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Boron content and some quality features of potato tubers under the conditions of using sulphur fertilizer

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Abstract. The objective of the study was to investigate the impact of sulphur application on the content and uptake of boron (B) with the yield of potato tubers. A field experiment with potato was conducted in 2009–2011, with S applied in different forms (elemental and K_2SO_4) and at different rates (0, 25 and 50 kg ha^{-1}).
The content of B in tubers depended significantly on each fertilizer S rate and form. The uptake of boron with dry mass of tubers was equally advantageous in the application of each rate and form with sulphur fertilization compared to controls. No significant effect of weather on the content and uptake of boron tubers was found. The tuber yield and starch content were significantly increased by both the fertilizer S rate and form. A positive correlation was found between B content and B uptake of the yield of tubers. B uptake positively correlated with tuber yield and with a yield of DM and with the yield of starch.
Sulphur applied as sulphate increased the content of SO_4-S in the soil. Application of elemental S at a rate of 50 kg ha^{-1} decreased the pH of the soil. Soil content of total C depended on each rate and form of S applied. No correlation was found between B content and B uptake between the analysed soil parameters. The content of total C in the soil was positively correlated with tuber yield. The pH of soil negatively correlated with tuber yield.

Key words: sulphur fertilization, boron, potato.

INTRODUCTION

Boron is an essential component of plants for proper development and growth. It plays a part in carbohydrate metabolism, synthesis of nucleic acids (DNA and RNA) and phytohormones. Boron regulates the development of tissues and the structure of cell walls, promotes the development of buds and flowering, and also acts as a protective antioxidant (Cakmak & Römheld, 1997; Korzeniowska, 2008). Boron reduces the oxidation of phenols and prevents discolouration of tubers. Boron deficiency induces the internal breakdown of tubers in sugar beet, turnip and potatoes (Brown et al., 2002). Hopkins et al. (2007) studied the role of boron on tuberization and yield in potato and reported a non-significant increase due to soil or foliar application of boron. Boron does not have a direct influence on yield or related attributes; however, it plays a supplementary role when applied with sulphur (Bari et al., 2001; Singh et al., 2018).

Plants uptake boron from the soil solution as ions BO_3^{3-} and $B_4O_7^{2-}$. The concentration of boron in the soil solution is a characteristic of the high dynamics of changes. For the duration of one vegetation season boron concentration can indicate toxic and deficiency values. At the same time, the distinction between toxic and deficiency concentration levels are very fine (Zhu et al., 2007; Szulc & Rutkowska, 2013). The uptake of boron anions through the roots is partly limited in the presence of other anions: Cl^-, SO_4^{2-}, $PO^{3-}{}_4$. This element is most intensively taken from acidic soils. Plants that require a lot of boron include some *Fabaceae* (alfalfa), root crops (beets, potatoes), vegetables, (cauliflower, celery) and fruit trees (apple trees) (Singh et al., 2018).

Our earlier research also showed an increase in macro- and microelements in potato tubers and cereal grains fertilized with sulphur (Klikocka et al., 2005; Klikocka, 2010; Klikocka & Głowacka, 2013; Klikocka et al., 2017). Sulphur deficiency occurs in many European and other countries (Järvan et al., 2008; Klikocka, 2011a; Tabak et al., 2019). Particularly in Poland, some regions are characterized by low SO_2 emissions to the atmosphere and low soil element content. Sulphur dioxide emissions have also been significantly reduced in Estonia (Podkuiko et al., 2017). Research on sulphur fertilization shows that sulphur should be added to fertilization to increase plant production and improve the quality of agricultural products (Klikocka, 2011b; Siebielec et al., 2017).

