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Boron content in soils under increasing magnesium and sulphur doses in a field experiment

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Abstract: The three-year field experiment (2015–2017) with graded doses of magnesium (Mg) and sulphur (S) was carried out at the Humpolec experimental station (49.5546239N, 15.3485489E; Czech Republic). The interactions between boron (B), Mg and S in the soil were studied. No boron was applied into soils. Contents of B, S and Mg in the soil were determined by the Mehlich 3 and NH_4 acetate methods. The crop rotation was: spring barley-oilseed rape-winter wheat. Three Kieserite doses (S and Mg fertiliser) were applied. Sulphur treatments were 10-20-40 kg S/ha to cereals and 20-40-80 kg S/ha to oilseed rape. The doses of Mg were: 13-26-52 kg Mg/ha to cereals and 26-52-104 kg Mg/ha to oilseed rape. A significant gradual decrease of B-Mehlich 3 was observed under Kieserite treatments during the experiment (from 1.24 mg B/kg in control in the 1st year to 0.92 mg B/kg in the 3rd year). On the contrary, B-NH_4 acetate contents in soils remained similar during 2015–2017 in control soils (0.33–0.39 mg B/kg) and significantly decreased under Kieserite treatments, namely by 55–57% in 2016 and by 43–48% in 2017. A significant decrease of B content in soils was noted since the second year of experiment after oilseed rape. The boron contents in soils were affected in several ways – by adsorption of B on magnesium oxides and other substances, exchange with SO_4^{2-} anions and possible leaching, and also by the uptake by grown crops, mainly oilseed rape.

Keywords: micronutrients; fertilisation; soil tests; plant nutrition; crops; plant uptake; precipitation

The interactions between boron (B), sulphur (S) and magnesium (Mg) in soils are not commonly studied. Magnesium belongs among the essential soil nutrients necessary for many plant functions. The availability of Mg to plants depends on the source of parent rock material, its chemical properties, grade of weathering, specific climatic and anthropogenic factors of the site, and also on agricultural systems (Gransee and Führs 2013). The crop rotation, cropping intensity or use of mineral and organic fertilisers also play an important role in Mg content and availability in soils. A considerable amount of Mg is bound in soils in exchangeable forms, which facilitates plant Mg uptake, but also Mg leaching (Gransee and Führs 2013). These characteristics can facilitate possible adsorption of boron compounds on Mg compounds (de la Fuente and Camacho 2006, Pécharman et al. 2018), as boron can be adsorbed, chelated or complexed in soils in many forms due to its structural complexity (Kot 2015).

Sulphur represents one of the main nutrients necessary for plant nutrition. Generally, more than 95% of sulphur is organically bonded (Eriksen et al. 1998) but these S fractions are not readily available for plants. Readily available forms of S in soil consist mainly of SO_4^{2-} anions (Mengel and Kirkby 2001). Therefore, sulphur is easily leached in deeper layers of the soil profile and the deficiency of this essential element can lead to a severe decline in crop yields and their quality (Matraszek-Gawron and Hawrylak-Nowak 2019). Sulphur is also an essential component of certain plant amino acids and proteins (Subedi and Ma 2009, Ma

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et al. 2015). Mandal et al. (2018) showed that the application of sulphur together with boron resulted in the highest available B and S in soils over control and higher crop growth compared to individual applications. Similarly, Sienkiewicz-Choleva and Kieloch (2015) showed a positive effect of S, B and Cu fertilisation on oilseed rape yields and fat content in grains. Uppal et al. (2015) showed that the pearl millet grain yield and its above-ground dry matter was improved significantly with balanced nutrients application in farmer's field; apart from NPK fertilisers, it contained also S + B + Zn, which were critically deficient in the soil nutrients.

Boron availability depends on ionic strength, pH, soil biological cycle, humification in soils and also on the association with variety of soil constituents including organic matter content, type and the amount of minerals or formation of colloids; it is also present in adsorbed/exchange forms, occluded in mineral phases (clays and Fe/Al hydroxides) (Matula 2007b, Majidi et al. 2010, Kot 2015, Mühlbachová et al. 2018). Boron is available for plants as undissociated boric acid, which means that it is complexed in a variety of organic molecules in soil (Hu and Brown 1997).

The aim of the research was to evaluate: (*i*) B-contents in soils under increasing sulphur and magnesium doses under the Kieserite treatments; (*ii*) B-uptake by grown crops and its effects on B-contents in soils; (*iii*) possible interactions between B, S and Mg contents in soils.

