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EFFECTS OF SULPHUR FERTILIZATION ON THE CONTENT AND UPTAKE OF MACROELEMENTS IN NARROW-LEAF LUPIN

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ABSTRACT

A three-year field experiment was performed at the Field Experiment Station at Wierzchucinek (53°26'N, 17°79'E). It was set up with the randomised split-plot design in *Haplic Luvisol,* made from loam of the loamy sand composition (18% of silt and clay fractions) showing a low sulphate sulphur (VI) content. The field experiment covered the following factors: sulphur application method (the first order factor: foliar and pre-sowing into soil), form of sulphur (the second order factor: elementary sulphur in a form of Siarkol Extra 80 WP and ionic sulphur in a form of sodium sulphate (VI) and doses of sulphur (the third order factor, in kg S·ha^{-1}: 0, 20, 40, 60.The aim of the research was to evaluate the effect of varied methods of applications, forms and rates of sulphur on the content of macroelements in the lupin seeds. The research demonstrated that the sulphur rate determined most the content of macroelements. The application of that nutrient resulted in, general, in a significant increase in the content of potassium and a decrease in the content of calcium, magnesium and phosphorus as compared with the control. The accumulation of potassium and phosphorus in the lupin seeds was more enhanced by the foliar sulphur application than by its soil application, however, for calcium, sulphur introduction into soil was more favourable. The use of the ionic form of that element, as compared with its elemental form, in general, significantly increased the content of sodium and phosphorus.

Key words: sulphur, narrow-leaf lupin, content of macroelements, uptake of macroelements.

INTRODUCTION

Literature reports over the recent years clearly show a growing sulphur deficit in the soils of many regions of the world (McGrath et al., 2003; Zhao et al., 2003; Stern, 2005), including Poland (Barczak, 2010). A decreased deposition of that nutrient in soils is mostly due to the reduction of the emissions of sulphur compounds by industrial plants (McNeill et al., 2005), as well as a low consumption of FYM and mineral fertilizers containing that element (Morris, 2007).

According to many authors, due to important functions in plant metabolism played by sulphur (Khan and Mazid, 2011) and due to its positive effect on the yield size and quality (Ryant and Skladanka, 2009; Cazzato et al., 2012), the element cannot be disregarded in crop fertilization. The research confirmed a high yield-forming effectiveness of sulphur not only for *Brassicaceae* family species (Lošak et al., 2000) but also for the papilionaceous plants (*Fabaceae)* (Zhao et al., 1999; Barczak, 2010; Cazzato et al., 2012). The share of sulphur in the fertilization of *Fabaceae* species is important due to the specific nature of nitrogen metabolism in that family (McNeill et al., 2005). The adequate soil richness in sulphur enhances nodulation and ensures the optimal amount of leghemoglobin and ferredoxin in nodules (Ganeshamurthy and Reddy, 2000). Among *Fabaceae* lupins are especially important. As reported by Tabe and Droux (2001), sulphur assimilation by developing lupin cotyledons is very important for the synthesis of storage proteins which determine its digestibility.

With the forecasts of increasing sulphur deficit in plant production and the need to maintain a high yield quality, one must consider that element in the fertilization not only for the highest-sulphur-requirements plants. As a result it is necessary to perform research into the effects of sulphur fertilizer application on the chemical composition of yields, especially the content of macroelements.

The aim of the present research was to evaluate the effect of varied methods of

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sulphur application, forms and rates on the content of macroelements in narrow-leaf lupin seeds and their uptake with seed and straw yield.

MATERIAL AND METHODS

At the Experiment Station of the University of Technology and Life Sciences located in the Kujawy and Pomorze Province, over 2005-2007 a three-factor field experiment using narrow-leaf lupin (*Lupinus angustifolius* L.), Elf cultivar was performed. The experiment was set up in three reps on light soil of the good rye complex soil, IIIb soil valuation class (*Albic Luvisols*). Three factors were investigated: A – sulphur application method (pre-sowing into soil, foliar application), B – nutrient form (elemental sulphur in a form of Siarkol, ionic as sodium sulphate (VI)) and C – sulphur rate: 0, 20, 40, 60 kg S·ha^{-1}. As for foliar application, the treatments with the fertilization of 20 kg S·ha^{-1} the solution was applied at the incompletely closed inter-rows phase (BBCH: 30-33), for the treatments with 40 kg S·ha^{-1} – at two dates: at the incompletely closed inter-rows phase and at the beginning of flowering (BBCH: 30-33 and 50-53), and wherever 60 kg S·ha^{-1} was applied – three times: at the incompletely closed inter-rows phase, at the beginning of flowering as well as at full flowering (BBCH: 30-33, 50-53, 65-67). In spring a homogenous phosphorus fertilization (30 kg P·ha^{-1}; in a form of 40% triple superphosphate) and potassium (60 kg K·ha^{-1} as 60% potassium salt) was applied pre-sowing. Prior to sowing, the lupin seeds were dressed with nitragin. The plot was 18 m^2 in size. The forecrop in each of the research years was spring barley. After its harvest, typical post-harvest treatments were performed, and at the turn of October and November – pre-winter plough.