Sulphur supplementation for mineral fertilization, mainly nitrogen, is a very significant and current problem in agriculture. The lack of wider scientific research on the fertilization of plants with sulphur results from the fact that, especially in Poland (which is mainly dependent on industry), the positive balance of this element in agroecosystems was maintained for many years, as a result of high SO_2 emissions to the atmosphere in the country. However, due to environmental protection initiatives aimed at reducing SO_2 emissions to the atmosphere in Western Europe a progressing negative sulphur balance in soil could be observed from the second half of the 1980s (Klikocka, 2011a). Studies concerning the content of sulphur in plants have shown that there is a group of plants particularly sensitive to deficiency of this element. These are *Brassicaceae* (rape), *Liliaceae* (garlic, onion), *Fabaceae* (bean), *Amaranthaceae* (sugar beet), *Solanaceae* (potato) and *Poaceae* (wheat) (Klikocka, 2011b).

Sulphur application has been found to increase the yield of potato tubers and improve tuber quality and resistance to *Streptomyces scabies* and *Rhizoctonia solani* (Klikocka et al., 2005; Klikocka, 2010). According to Wang et al. (2008), potato is not considered a high S-demanding crop, with S concentrations ranging from 1.2 to 2.8 g kg^{-1} in the dry matter of tuber and haulm, but considerable amounts of S can be removed from the soil over the long term when yields are high. In S-deficient soil, application of S fertilizer can significantly increase the tuber yield and starch content of potato, while contributing to a decrease in tuber N concentration due to increased dry matter production (Kołodziejczyk, 2014). Furthermore, Eppendorfer & Eggum (1994) found that S deficiency significantly influenced the amino acid composition of potato; the concentration of the S-containing amino acids methionine and cysteine decreased by 30% and 60%, respectively, in S-deficient soil.

Potato (*Solanum tuberosum* L.) is the fourth most important food crop in the world, providing more food than the combined world output of fish and meat. Potato tube yield depends on agrotechnical treatments, cultivars and environmental conditions (Barbaś & Sawicka, 2020). Potato tubers contain 1–1.2% mineral compounds, the most basic being potassium, magnesium, calcium and phosphorus (Gugała & Zarzecka; 2011, Klikocka & Głowacka; 2013). In the study by Wierzbicka (2012), the average boron content in potato tubers was 0.10 mg 100 g^{-1} fresh mass, which on average corresponds to 7% of the daily human demand for boron.

However, there is little information available concerning the influence of S supply on boron content in potato tubers. We therefore made an attempt to determine the effect of the form (sulphate or elemental) and rate (0, 25, 50 kg ha^{-1}) of sulphur application on the content and uptake of boron (B) in the dry mass of potato tubers.

MATERIALS AND METHODS

Field experiments were conducted in 2009–2011 in south-eastern Poland (50°42' N, 23°15' E). A two-factor experiment was carried in a randomized split-plot design (with four replications). The soil in the experiment was marked as Cambisols (WRB 2015) consisting of light silty sand (sand 68%, silt 31% and clay 1%). In the soil a high content of phosphorus (P) (53.5 mg kg^{-1}) was found, an average content of potassium (K) and magnesium (Mg) (respectively 85.2 and 33.7 mg kg^{-1}), and low total and available sulphur ($S\text{-}SO_4^{2-}$) (respectively 87.0 and 12.4 mg kg^{-1}). The soil reaction was slightly acidic (pH 5.7) and total C content amounted to 9.0 g kg^{-1}.

The object of the study was potato (*Solanum tuberosum* L.) of the medium-early edible Irga variety fertilized with sulphur in the amount of 0, 25 and 50 kg S ha^{-1} in the form of potassium sulphate (K_2SO_4) and elemental sulphur (S^0). The area of the plots was 30 m^2 for planting and observation, and 19.5 m^2 (3.0 m × 6.5 m) for harvesting.