MATERIAL AND METHODS

Field experiment. The trial represents the second part of a three-year field experiment conducted in 2015–2017 at the Humpolec experimental station (Bohemian-Moravian Highlands, Czech Republic, 49.5546239N, 15.3485489E), altitude 525 m a.s.l. The first part of this field trial comprises the effects of increasing doses of phosphorus on boron availability and B-uptake (Mühlbachová et al. 2018).

The soil type is Gleic Cambisol with sandy-loam texture. The basic soil contents of nutrients based on the Mehlich 3 method were: 85 mg P/kg, 170 mg K/kg, 115 mg Mg/kg, 11.8 mg S/kg, 2 350 mg Ca/kg. Soil pH_{CaCl_2} was 6.31. The crop rotation was: spring barley (cv. KWS Irina; year 2015)-winter oilseed rape (cv. Basalti; year 2016)-winter wheat (cv. Elly; year 2017). The nitrogen was applied in form of CAN (calcium ammonium nitrate, 27% N) in all experimental treatments: 30 kg N/ha in the year 2015, 160 kg N/ha in 2016 and 130 kg N/ha in 2017. The fertilisation rates were different for cereals (0-10-20-40 kg S/ha; 0-13-26-52 kg Mg/ha) and for oilseed rape (0-20-40-80 kg S/ha; 0-26-52-104 kg Mg/ha) and were applied as Kieserite (K+S Minerals and Agriculture, GmbH, Kassel, Germany). The Kieserite was applied: 10. 4. 2015, 28. 5. 2016 and 17. 10. 2016. Each treatment was replicated four times every experimental year. The area of experimental plots was 21 m^2, regularly ploughed to 0.22 m. Crops were sprayed with insecticides and herbicides according to standard agronomical practices.

Each experimental plot was individually harvested in the phase of full maturation of a given crop – BBCH 89–92 (12. 8. 2015; 25. 7. 2016; 6. 8. 2017). The yield of grain, seeds and straw was determined (Table 1) as a part of important data used subsequently for calculation of B-uptake by plants. The soil samples were taken from the depth 0–30 cm at harvest time.

The temperatures and precipitations at the Humpolec experimental station in the experimental period 2015–2017 are shown in Figure 1.

Plant and soil analysis. The analytical procedures were following: the Mehlich 3 method (Mehlich 1984) was used as the universal extraction procedure for soil testing provided by the Central Institute for Supervising and Testing in Agriculture in the Czech Republic. The soil was shaken 10 min (modification by Trávník et al. 1999) with the Mehlich 3 extractant (0.2 mol/L CH_3COOH, 0.015 mol/L NH_4F, 0.013 mol/L HNO_3, 0.25 mol/L NH_4NO_3, 0.001 mol/L EDTA) in 1:10

Table 1. The grain/seed and straw yields (t/ha) in the field experiment

Treatment	Yield grain/seed			Yield straw		
	barley 2015	rape 2016	wheat 2017	barley 2015	rape 2016	wheat 2017
Control	8.46 ± 0.27^{a}	2.51 ± 0.07^{a}	9.05 ± 0.34^{a}	4.90 ± 0.29^{a}	4.24 ± 0.11^{a}	3.89 ± 0.16^{a}
S-10/20	8.35 ± 0.32^{a}	2.55 ± 0.1^{ab}	8.93 ± 0.21^{a}	5.09 ± 0.22^{a}	4.46 ± 0.08^{ab}	3.83 ± 0.14^{a}
S-20/40	8.50 ± 0.24^{a}	2.79 ± 0.13^{c}	8.97 ± 0.27^{a}	5.35 ± 0.17^{a}	4.75 ± 0.31^{b}	3.85 ± 0.18^{a}
S-40/80	8.40 ± 0.17^{a}	2.73 ± 0.1^{bc}	8.93 ± 0.22^{a}	5.19 ± 0.16^{a}	4.74 ± 0.22^{b}	3.83 ± 0.14^{a}

Different letters indicate the significant difference according to one-way ANOVA (Tukey's test) in individual years