In the lupin seeds from all the experimental treatments the following traits were determined:

- the nitrogen content with the Kjeldahl's method;
- the content of potassium, calcium and sodium – using the atomic emission spectrophotometry technique;
- magnesium – with the atomic absorption spectrometry;
- phosphorus – with the colorimetric technique with ammonium molybdate.

The uptake of nutrients was calculated as the sum of products of the seed and straw yield (Barczak, 2010) by the content of nitrogen, phosphorus, potassium, magnesium and sodium, respectively. To evaluate the significance of the differences in the treatment means, the Tukey range test at the significance level of P=0.05.

RESULTS AND DISCUSSION

The uptake of nitrogen in narrow-leaf lupin was significantly higher as a result of foliar application of sulphur, as compared with the application into soil; the difference accounted for 7.1% (Table 1). Of the two sulphur forms considered in the research, the elemental form was more favourable, with the nitrogen uptake on average 3.3% higher than after the application of the ionic form of that element.

The factor which significantly determined the nitrogen content in narrow-leaf lupin seeds and its uptake with the yield was the sulphur rate. The greatest increases, as compared to the control treatment, were identified as a result of the application of 60 kg S·ha^{-1} however between the treatments of 40 and 60 kg S·ha^{-1}, in general, no significant differences were found. A positive relationship between the supply of papilionaceous plants with sulphur and the content and uptake of nitrogen, both in the biomass and in the seeds, was confirmed in the report by Islam et al. (2012). One can assume that it is a result of an increased number and weight of nodules on the plant roots, thus intensifying the process of biological reduction of molecular nitrogen and protein synthesis (Ganeshamurtha and Reddy, 2000). The relationship is accounted for by the presence of sulphur in nitrogenase and ferredoxin, the enzymes playing the key role in that process (Khan and Mazid, 2011).

Table 1. Content and uptake of nitrogen in narrow-leaf lupin

Dose of sulphur $kg \cdot ha^{-1}$ (C)	Method of sulphur application (A)						Form of sulphur (B)		Mean
	Foliar fertilizer			Soil fertilizer			Siarkol	Na_2SO_4	
	Siarkol	Na_2SO_4	Mean	Siarkol	Na_2SO_4	Mean			
Content of nitrogen ($g \cdot kg^{-1}$)									
0	48.0	48.2	48.1	48.0	48.0	48.0	48.0	48.1	48.0
20	49.1	48.6	48.8	48.8	48.4	48.6	48.9	48.5	48.7
40	49.6	49.0	49.3	49.2	48.9	49.1	49.4	49.0	49.2
60	50.1	48.9	49.5	49.5	49.5	49.5	49.8	49.2	49.5
Mean	49.2	48.7	48.9	48.9	48.7	48.8	49.0	48.7	48.9
$LSD_{0.05}$: C-0.4									
Uptake of nitrogen ($kg \cdot ha^{-1}$)									
0	136.7	133.7	135.2	141.5	135.7	138.6	139.1	134.7	136.9
20	158.9	157.7	158.3	153.1	151.0	152.1	156.0	154.3	155.2
40	180.8	179.8	180.3	162.6	156.6	159.6	171.7	168.2	169.9
60	185.0	176.2	180.6	167.0	154.3	160.7	176.0	165.2	170.6
Mean	165.4	161.8	163.6	156.1	149.4	152.7	160.7	155,6	158.1
$LSD_{0.05}$: A–6.1; B-1.0; C-0.8; AxB-5.9; AxC-5.6; BxC-1.4									

Nitrogen metabolism in *Fabaceae* family species is much affected by potassium. The supply of the plants with potassium determines the ratio of non-protein nitrogen to protein nitrogen in the plant since it is the nutrient which affects the protein biosynthesis by increasing the amount of assimilates in the cell and the activation of nitrate reductase (V) (Khan and Mazid, 2011). It was demonstrated that foliar sulphur application, as compared with its application into soil showed a significantly better effect on the potassium content in lupin seeds and its uptake with the yield; the respective differences were, on average: 3.2% and 9.4% (Table 2).