After harvesting of spring Triticale, 3 t ha^{-1} of straw from spring Triticale (as organic fertilizer) and 46 kg N ha^{-1} (urea $CO(NH_2)_2$, for stabilization of the C:N ratio) was applied, and the soil was ploughed (20 cm, second or third week of August). Spring fieldwork was carried out in the third week of March, using shallow ploughing (15 cm). Each year mineral fertilizers were applied pre-planting (kg ha^{-1}): N - 100 (as ammonium nitrate); P - 40 (as mineral superphosphate - triple granular); and K - 140 (as potassium chloride in control plots and plots with elemental S, and as potassium chloride balanced with potassium sulphate in plots with sulphate sulphur - 116 kg of K as K_2SO_4 + 24 kg of K as KCl). Potato planting was carried out in the second third of April. Row-space was 67.5 cm with 44,000 tubers planted per ha. The distance between plants in a row was 30 cm.

Chemical application of fungicides and herbicides for the control of pests and potato diseases was carried out using the recommendations of the Institute of Plant Protection (IOR-Poland).

Table 1. Meteorological conditions in 2009–2011 and the long-term average from 1971–2005 (Zamość Research Station)

	Months (k)						Sum - Mean (IV-IX)		
Years	Apr	Mai	Jun	Jul	Aug	Sep	*k*	*p*	*t*
2009	0.46	2.39	2.06	0.39	0.78	0.68	1.10	350.1	3,122
2010	1.13	2.02	1.14	2.08	1.34	1.79	1.56	489.0	2,967
2011	1.14	0.75	0.95	2.39	2.27	0.05	1.33	404.2	2,923
1971–2005	1.85	1.50	1.56	1.72	0.99	1.35	1.44	393.5	2,690

p – precipitation (mm); *t* – temperature (°C); k – Selyaninov's hydrothermal coefficient [$k = (p \times 10)/\sum t$). The value of the Sielianinov's coefficient (Skowera, 2014): extremely dry $k \leq 0.4$, very dry $0.4 < k \leq 0.7$, dry $0.7 < k \leq 1.0$, rather dry $1.0 < k \leq 1.3$, optimal $1.3 < k \leq 1.6$, rather humid $1.6 < k \leq 2.0$, humid $2.0 < k \leq 2.5$, very humid $2.5 < k \leq 3.0$, extremely humid $k > 3.0$.

Table 1 presents rainfall and air temperature during the vegetation season (IV–IX) in 2009–2011. The hydrothermal coefficient of Selyaninov was analysed based on meteorological data. The 2009 growing season was rather dry (1.10), while the 2010 and 2011 seasons were optimum (respectively 1.56 and 1.33).

After potato harvest, the tuber yield in t ha^{-1} and the percentage starch content (using the Reiman-Parow hydrostatic balance) were determined. Tuber samples (from each plot) after drying were ground into particles smaller than 0.12 mm. Boron (B) was analysed in dry mass (DM) of potato tubers by colourimetry using diantrimide (Poulain & Al Mohammad, 1995) after digestion of the dried tubers at 550 °C and dissolution of the residue in hydrochloric acid solution. In soil samples taken annually from each plot in spring (before sowing fertilizers) and after the harvesting of potato tubers, the content of sulphate sulphur, total carbon and soil pH were determined using methods indicated in Table 2. The analyses were carried out in the Laboratory of the Institute of Plant Nutrition and Soil Science at FAL in Braunschweig (Germany) (Table 2).

Table 2. Analytical methods for plant tissue materials and soil

Parameter	Method
Plant tissue material	
Dry matter	Oven method (at 105 °C)
Starch	Specific gravity method using a Reimann-Parow hydrostatic balance
Boron	Determined by colourimetry with diantrimide (Poulain & Al Mohammad, 1995) after digestion of the dried potato tubers at 550 °C and dissolution of the residue in hydrochloric acid solution
Soil	
pH	Determined potentiometrically in 0.01 M $CaCl_2$ suspension using a Methrohm 605 pH-meter
Total C	Dry combustion; LECO EC-12®, model 752-100
SO_4^{2-}	Extracted using 0.025 m KCl and determined by ion-chromatography

The results were subject to an analysis of variance (ANOVA) using the Snedecor F test, and mean values were compared by the Tukey test using Statistica software, version 7.0 (StatSoft Inc.: Tulsa, OK, USA, 2007; StatSoft Polska Kraków, 2007) and Excel 7.0 (2007 Microsoft Office System). The significance level for rejection of the null hypothesis was 5% ($p < 0.05$). The relationships between the tested parameters were determined by Pearson's correlation.