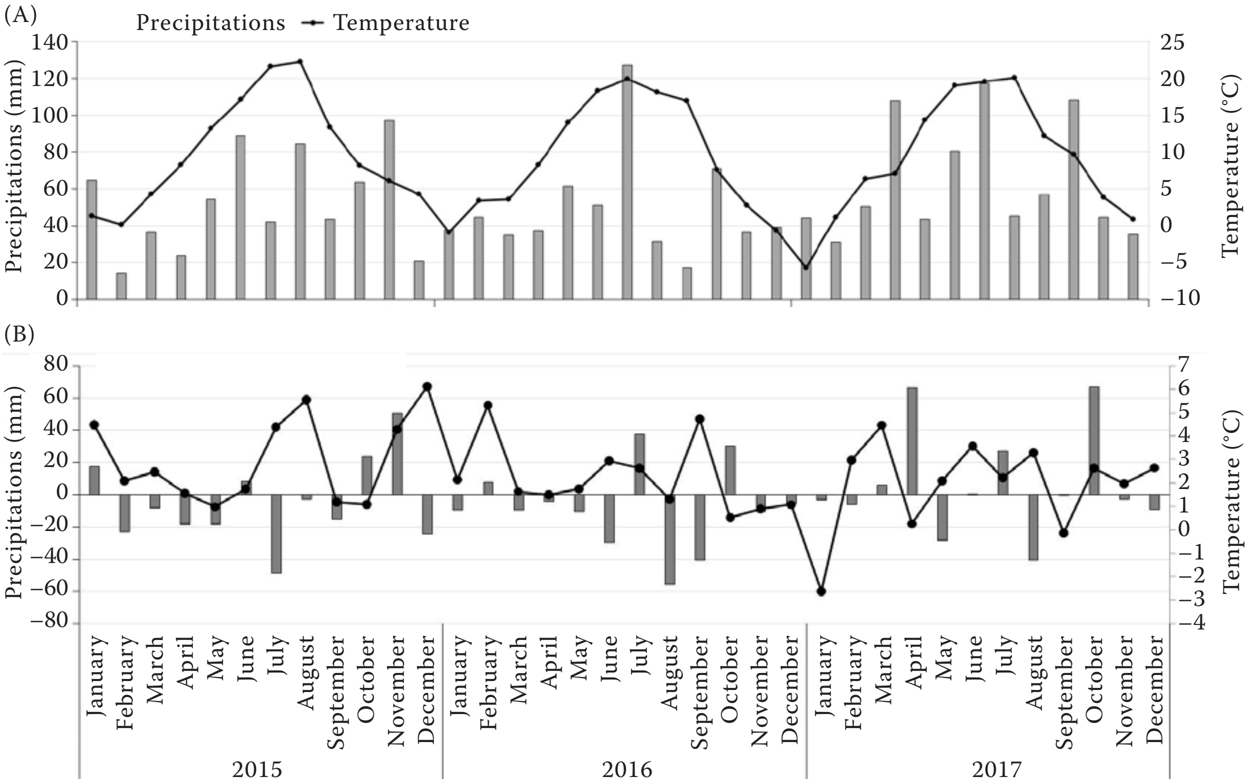

Figure 1. Temperatures and precipitations in the years 2015–2017 (A) and the difference from long-term average (B)

ratio (*w*:*v* – 10 g of soil and 100 mL of extractant), subsequently the suspensions were filtered.

The exchangeable nutrient contents in soils were determined according to Matula (2007a). The soil (5 g) was extracted in 100 mL of 0.5 mol/L ammonium acetate and 0.005 mol/L ammonium fluoride solution adjusted to pH = 7. The soil suspensions were left for 16 h, thereafter they were shaken manually 4 times before filtration.

Concentrations of B in grown crops were determined after digestion in conc. HNO_3 and 30% H_2O_2 using microwave Milestone 1200 (Connecticut, USA). Boron content in soils and plants was determined by the ICP-OES Thermo Jarrel Ash (Nebraska, USA). The overall nutrients uptake was calculated from the yields and the B-contents in plants. All the mentioned analytical procedures are further described in Mühlbachová et al. (2018). The Mg, S and B contents are given in Tables 2–4.

Statistical analysis. The results from the overall period 2015–2017 were statistically analysed with Statistica 13.0 software (TIBCO Software Inc., Paulo Alto, USA). The one-way (treatments) and two-way (treatments and years) analyses of variance ANOVA and Tukey's test were used to determine the significant differences among the years and treatments. The correlation coefficients (*r*) based on the Spearman's equations were calculated.

