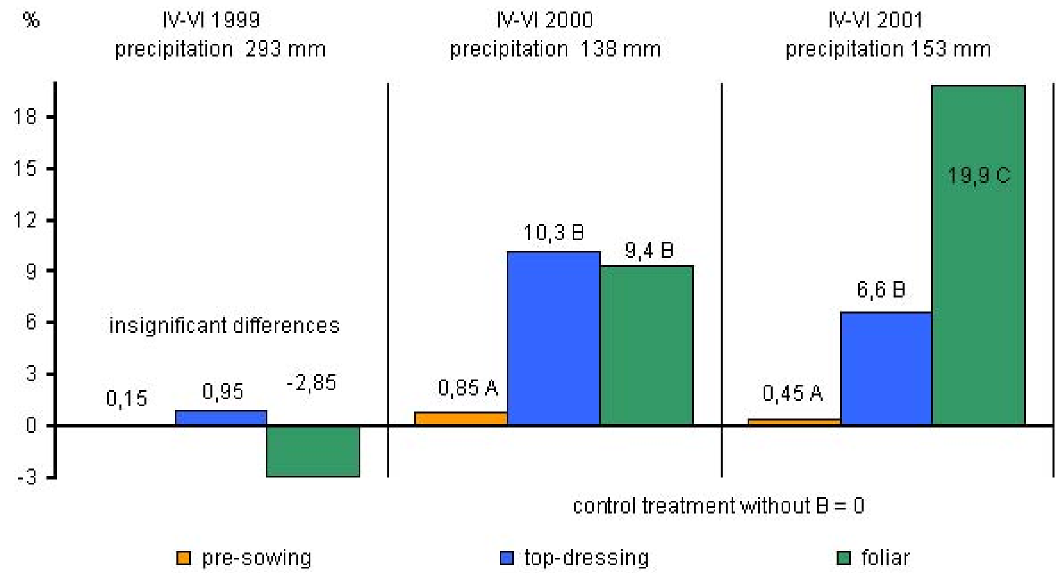
The research result analysis involved statistical methods; variance analysis, correlation analysis and stepwise multiple regression analysis with Statgraphics package and AWAR program [9,10]. The significance of cross-object differences in variance analysis were evaluated with the Tukey test ($\alpha = 0.05$).

The weather conditions differed over subsequent research years which were mostly true over the period of the most intensive plant growth and development (April – June). Winter throughout the three years showed mild temperatures, higher that the multi-year norms at lower precipitation. In 1999 spring recorded a heavy precipitation, especially in April (about 50 mm above the multi-year mean) and in June (80 mm above the norm). Two successive years showed mostly opposite trends (precipitation below the multi-year mean) with quite considerable water deficits in June 2000 or in May 2001. The conditions showed a considerable effect on the availability of soil boron to oat plants and, at the same time, the effectiveness of the fertilisation applied.

RESULTS

It was found that the effect of boron on oat grain yielding depended on the amount of precipitation over an intensive plant development (April through June) (Fig. 1). A significant correlation of the years with the experimental factors made it impossible to calculate the synthesis of the results for the three research years. The results of the experiments for successive years together with the variance analysis of yielding variation carried out with the Tukey test at $\alpha = 0.05$ are given in Table 2. In 1999, with the total precipitation over April-June over 100 mm higher that the respective multi-year mean, no significant changes in oat grain yielding due to boron fertilisation were recorded, irrespective of the application method. Over the two successive years (2000 and 2001), with the precipitation over that period lower than the multi-year mean norm by about 50 and 30 mm, respectively, there were observed significant increases in the grain yields as a result of boron fertilisation. Over the years top-dressing with H_3BO_3 significantly increased oat grain yields from 8.5 to 16.2% as compared with the K control which did not involve boron fertilisation. Yet greater yielding was recorded due to foliar fertilisation with boron. In 2000 significant increases in oat grain in foliar fertilisation objects ranged from 8.0 to 12.2%. In 2001, when H_3BO_3 solution was sprayed and drought had been present already for a few weeks – oat grain yield increases were the greatest in the experiment (19.4-20.3%). Although the yield increases due to top-dressing with boron did not really show any dependence on the boron doses, in foliar fertilisation – quite a clear positive effect of the doses was recorded, which was seen by a high correlation coefficient obtained for the characteristics ($r = 0.850$, $\alpha = 0.01$).