RESULTS AND DISCUSSION

The analysis of variance showed that the differences in the content and uptake of boron with the yield of the tubers were statistically significant. The experimental factors had different effects on the analysed characteristics (Table 3). The content of B in tubers depended significantly on the rate and form of S fertilizer. In ascending order, the following combinations worked best: (1) 50 kg SO_4 ha^{-1} - 100%, (2) 25 kg S ha^{-1} - 96.2%, (3) 50 kg S ha^{-1} - 93.5%, (4) 25 kg SO_4 ha^{-1} - 90.9%, (5) 0 kg S ha^{-1} (Control) - 84.9%. In our own study potato tubers accumulated on average 9.11 mg kg^{-1} DM of boron. In the study of Hajduk et al. (2012), potato tubers accumulated much less boron (2.2–7.5 mg kg^{-1} DM).

Table 3. The influence of S fertilization on the content (mg kg^{-1}) and uptake (g ha^{-1}) of B in potato tubers and yield of tubers (t ha^{-1})

S rate (kg ha^{-1})	S form	Boron		Yield of tubers (t ha^{-1})
		Content (mg kg^{-1} DM)	Uptake (g ha^{-1})	
0 – Control		8.28 e	47.99 b	25.56 c
25	SO_4-S	8.86 d	55.63 a	28.06 a
25	S°	9.38 b	54.05 a	26.17 b
50	SO_4-S	9.75 a	56.44 a	27.02 ab
50	S°	9.12 c	55.54 a	27.44 ab
0 – Control		8.28 A	47.99 A	25.56 B
25	Mean	9.12 A	54.84 A	27.12 A
50		9.51 A	55.54 A	27.23 A
0 – Control		8.28 A	47.99 A	25.56 B
SO_4-S	Mean	9.30 A	56.03 A	27.54 A
S°		9.33 A	54.35 A	26.81 A
Years	2009	9.49 A	52.82 A	25.03 C
	2010	8.99 A	53.82 A	27.07 B
	2011	8.86 A	54.61 A	28.46 A
F-distribution	R	1.04	1.21	5.20
	F	0.50	1.46	6.55
	R × F	4.04	3.22	3.11
	Y	0.97	0.39	15.67
p-value	R	0.3683	0.3130	0.0123
	F	0.6125	0.2510	0.0048
	R × F	0.0069	0.0209	0.0241
	Y	0.1042	0.6822	0.0000
LSD	R	n.s.	n.s.	1.19
P = 0.05	F	n.s.	n.s.	1.19
	R × F	0.22	5.32	1.60
	Y	n.s.	n.s.	1.19

Explanations: Variable: R rate ($df_1 = 2$, $df_2 = 27$); F form ($df_1 = 2$, $df_2 = 27$); RF rate x form ($df_1 = 4$, $df_2 = 45$); Y years ($df_1 = 2$, $df_2 = 45$): where df_1 – variable degree of freedom; df_2 – error degree of freedom; F – distribution in analysis of variance, *p*-value of F variance ratio; LSD – least significant difference; n.s. – not significant.

Uptake of boron with a dry mass of tubers was equally advantageous for all rates and forms of sulphur fertilization compared to controls. In our own study, potato tubers have an uptake of boron on average 53.75 g ha^{-1}. No significant effect of weather on the content and uptake of boron tubers was observed (Table 3).