Table 2. Magnesium content (mg/kg) in soils determined by the Mehlich 3 method and in NH_4-acetate

Treatment	Mg – Mehlich 3			Mg – NH_4 acetate		
	barley 2015	rape 2016	wheat 2017	barley 2015	rape 2016	wheat 2017
Control	178.2 ± 14.8^a	186.5 ± 11.6^a	186.1 ± 10.5^a	135.7 ± 22.2^a	136.8 ± 14.8^a	134.7 ± 15.6^a
S-10/20	175.7 ± 14.5^a	176.5 ± 13.3^a	182.4 ± 13.2^a	135.6 ± 7.7^a	138.7 ± 10.7^a	132.5 ± 7.0^a
S-20/40	168.8 ± 7.0^a	181.2 ± 10.9^a	189.2 ± 11.0^a	133.8 ± 27.1^a	137.4 ± 17.4^a	130.2 ± 11.5^a
S-40/80	167.3 ± 14.1^a	197.6 ± 7.8^a	202.6 ± 7.8^a	154.8 ± 11.5^a	159.3 ± 11.1^a	150.4 ± 9.7^a

Different letters indicate the significant difference according to one-way ANOVA (Tukey's test) in individual years

Table 3. Sulphur content (mg/kg) in soils determined by the Mehlich 3 method and in NH_4-acetate

Treatment	S – Mehlich 3			S – NH_4 acetate		
	barley 2015	rape 2016	wheat 2017	barley 2015	rape 2016	wheat 2017
Control	12.19 ± 0.86^{a}	12.99 ± 0.27^{ab}	9.79 ± 0.74^{a}	17.59 ± 0.63^{cd}	10.60 ± 0.36^{a}	8.46 ± 0.62^{a}
S-10/20	17.68 ± 2.58^{c}	17.35 ± 1.53^{c}	10.92 ± 0.99^{a}	19.71 ± 0.97^{d}	14.55 ± 1.32^{b}	9.44 ± 0.65^{a}
S-20/40	17.28 ± 2.44^{bc}	17.03 ± 0.89^{bc}	11.42 ± 1.07^{a}	20.37 ± 1.49^{d}	14.27 ± 0.74^{b}	9.68 ± 0.81^{a}
S-40/80	18.88 ± 3.08^{c}	19.46 ± 2.52^{c}	12.07 ± 1.32^{a}	23.63 ± 1.33^{e}	16.62 ± 2.15^{bc}	11.02 ± 1.60^{a}

Different letters indicate the significant difference according to two-way ANOVA (Tukey's test.) taking treatments and years in consideration

RESULTS AND DISCUSSION

Boron content in soils. B-Mehlich 3 content in soils is shown in Table 4; it decreased under the Kieserite fertilisation significantly with time (r = –0.917; $P <$ 0.001; Table 5) and ranged from the maximum 1.34 mg B/kg in the year 2015 to 0.89 mg B/kg in the year 2017. Seth et al. (2018) found the critical level of boron extracted by the Mehlich 3 method for plant nutrition at 0.4–0.65 mg/kg. Zbíral (2016) suggested the criteria for B-Mehlich 3 contents depending on soil type: 0.55–0.85 mg B/kg for soils with low B contents and 0.75–1.4 mg B/kg for soils high in B. Considering our results and suggested limits, despite the continual decrease in B-Mehlich 3 concentrations during three years of experiment, the boron content in soils was still sufficient for crop growth (Table 4).

B-NH_4 acetate contents in soils showed a different trend in comparison with B-Mehlich 3. The NH_4-acetate B contents in control soils were similar in all three years of the field trial (0.33–0.39 mg B/kg) and significantly decreased already under the lowest Kieserite treatment (Table 4) since the second year of the experiment. Thereafter, B-NH_4 acetate contents remained similar, irrespective of the Kieserite application dose. Whereas no correlation was found between B-NH_4 acetate contents and the whole duration of experiment, the significant inverse relationship (r = –694; $P <$ 0.001) was found for Kieserite treatments (Table 5).