Fig. 1. Response of oat grain yields to boron fertilisation against precipitation over April – June (mean effect in %)



Percentages marked with the same letter within years were statistically equal according to Tukey's test at a = 0.05

Table 2. Response of oat grain yields to boron fertilization

Treatment		1999 Yield $t \cdot ha^{-1}$	1999 1000 grain weight, g	2000 Yield $t \cdot ha^{-1}$	2000 1000 grain weight, g	2001 Yield $t \cdot ha^{-1}$	2001 1000 grain weight, g
Control (without B)		5.97	31.9	4.10	34.2	3.20	34.2
%							
Pre-sowing	A_1B_1	- 0.2	+ 1.9	- 2.7	+ 5.0	+ 3.4	+ 2.9
	A_1B_2	+ 0.7	+ 2.2	+ 3.7	+ 4.1	+ 1.6	- 0.6
	A_1B_3	- 0.4	+ 1.2	+ 2.4	**+ 6.4***	+ 0.6	+ 0.9
	A_1B_4	+ 0.5	+ 1.6	0.0	**+ 5.6***	- 3.8	+ 0.6
Mean		+ 0.15	+ 1.7	+ 0.85	+ 5.3	+ 0.45	+ 1.0
Top-dressing	A_2B_1	+ 0.8	- 0.6	**+ 11.0***	+ 4.1	+ 0.3*	+ 2.9
	A_2B_2	- 0.5	+ 1.6	**+ 11.7***	**+ 6.4***	**+ 11.9***	+ 2.1
	A_2B_3	+ 2.7	- 0.3	**+ 8.5***	**+ 5.8***	+ 16.2*	**+ 3.8***
	A_2B_4	+ 0.8	+0.6	+ **10.0***	+ **6.4***	- 2.2	+ 2.6
Mean		+ 0.95	+ 0.3	+ 10.3	+ 5.7	+ 6.6	+ 2.8
Foliar	A_3B_1	- 3.9	+ 1.2	+ 7.8	**+ 5.3***	**+ 19.4***	+ 2.9
	A_3B_2	- 5.4	+ 2.2	**+ 8.0***	**+ 5.3***	+ **19.7***	**+ 4.7***
	A_3B_3	+ 1.8	- 0.6	+ **9.5***	+ 3.8	+ **20.3***	**+ 4.4***
	A_3B_4	- 3.9	+ 0.6	+ **12.2***	**+ 5.6***	+ **20.3***	**+ 5.6***
Mean		- 2.85	+ 0.8	+ 9.4	+ 5.0	+ 19.9	+ 4.4

A, B – see Material and Methods
TGW – 1000 grain weight
* statistically significant according to Tukey test at $\alpha = 0.05$

One of the more important metabolic functions of boron in plants is its effect on the formation and germination of pollen. A shortage of this element can, therefore, cause negative effects in a form of shortages of grain in spikelets or its underdevelopment (screenings). In the present research increasing 1000 grain weight, due to boron fertilisation, occurred irregularly. The biggest number of significant increases in the 1000 grain weight, as compared with the control, however, was observed in objects in which there were also noted significant increases in yields. The increased grain yields could have been mostly due to the increasing 1000 grain weight as a result of boron fertilisation.

Yield-enhancing effect of boron was confirmed by the multiple regression equation with the stepwise selection. The oat grain yield constituted the dependent variable. The contents of macro- and microelements in test plant parts, assumed as independent variables, gave the following equation:

$$y = 0.2412 + 1.1386\,K + 0.0203\,Mn + 0.010\,B \quad R^2 = 0.85; \alpha = 0.005$$

where:
y = oat grain yield in tonnes per 1 ha,
K, Mn, B – contents of microelements in test oat parts, mg $B \cdot kg^{-1}$ of dry matter.
Where the content of mineral components in oat straw constituted independent variables, the following equation was obtained:

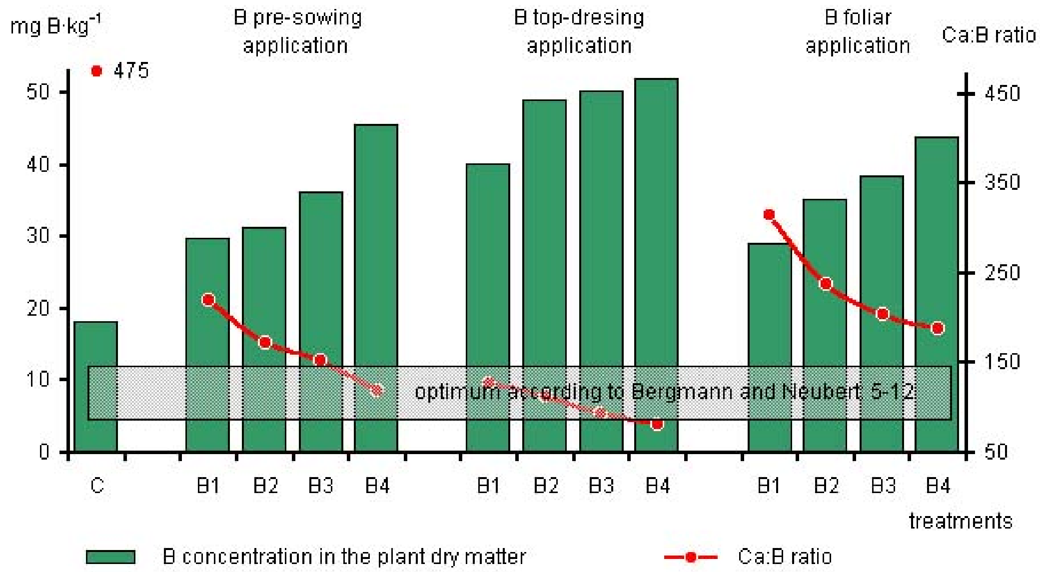
$$y = 4.6558 + 1.0683\,Mg + 0.0851\,B – 0.1318\,Zn \quad R^2 = 0.87; \alpha = 0.00$$

where:
y = oat grain yield in tonnes per 1 ha,
Mg, B, Zn – contents of microelements in oat straw, mg $B \cdot kg^{-1}$ of dry matter.

The equations describe 85-87% of the yielding variation researched and show that the oat grain yield weight depended on the content of potassium, manganese and boron in plants over sampling the test oat parts, namely at the beginning of panicle occurring. The importance of boron, and also magnesium in obtaining high yields is confirmed by the next equation. Zinc which is determined with minus shows the effect of diluting this microelement in high straw yields.

All the three methods of boron application resulted in a considerably regular, generally proportional to the dose, increase in its content in plants analysed at the beginning of panicle occurring. As compared with the control (K), the highest doses of B increased its content in oat test parts by 148% for pre-sowing application, by 184% – top-dressing and 140% – foliar fertilisation (Fig. 2).

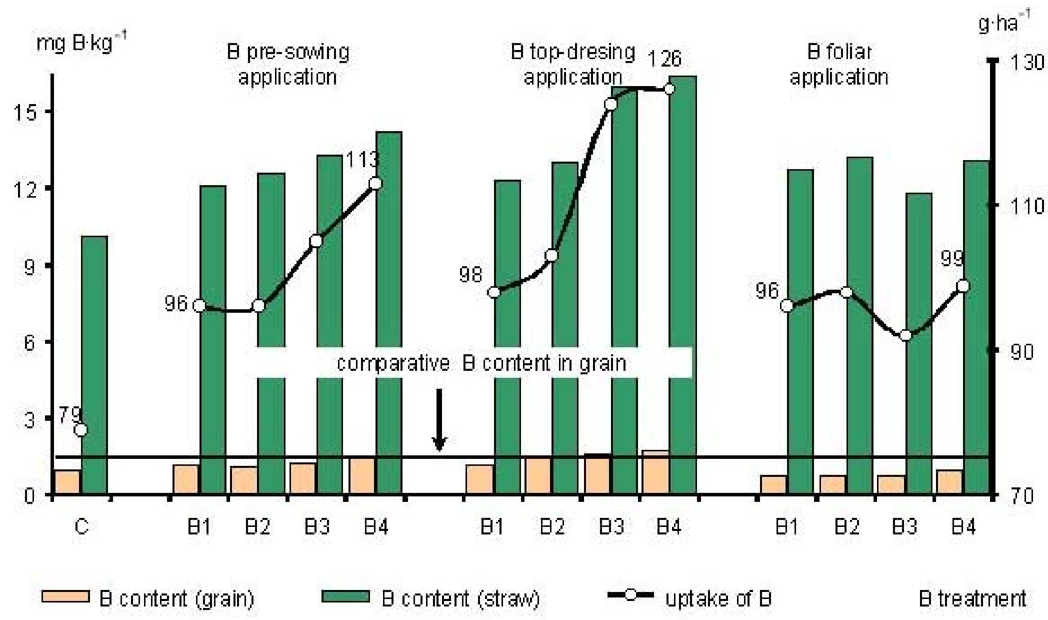
Fig. 2. Ca:B quantitative ratio against B concentration in the oat test organs (mean results)