Sulphur application had a positive effect on the tuber yield. The application of each rate of sulphur, regardless of its form, had a significantly positive effect on tuber yield compared to the control group (in which sulphur was not used). However, the most favourable tuber yield was obtained after the application of 25 kg ha^{-1} of sulphate sulphur (SO_4-S) (Table 3). A less favourable result was achieved after using elemental sulphur. As reported by Klikocka et al. (2005), elemental sulphur must undergo some biochemical and microbiological processes in the soil before it becomes available to plants, so a rate of 25 kg ha^{-1} in the elemental form is not as effective as sulphate that is directly available to plants. A positive impact of sulphur fertilization (in the form of potassium sulphate, ammonium sulphate, single superphosphate, gypsum and elemental sulphur) on potato yields has been reported by numerous authors, such as Carew et al. (2009). The effect may result from a slight decrease in soil pH (pH) due to the use of sulphur, in conditions where the boron anion is better absorbed (Singh et al., 2018).

Kumar et al. (2007) reported that tuber dry-matter percentage was higher after the application of K in the form of potassium sulphate and nitrate than potassium chloride. In the presented studies, an inverse relationship was noted. This is because the addition of each rate and form of S to NPK fertilization caused a significant reduction in the percentage of dry matter. This content was highest on control plots where sulphur was not used (Table 4).

Wang et al. (2008) state that in S-deficient soil the application of S fertilizer can significantly increase tuber yield and the starch content of potato. A similar phenomenon was noted in the presented research. It was found that each rate and form of sulphur used significantly increased the starch content in potato tubers. It was noted that the most favourable rate was 25 kg ha^{-1} of sulphate sulphur (SO_4-S) (Table 4).

Table 4. The influence of S application on quality of potato tubers

S rate (kg ha^{-1})	S form	Dry Mass of tubers (%)	Dry Mass Yield (t ha^{-1})	Starch content (%)	Yield of starch (t ha^{-1})
0 – Control		22.75 a	5.81 b	14.63 c	3.74 b
25	SO_4-S	22.38 b	6.28 a	14.73 bc	4.14 a
25	S^o	22.10 b	5.78 b	14.97 a	3.92 ab
50	SO_4-S	21.50 c	5.80 b	14.85 ab	4.04 a
50	S^o	21.52 c	5.90 b	14.78 bc	4.06 a
0 – Control		22.75 A	5.81 A	14.63 B	3.74 B
25	Mean	22.24 B	6.03 A	14.85 A	4.03 A
50		21.51 C	5.85 A	14.82 A	4.05 A
0 – Control		22.75 A	5.81 A	14.43 B	3.74 C
SO_4-S	Mean	21.94 B	6.04 A	14.79 A	4.09 A
S^o		21.81 B	5.56 A	14.88 A	3.99 B
Years	2009	22.32 A	5.58 B	14.11 C	3.53 C
	2010	22.14 A	5.99 A	14.99 B	4.06 B
	2011	21.69 B	6.17 A	15.28 A	4.35 A
F-distribution	R	67.07	1.95	10.63	7.28
	F	56.42	2.43	6.14	8.94
	R × F	29.75	3.21	4.83	3.26
	Y	17.41	11.16	189.70	38.77
p-value	R	0.0000	0.1621	0.0004	0.0030
	F	0.0000	0.1069	0.0063	0.0010
	R × F	0.0000	0.0210	0.0025	0.0197
	Y	0.0000	0.0001	0.0000	0.0000
LSD	R	0.22	n.s.	0.10	0.19
P = 0.05	F	0.22	n.s.	0.10	0.19
	R × F	0.29	0.33	0.16	0.25
	Y	0.22	0.24	0.10	0.19

Explanations: as in Table 3.

The study of Singh et al. (2018) and Sharma et al. (2011) revealed that application of sulphur led to a significantly high yield and quality of potato tubers in terms of DM and starch content. According to Singh et al. (2018), Eppendorfer & Eggum (1994) the plants without the application of sulphur and boron might suffer from deficiency so dry matter and starch content was lowest. For yield of tubers, yield of dry mass, starch content and yield of starch the most favourable growing season was 2011. In this season July and August were humid ($k = 2.39$ and 2.27) and September was extremely dry ($k = 0.05$). In the study by Pszczółkowski et al. (2019) the highest content and yield of dry matter and starch were obtained in years with optimum and well-distributed rainfall, while the highest starch content was recorded in dry and sunny years. Makaraviciute (2003) observed in their research that the use of different rates and forms of fertilizers as well as changing weather during the potato growing season had an irregular effect on the content. In favourable meteorological conditions, the use of NP and K fertilizers in the form of potassium sulphate and the addition of microelements increased the amount of starch and dry matter in most of the studied varieties' mass in potato tubers.