Temperature and precipitations. The excess or deficit of precipitations could affect nutrient content in soils at time of harvest. The years 2015 and 2016 were particularly characterised by longer periods of lower precipitations in comparison with long-term average (Figure 1B). Sulphur content in soils determined at harvest 2017 was lower in comparison with the years 2015 and 2016. In fact, more intensive precipitations noted mainly in April, June and July 2017 could affect sulphur leaching into deeper soil horizons (Matula 2007b). Effect of precipitations on Mg and B contents in soils was not clear. Mg contents in soils remained quite stable during the whole time of experiment. The decrease of B-Mehlich 3 contents could suggest the hypothesis of possible boron leaching due to the precipitations, but also eventual adsorption in soil sorption complex. On the other hand, NH_4-acetate B content evidently did not decrease with time. It remained very similar in control treatments in all years of the experiment and since the 2nd year, it clearly decreased under the Kieserite treatments. These results could favour possible adsorption way, in which magnesium and potential boron adsorption on its oxides can

Table 4. Boron content (mg/kg) in soils determined by the Mehlich 3 method and in NH_4-acetate

Treatment	B – Mehlich 3			B – NH_4 acetate		
	barley 2015	rape 2016	wheat 2017	barley 2015	rape 2016	wheat 2017
Control	1.24 ± 0.06^{d}	1.07 ± 0.04^{c}	0.94 ± 0.06^{ab}	0.33 ± 0.02^{cd}	0.35 ± 0.05^{fg}	0.39 ± 0.06^{g}
S-10/20	1.34 ± 0.04^{d}	1.02 ± 0.02^{bc}	0.89 ± 0.04^{a}	0.28 ± 0.01^{cde}	0.15 ± 0.02^{a}	0.22 ± 0.02^{abc}
S-20/40	1.30 ± 0.09^{d}	1.03 ± 0.03^{bc}	0.98 ± 0.04^{abc}	0.29 ± 0.01^{ef}	0.16 ± 0.03^{ab}	0.22 ± 0.01^{abc}
S-40/80	1.26 ± 0.04^{d}	1.02 ± 0.03^{bc}	0.92 ± 0.04^{ab}	0.29 ± 0.03^{def}	0.16 ± 0.02^{a}	0.20 ± 0.01^{ab}

Different letters indicate the significant difference according to two-way ANOVA (Tukey's test) taking treatments and years in consideration

Table 5. Correlations between the year of experiment, treatments and Mg, S and B determined by the Mehlich 3 and NH_4 acetate methods in 2015–2017

		Year	Treatment	Mehlich 3			NH_4 acetate		
				Mg	S	B	Mg	S	B
Year		–	ns	0.506**	–0.600***	–0.917***	ns	–0.912***	ns
Treatment			–	ns	0.516***	ns	0.316*	ns	–0.694***
Mehlich 3	Mg			–	ns	–0.463**	0.450**	–0.514***	ns
	S				–	0.457**	ns	0.687***	–0.362*
	B					–	–ns	0.816***	0.344*
NH_4 acetate	Mg						–	ns	ns
	S							–	ns
	B								–

ns – not significant; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$

play an important role. The boron needs of oilseed rape (Tables 6 and 7) are also necessary to take in consideration.

Interactions between magnesium and boron in soils. The inverse correlation was obtained for Mg and B, determined by the Mehlich 3 method ($r = -0.463$; $P < 0.001$) in frame of all years 2015–2017 (Figure 2, Table 5). This relationship was given mainly by a significant B-Mehlich 3 decrease during three years of experiment because Mg-Mehlich 3 contents in soils under the Kieserite treatments increased only slightly and non-significantly (Table 2) since the second year of the experiment. No significant correlations were found between B-NH_4 acetate which decreased in correspondence with the Kieserite treatments and Mg-NH_4 acetate.

Magnesium in such circumstances can create bonds with boron anionic forms when magnesium complexes with borylborohydride, diborane or alkylborane anions were found (Pécharman et al. 2018). Boron can be also adsorbed on magnesium oxides (Dionisiou et al. 2006) or on the surface of Mg-Al (NO_3) double-layered hydroxides (Kentjono et al. 2010). These processes are reported for boron removal from wastewaters, however, similar adsorption processes are not excluded also in soils.

Interactions between sulphur and boron in soils. The decrease of B-Mehlich 3 contents in soils observed in the three-year period resulted in a positive correlation with S-Mehlich 3 much probably due to the decrease of S-Mehlich 3 observed in the third year of experiment (Figure 3, Table 3). In fact, more intensive precipitations in April, June and July 2017 (Figure 1) could cause sulphur leaching into deeper soil horizons (Matula 2007b). Taking in consideration data of individual years, the correlation between S and B-Mehlich 3 content in soils was found only in the year 2016 ($r = -0.569$; $r < 0.05$) (Figure 4). Boron is complexed on the soil constituents mainly in many more or less mobile, mainly anionic forms (Majidi et al. 2010, Kot 2015) and available forms of sulphur in soil are primarily SO_4^{2-} anions. The interaction between sulphur added in Kieserite and boron in the soil complex and possible gradual release of boron from soil mineral particles or Fe/Al hydroxides (Matula 2007b) are not excluded.