The values of the Ca:B quantitative ratio in young plant parts show better boron supply in plants than the absolute content of B given. Even with a relatively good plant boron supply, a too excessive content of Ca in plants can create conditions of boron deficit. All that is a result of the antagonism of those two elements. The narrowing Ca:B ratio shows an enhanced plants boron supply. A graphic comparison of Ca:B in respective experimental objects clearly shows an effectiveness of soil application of boron in enhancing the Ca:B ratio, most considerably for top-dressing. Almost in all the objects it was due to changes in the content of boron in leaf tissues.

The present research results show that the boron fertilisation applied enriched also the final oat yields (grain and straw) in that microelement (Fig. 3). Similarly as in the test parts, there was observed a clear advantage of higher boron doses applied into soil – both pre-sowing and as top-dressing. The highest contents of boron in oat grain and straw yields and the highest level of uptake were recorded in objects with soil fertilisation with boron. Despite a clear effect of foliar fertilisation on the content of boron in oat straw, the level of the average-comparable content in grain was not reached – even due to the highest dose of all applied (object A_3B_4). Boron does not get reutilized in plant, and so a single foliar application over shooting could not satisfy a high demand of plants over grain formation. This dependence, showing the advantage of boron soil-fertilisation methods in cereals, was confirmed by a correlation of a high coefficient value $r = 0.81$; $\alpha = 0.01$, between concentration of boron in soil and in oat grain.

Fig. 3. Boron uptake by yields against B concentration in oat grain and straw (mean results)



comparative B content in grain - average B concentration in oat grain (1.44 mg B·kg^{-1} of dry matter) stated on the basis of mass analyses performed by Regional Agrochemical Stations (OSChR) [7]

Table 3. Soluble boron content in soil after harvest (mg of B·kg^{-1} of air dry soil)

Treatment		Year			Mean
		1999	2000	2001	
Control (without B)		0.70	0.44	0.35	0.50
Pre-sowing	A_1B_1	0.50	0.36	0.13	0.33
	A_1B_2	0.60	0.36	0.16	0.37
	A_1B_3	0.92	0.86	0.38	0.72
	A_1B_4	0.90	0.94	0.62	0.82
Top-dressing	A_2B_1	0.50	0.76	0.36	0.54
	A_2B_2	0.50	0.70	0.60	0.60
	A_2B_3	0.80	0.81	0.85	0.82
	A_2B_4	0.88	1.40	1.08	1.12
Foliar	A_3B_1	0.50	0.36	0.66	0.51
	A_3B_2	0.70	0.50	0.47	0.56
	A_3B_3	0.50	0.50	0.51	0.50
	A_3B_4	0.44	0.50	0.54	0.49

A, B – see Material and Methods

The soil chemical analysis, following the completion of the experiments, showed that the soil fertilisation with boron applied increased the content of its forms soluble in soil – mostly when applied as top-dressing – to 124%, as compared with the control, which resulted in a change in the class of boron content from the third (low) to the second (average) (Table 3). It is obvious that the foliar application did not affect the content of boron in soil.