Table 2. Content and uptake of potassium in narrow-leaf lupin

Dose of sulphur $kg \cdot ha^{-1}$ (C)	Method of sulphur application (A)						Form of sulphur (B)		Mean
	Foliar fertilizer			Soil fertilizer			Siarkol	Na_2SO_4	
	Siarkol	Na_2SO_4	Mean	Siarkol	Na_2SO_4	Mean			
Content of potassium ($g \cdot kg^{-1}$)									
0	12.6	12.6	12.6	12.7	12.4	12.5	12.6	12.5	12.6
20	12.6	13.0	12.8	12.9	12.2	12.5	12.7	12.6	12.7
40	13.2	12.7	13.0	12.7	11.8	12.3	13.0	12.2	12.6
60	13,3	13.0	13.2	12.9	12.4	12.7	13.1	12.7	12.9
Mean	12.9	12.8	12.9	12.8	12.2	12.5	12.9	12.5	12.7
$LSD_{0.05}$: A-0.2, B-0.2, AxB-0.3, AxC-0.3									
Uptake of potassium ($kg \cdot ha^{-1}$)									
0	41.2	40.1	40.6	38.8	38.7	38.7	40.0	39.4	39.7
20	46.1	44.2	45.1	44.6	42.9	43.7	45.3	43.6	44.4
40	51.7	49.2	50.5	45.5	42.1	43.8	48.6	45.6	47.1
60	53.1	48.4	50.8	47.6	41.1	44.4	50.4	44.8	47.6
Mean	48.0	45.5	46.7	44.1	41.2	42.7	46.1	43.3	44.7
$LSD_{0.05}$: A-0.6; B-0.7; C-0.4; AxC-0.7; BxC-0.8									

Potassium accumulation was more enhanced by the elemental sulphur form than the ionic form; the average differences for the content was 3.2%, and for the uptake – 6.5%. The higher the rates of applied sulphur, the higher the uptake of potassium was. Already the application of 20 kg S·ha^{-1} increased it, as compared with the control treatment, by 11.8%, while the use of 60 kg S·ha^{-1} – by 19.9%.

Foliar sulphur application significantly increased the content of phosphorus in lupin seeds and its uptake with the yield, as compared with its application into soil, the respective differences for three research years were, on average, 4.0% and 13.3% (Table 3). A greater accumulation of phosphorus in lupin seeds was due to the ionic sulphur form. Similarly with results reported by Uziak et al. (1982) investigating yellow lupin as well as Uziak and Szymańska (1987) researching Ornitphopus, the application of the rates of 20 and 40 kg S·ha^{-1}, in general, resulted in a significant decrease in the content of phosphorus in lupin seeds, as compared with the control. The rate of 60 kg S·ha^{-1}, as compared with 40 kg S·ha^{-1}, did not change the content of that element significantly. A decrease in the content of phosphorus in the case of sulphur fertilization could have been due to the dilution of phosphorus as a result of increased yield due to sulphur fertilization (Barczak, 2010) and not to the antagonistic interaction of the phosphate ion (V) and sulphate (VI) ion. Despite a decreasing phosphorus content in lupin seeds as a result of sulphur fertilization, its uptake for the rate range of 0-40 kg S·ha^{-1} was increased. The greatest increase was recorded after the application of 40 kg S·ha^{-1}; the difference, as compared with the treatment without fertilization with that nutrient accounted for 10.7%, on average. Interestingly, the related literature also offers reports on a lack clear-cut relationship between the sulphur fertilization and the content of phosphorus in the plant yield (Fečenko and Ložek, 1999; Lošak et al., 2000).

Table 3. Content and uptake of phosphorus in narrow-leaf lupin

Dose of sulphur kg·ha^{-1} (C)	Method of sulphur application (A)						Form of sulphur (B)		Mean
	Foliar fertilizer			Soil fertilizer			Siarkol	Na_2SO_4	
	Siarkol	Na_2SO_4	Mean	Siarkol	Na_2SO_4	Mean			
Content of phosphorus (g·kg^{-1})									
0	6.02	6.20	6.11	5.82	6.04	5.93	5.92	6.12	6.02
20	5.70	6.14	5.92	5.55	5.73	5.64	5.63	5.93	5.78
40	5.72	6.16	5.94	5.41	5.75	5.58	5.56	5.96	5.76
60	5.62	5.72	5.67	5.54	5.61	5.57	5.58	5.67	5.62
Mean	5.77	6.05	5.91	5.58	5.78	5.68	5.67	5.92	5.80
$LSD_{0,05}$:A-0.11, B-0.10, C-0.15, BxC-0.16									
Uptake of phosphorus (kg·ha^{-1})									
0	19.9	20.0	19.9	19.4	19.2	19.3	19.7	19.6	19.6
20	21.4	22.1	21.7	20.2	19.7	19.9	20.8	20.9	20.8
40	22.9	24.5	23.7	19.2	20.1	19.7	21.0	22.3	21.7
60	23.4	23.3	23.4	20.0	19.2	19.6	21.7	21.3	21.5
Mean	21.9	22.5	22.2	19.7	19.6	19.6	20.8	21.0	20.9
$LSD_{0,05}$: A-1.7; B-0.1; C-0.4; AxB-1.7; AxC-1.5; BxC-0.5									