On the contrary to Mehlich 3, NH_4 acetate better determined readily available boron leading to

Table 6. Boron contents (mg B/kg dry matter) in crops grown under increasing Kieserite rates

Treatment	Grain/seed			Straw		
	barley 2015	rape 2016	wheat 2017	barley 2015	rape 2016	wheat 2017
Control	1.67 ± 0.16^{b}	11.91 ± 0.76^{b}	1.07 ± 0.10^{b}	4.58 ± 0.78^{a}	26.00 ± 4.21^{b}	1.98 ± 0.38^{b}
S-10/20	1.01 ± 0.06^{a}	11.07 ± 0.27^{ab}	0.69 ± 0.10^{a}	3.68 ± 0.64^{a}	21.05 ± 2.28^{a}	1.62 ± 0.16^{ab}
S-20/40	0.88 ± 0.07^{a}	11.06 ± 0.36^{ab}	0.65 ± 0.06^{a}	2.84 ± 0.59^{a}	23.78 ± 3.37^{ab}	1.49 ± 0.06^{a}
S-40/80	0.87 ± 0.04^{a}	10.70 ± 0.32^{a}	0.61 ± 0.03^{a}	3.20 ± 0.59^{a}	22.63 ± 2.08^{a}	1.56 ± 0.09^{ab}

Different letters indicate the significant difference according to one-way ANOVA (Tukey's test) in individual years

Table 7. Boron uptake (g B/ha) by crops grown under increasing Kieserite rates

Treatment	Grain/seed			Straw		
	barley 2015	rape 2016	wheat 2017	barley 2015	rape 2016	wheat 2017
Control	14.62 ± 1.72^{b}	29.87 ± 1.68^{ab}	9.70 ± 0.86^{b}	23.42 ± 2.78^{b}	110.01 ± 17.11^{a}	7.69 ± 1.52^{b}
S-10/20	8.43 ± 0.52^{a}	28.17 ± 046^{ab}	6.15 ± 0.77^{a}	18.81 ± 2.52^{a}	93.96 ± 10.81^{a}	6.20 ± 0.70^{ab}
S-20/40	7.48 ± 0.68^{a}	30.80 ± 1.21^{b}	5.85 ± 0.57^{a}	15.11 ± 2.78^{a}	112.28 ± 11.43^{a}	5.75 ± 0.41^{ab}
S-40/80	7.27 ± 0.35^{a}	29.15 ± 0.38^{ab}	5.44 ± 0.31^{a}	16.70 ± 3.56^{a}	107.51 ± 14.06^{a}	5.96 ± 0.39^{ab}

Different letters indicate the significant difference according to one-way ANOVA (Tukey's test) in individual years

significant interactions between boron and sulphur in the years 2016 and 2017 (Figure 5). Significant inverse correlations between S-NH$_4$ acetate and B-NH$_4$ acetate contents were found in the 2nd ($r = -0.787, P < 0.001$) and 3rd year ($r = -0.576; P < 0.05$) in soils. This suggests that the adverse effect of sulphur on boron contents in soils was more pronounced by higher B-uptake of oilseed rape. In case of readily available B-NH$_4$ acetate boron, the negative effect of sulphur together with higher B-uptake by oilseed rape persisted to the 3rd year of experiment. Antagonistic interactions were described also between B and P (Kaya et al. 2009, Mühlbachová et al. 2018) and between B and Zn (Černý et al. 2016). Similar interactions can appear also with other elements as Mg or S.

Effect of crops on boron content in soils. B-content in crops and B-uptake is shown in Tables 5 and 6. The B-content decreased in grain, seeds and straw already under the lowest dose of Kieserite treatments. A decrease of boron content in soils under the Kieserite treatments was noted in the 2nd year when oilseed rape containing about 6.7 times more boron than the spring barley and 14.1 times more than winter wheat was grown. This resulted in higher B uptake by oilseed rape, which could affect boron content in soils. An important role in the Kieserite treatments could play also the possible boron adsorption processes on Mg oxides (de la Fuente and Camacho 2006, Dionisiou et al. 2006, Pécharman et al. 2018) or on other soil mineral or organic constituents (Kot 2015), which could affect lower B-uptake observed in cereals. Interactions between S and B have not been commonly reported, but Shankar et al. (2013) in his models of plant uptake indicated that whereas soil S had significant positive effects on plant nutrient status in dry matter of plants, negative effects were found for B. In addition, De Oliveira Costa et al. (2019) found negative correlations between S and B content in forage leaves, which is in good accordance with our results.