Table 5 shows soil pH and soil content of total carbon and SO_4-S after the potatoes were harvested. Generally, the application of S significantly increased SO_4-S content in the soil. Soil content of SO_4-S depended more on the form of S than on the rate of application and was highest after the application of elemental S at 50 kg ha^{-1}.

Table 5. The influence of S application on the soil characteristics

S rate (kg ha^{-1})	S form	pH (0.01 M KCl)	Total C (g kg^{-1})	SO_4-S (mg kg^{-1})
0 – Control		5.28–5.30	8.00 c	24.88 b
25	SO_4-S	5.24–5.33	7.93 c	29.03 ab
25	S^o	5.16–5.37	9.74 a	26.03 b
50	SO_4-S	5.12–5.39	9.04 b	33.40 a
50	S^o	5.12–5.15	9.38 ab	26.79 b
0 – Control		5.28–5.30	8.00 C	24.88 A
25	Mean	5.22–5.35	8.84 B	27.53 A
50		5.12–5.27	9.21 A	30.10 A
0 – Control		5.28–5.30	8.00 C	24.88 B
SO_4-S	Mean	5.18–5.36	8.49 B	31.21 A
S^o		5.15–5.25	9.56 A	26.41 B
Years	2009	5.26–5.39	7.66 C	23.75 B
	2010	5.20–5.27	9.19 B	35.86 A
	2011	5.16–5.22	9.61 A	24.47 B
F-distribution	R	-	24.46	3.12
	F	-	67.22	6.31
	R × F	-	18.56	3.99
	Y	-	48.81	27.10
p-value	R	-	0.0000	0.0601
	F	-	0.0000	0.0056
	R × F	-	0.0000	0.0074
	Y	-	0.0000	0.0000
LSD	R	-	0.28	n.s.
$P = 0.05$	F	-	0.28	3.82
	R × F	-	0.54	4.80
	Y	-	0.28	3.82

Explanations: as in Table 3.

The application of elemental S noticeably reduced soil pH. The application of S in the form of sulphate generally increased the content of SO_4-S in the soil, while fertilization with elemental S at a rate of 50 kg ha^{-1} decreased soil acidity. Irrespective of the form of S, the rate of 50 kg ha^{-1} was more favourable to total C content in the soil. Sulphate applied with mineral fertilizers is more prone to leaching, and S sequestration depends on both the fertilizer type and the S application rate (Scherer et al., 2012).

The content of SO_4-S and content of total C in the soil and pH of soil did not correlate with the content and uptake of B by the yielsd of tubers (Table 5). The pH of soil negatively correlated with the yield of tubers and with starch content and yield of starch. There was a positive correlation between the pH of the soil and dry mass of tubers and with yield of DM and with starch content and yield of starch. The content of total C in the soil negatively correlated with the dry mass of tubers. No correlation was found between the content of SO_4-S and the analysed features. The pH of soil negatively correlated with total C content in the soil. Also, a positive correlation was noted between B uptake and yield of tubers. A positive correlation was found between B content and B uptake and between B uptake and yield of DM and yield of starch. Tuber yield negatively correlated with dry mass of tubers. A positive correlation was identified between tuber yield and yield of DM and starch content and yield of starch (Table 6).