DISCUSSION

Availability of boron to plants, uptaken passively with the water transpiration current decreases very clearly over drought, and fertilisation with this microelement then brings the expected effects. Good soil moisture in the first research year ensured an adequate solubility and availability of boron to plants from the natural soil resources and so an additional supply of this microelement from fertilisers did not show any more effect on yielding, although it was seen in the chemical composition of plants. Over the subsequent years over a temporary drought which occurred in critical plant development stages of the greatest demand for nutrients, boron availability slumped rapidly leading to shortages and the boron fertilisation applied gave expected yield-enhancing effects. However it was true only for top-dressing and foliar fertilisation. What is characteristic is no reaction of oat yields to pre-sowing boron application in all the three research years, and so independently of the soil moisture conditions over intensive nutrients uptake, which must have been due to a longer time needed from boron application to the period of the greatest demand for it in plants (May, June). The effect of pre-sowing fertilisation with boron, however, was seen in changes in the content in plants and the B uptake with yield.

All the soils selected for the experiments showed deficits of boron, which was the basic methodological assumption, conditioning the reaction of plants to fertilisation with this microelement. Although the soil analysis following the completion of the experiments confirmed low contents of boron in control soil (K), plant analysis of the test oat parts from these objects showed an over optimal supply in oat with this microelement. Based on these results one can point to an excessive strictness of the soil test applied (with 1 mole $HCl \cdot dm^{-1}$), suspecting that soils used in the experiments were better supplied with available boron. The conclusions are confirmed by doubts in the literature about the applicability of the group test used since 1986 based on extracting soil in 1 mole $HCl \cdot dm^{-1}$ to evaluate the content of soluble boron in soil [8,13,26,27]. The reports stress a greater applicability of the specific method following Berger and Truog, involving an extraction of soil with hot water [12,15].

The results obtained can also suggest a controversy about the range of optimal boron content in oat test parts reported by Bergmann and Neubert [4]. Despite the original high content of boron in biomass, oat reacted positively to fertilisation with this microelement, which resulted not only in the grain yield increases observed but also an increased concentration in plants and B uptake with yields. The results show much higher, than those reported in literature, boron requirements in oat, and so also a need for correcting calibration of B content in the test oat parts (following Bergmann and Neubert [4]).

Despite good yield-enhancing effects, foliar fertilisation could not enhance the content of boron in grain (effect of no boron reutilization), which shows that despite relatively lower costs of foliar application, the treatment cannot compete with the traditional soil fertilisation ensuring ionic balance in soil and the continuity of dynamics of the microelement uptake and, as a result, an adequate boron supply in grain. The importance of this issue is related to the results of western-European research of the last decade on the effect of boron in mammals, which unambiguously show important functions of this element related to the metabolism of calcium and fluorine. There is evidence of a strict relationship between arthritis, osteoporosis, disturbed brain action and boron deficits in the body [18]. A necessity of ensuring an adequate quality of the agricultural produce so much important from the nutritional point of view, to include cereal grain, is defined by directives of the White Paper of Food Safety of the EU [5].

To sum up, one shall stress a positive effect of the boron fertilisation applied; both as regards the effect on the weight and the quality of the oat yields obtained. There were obtained no visual symptoms of excessive amounts of boron in oat plants or decreases in yield in the objects of cereal-high B doses, although the symptoms were noted in cultivars of older generations, even as an after-effect [14,22]. The results show higher nutritional requirements of new-generation oat cultivars of boron than those generally reported on in literature. Irrespective of the imperfections, showed in the present research of criteria for evaluating boron supplies in soil and plants, it is yet another reason to verify the tests.

CONCLUSIONS

1. The research showed yield-enhancing effect of boron applied in a form of top-dressing or foliar fertilisation in oat cultivation over the insufficient-spring-moisture years. There was found no significant effect of pre-sowing boron fertilisation on the oat yield.
2. Soil fertilisation with boron, both pre-sowing and as top-dressing, contrary to foliar fertilisation, significantly increased the content of boron in grain and enriched soil with available boron compounds.
3. The results obtained show that oat fertilisation was most effective when boron doses were applied from 1.8 to 2.4 kg $B \cdot ha^{-1}$ in a form of top-dressing over tillering. It results from both the increase in yields obtained, changes in the value of the Ca:B ratio in plants, increase in boron uptake and a favourable effect on the content of this microelement in grain with no harmful effect.
4. The research showed a need for verifying both the boron soil test with 1 mole $HCl \cdot dm^{-3}$ and the plant criterion following Bergmann and Neubert. It results from the recorded over-optimal contents of boron in oat cultivated in soil of low boron content (following the test) and a further increase in B concentration in plants and yield increases with increasing boron doses.

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