B-Mehlich 3 and B-NH$_4$ acetate contents in soils. A positive correlation between B-Mehlich 3 and B-NH$_4$ acetate contents in soils was found for the period 2015–2017 ($r = 0.344, P < 0.05$) (Table 5). The low relationship between B-Mehlich 3 and B-NH$_4$ acetate contents in soils can be explained by different dynamics of B-Mehlich 3 and B-NH$_4$ acetate contents in soils observed under the Kieserite treatments. Mehlich 3 extractant showed a continual decrease of B contents in soils throughout the experimental period. From this perspective, Mehlich 3 method

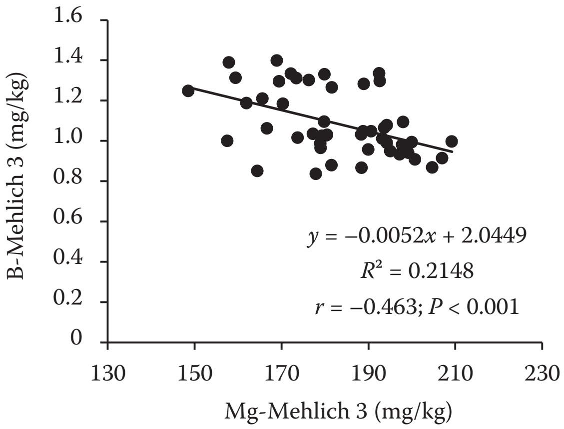

Figure 2. Correlation between Mg-Mehlich 3 and B-Mehlich 3 in the years 2015–2017