Table 6. Significant correlation coefficients (r_{xy}) between elements in plants, soil properties and yield of potato tubers (mean values from 2009–2011)

Specification (n = 60)	No.	Number of features 2	3	4	5	6	7	8	9	10
B content (mg kg^{-1})	1	**0.774**	-0.132	-0.136	-0.200	-0.161	-0.162	0.075	-0.054	0.040
B uptake (g ha^{-1})	2	-	**0.473**	-0.171	**0.462**	0.052	**0.368**	-0.023	0.121	0.135
Yield of tubers (t ha^{-1})	3	-	-	**-0.435**	**0.929**	**0.365**	**0.902**	**-0.277**	**0.340**	0.150
Dry Mass of tubers (%)	4	-	-	-	-0.074	**-0.366**	**-0.496**	**0.436**	**-0.314**	-0.058
Yield of DM (t ha^{-1})	5	-	-	-	-	**0.249**	**0.793**	-0.141	**0.254**	0.154
Starch content (%)	6	-	-	-	-	-	**0.729**	**-0.357**	**0.327**	0.139
Yield of starch (t ha^{-1})	7	-	-	-	-	-	-	**-0.351**	**0.393**	0.171
pH of soil	8	-	-	-	-	-	-	-	**-0.335**	0.040
Total C content (g kg^{-1})	9	-	-	-	-	-	-	-	-	0.117
SO_4-S content (mg kg^{-1})	10	-	-	-	-	-	-	-	-	-

* Bold letters mean significant differences (*P* 0.05 = 0.250 and *P* 0.01 = 0.325).

As reported by Jaggi et al. (2005) and Scherer et al. (2012), sulphur deficiency in world soils has led to the supplementation of S fertilizer to enhance the production and improvement of quality of crops. Among S-containing fertilizers, elemental S (S^o) is becoming increasingly popular in field crops. The use of S^o helps to reduce leaching and run-off losses, leaving prolonged residual effects on the S nutrition of the succeeding crop.

The biochemical oxidation of S° produces H_2SO_4, which decreases soil pH and makes soil conditions more favourable for plant growth (Jaggi et al., 2005; Safaa et al., 2013). Therefore, supplementation of mineral fertilization for potatoes with sulphur, and particularly its elemental form, should be recommended. Kalembasa & Kuziemska (2013) found that plants take up boron (B) in greater quantities from acidic and weakly acidic soils, and its uptake by plants decreases with increasing pH. This phenomenon can be referred to as the presented own research.

Based on the present study, an optimum rate of 50 kg ha^{-1} of elemental sulphur may be proposed for potato. This will introduce an additional 39.9 mg kg^{-1} SO_4-S into the soil (assuming that the average depth of the topsoil is 25 cm and soil density is 1.5 Mg m^{-3}). At present, 91.7% of soil profiles in Poland contain less than 10.0 mg kg^{-1} SO_4-S, so that they are classified as low-sulphur, which entails a possibility that such soils may be deficient in sulphur (Siebielec et al., 2017). The soil on which the experiment was carried out contained 10.1 mg kg^{-1} SO_4-S, which was very low content.

CONCLUSIONS

1. Fertilization with sulphate sulphur at 25 kg S ha^{-1} and elemental sulphur at 50 kg ha^{-1} proved most favourable for the yield of potato tubers and the yield of dry matter and starch. The content of starch was significantly increased by both rates of supplementation and both forms of sulphur fertilizer.
2. The application of sulphur increased B content and uptake irrespective of the rate or form of S fertilizer. Boron content was highest when sulphate (SO4-S) was applied at 50 kg S ha-1. Boron uptake by the yield of tubers was significantly increased by both rates and forms of the applied S fertilizer.
3. Fertilization with sulphur at 50 kg ha-1 and in its elemental form significantly increased the content of total carbon in the soil. On the other hand, the use of sulphate, regardless of the rate, fostered the content of total nitrogen in the soil.
4. A positive correlation was identified between B content and B uptake in the yield of tubers. B uptake positively correlated with tubers yield and with the yield of DM and yield of starch. No correlation was determined between B content and B uptake in the analysed parameters of the soil. The content of total C in the soil was positively correlated with tuber yield. The pH of soil negatively correlated with tuber yield.
5. Sulphur fertilization can also be recommended for organisational reasons because it has a generally positive biological effect.

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