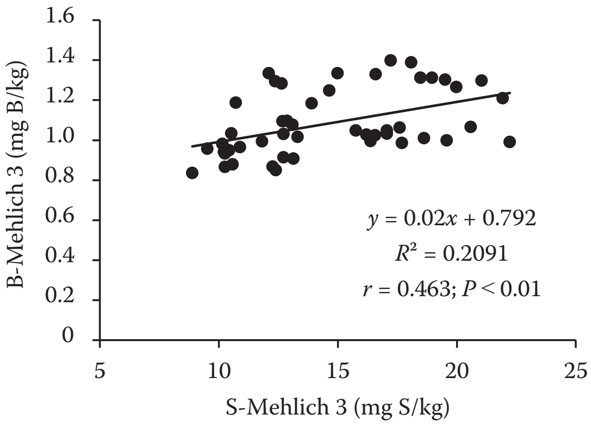

Figure 3. Correlation between S-Mehlich 3 and B-Mehlich 3 in the years 2015–2017

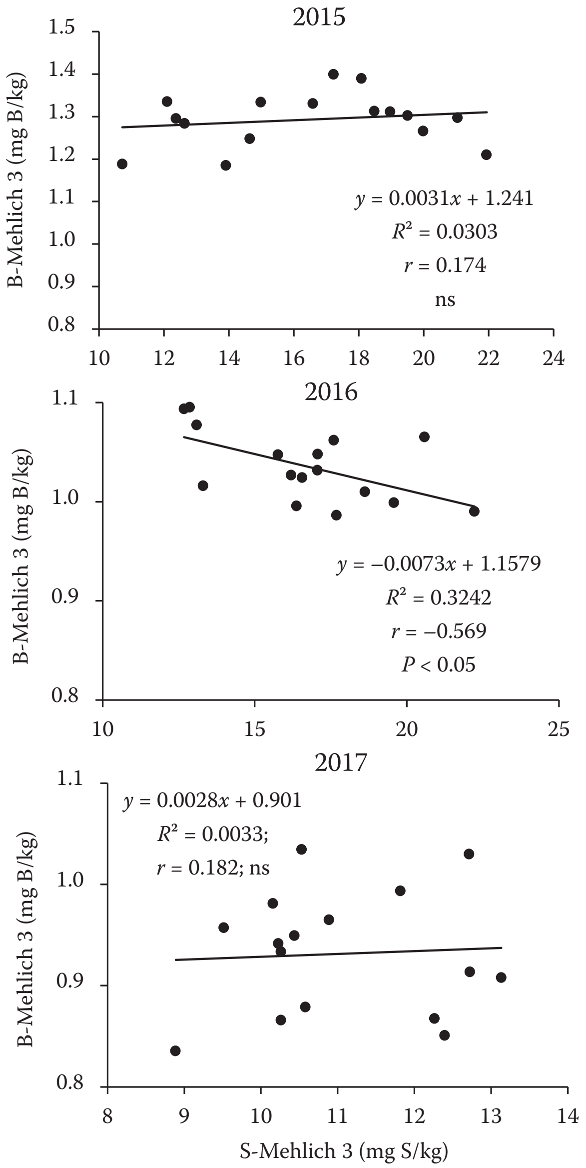

Figure 4. Correlations between S-Mehlich 3 and B-Mehlich 3. ns – not significant

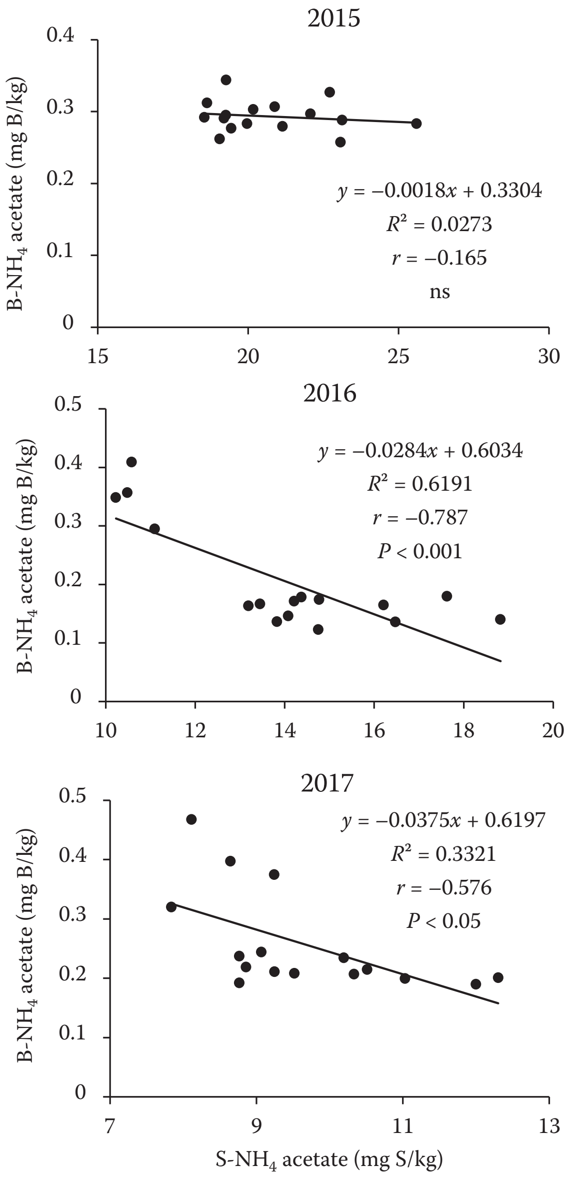

Figure 5. Correlations between S-NH_4 acetate and B-NH_4 acetate. ns – not significant

can be useful for determination of soil B-contents in soil testing provided by the Central Institute for Supervising and Testing in Agriculture (Zbíral 2016) as this extractant may show long-time trends in B contents in soils. B-NH_4 acetate responded better to the Kieserite treatments in individual years. Comparing soil tests, Matula (2009) found higher coincidence for boron with Mehlich 3 for NH_4 acetate than for water extraction.

In conclusion, several mechanisms of the observed decrease of boron content in soils under the Kieserite application could appear. The adsorption of boron on magnesium oxides and other Mg compounds in soils cannot be excluded. Also, interactions of boron with sulphur present as SO_4^{2-} and subsequent leaching are possible. In addition, crops as oilseed rape with higher B-uptake can play also an important role, particularly in case of exchangeable boron contents in soils. Crops that need higher quantities of nutrients should therefore be sufficiently supplied also with boron, as possible boron deficiency could persist also in period following crops with high nutrient demands. For instance, postharvest residues of oilseed rape contained about 3.6 times more B than was the B-uptake by seeds. If possible, postharvest residues should therefore remain in the field as they can contain considerable amounts of nutrients including boron.

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