Of the factors studied, the sulphur rate was the only one which affected the content of calcium and magnesium in lupin seeds and the uptake of those elements with the yield of seed and straw (Tables 4 and 5).

The plots fertilized with sulphur, showed a significantly lower content of calcium and magnesium than the control. The application of the sulphur rates (20, 40 and 60 kg S·ha^{-1}), similarly as in Skwierawska et al. (2008), in general, decreased the calcium uptake with the yield; respective differences, as compared with the no-fertilization treatment, were, on average, as follows: 6.5, 4.7 and 3.7%.

The application of 60 kg S·ha^{-1}, however, increased the uptake of magnesium, as compared with the control, by 23.9%. The relevant literature shows some discrepancy in terms of the effect of sulphur fertilization on the content of calcium and magnesium in crop yields.

Most researchers claimed that a good supply of sulphur decreases the contents of those nutrients (Uziak et al., 1982; Fečenko and Ložek, 1999; Brodowska and Kaczor, 2009). On the other hand, Brodowska and Kaczor (2009) demonstrated that fertilising with that nutrient, irrespective of its form; ionic or elemental, clearly increased the uptake of both elements by the plants. One could suspect that this is mostly due to the yield increasing effect of sulphur. However, some reports showed that sulphur did not affect or slightly increased the content of calcium and magnesium (Uziak and Szymańska, 1987).

Table 4. Content and uptake of calcium in narrow-leaf lupin

Dose of sulphur kg·ha^{-1} (C)	Method of sulphur application (A)						Form of sulphur (B)		Mean
	Foliar fertilizer			Soil fertilizer			Siarkol	Na_2SO_4	
	Siarkol	Na_2SO_4	Mean	Siarkol	Na_2SO_4	Mean			
Content of calcium (g·kg^{-1})									
0	1.60	1.61	1.61	1.64	1.67	1.66	1.62	1.64	1.63
20	1.47	1.51	1.49	1.51	1.64	1.57	1.49	1.58	1.53
40	1.55	1.56	1.56	1.55	1.58	1.56	1.55	1.57	1.56
60	1.39	1.48	1.43	1.55	1.67	1.61	1.47	1.57	1.52
Mean	1.50	1.54	1.52	1.66	1.57	1.60	1.53	1.59	1.56
$LSD_{0,05}$: A-0.03; C-0.11									
Uptake of calcium (kg·ha^{-1})									
0	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7
20	7.6	11.2	9.4	10.2	11.2	10.7	8.9	11.2	10.0
40	7.7	11.7	9.7	10.3	11.0	10.6	9.0	11.3	10.2
60	8.3	10.8	9.5	11.3	10.9	11.1	9.8	10.8	10.3
Mean	8.6	11.1	9.8	10.6	11.0	10.8	9.6	11.0	10.3
$LSD_{0.05}$: C-0.4; AxC-1.9; BxC-0.8									

Table 5. Content and uptake of magnesium in narrow-leaf lupin

Dose of sulphur kg·ha^{-1} (C)	Method of sulphur application (A)						Form of sulphur (B)		Mean
	Foliar fertilizer			Soil fertilizer			Siarkol	Na_2SO_4	
	Siarkol	Na_2SO_4	Mean	Siarkol	Na_2SO_4	Mean			
Content of magnesium (g·kg^{-1})									
0	2.45	2.50	2.47	2.47	2.52	2.49	2.46	2.51	2.48
20	2.43	2.45	2.44	2.38	2.38	2.38	2.41	2.41	2.41
40	2.33	2.41	2.37	2.38	2.35	2.37	2.36	2.38	2.37
60	2.43	2.39	2.41	2.34	2.30	2.32	2.38	2.34	2.36
Mean	2.41	2.44	2.42	2.39	2.39	2.39	2.40	2.41	2.41
$LSD_{0.05}$: C-0.11									
Uptake of magnesium (kg·ha^{-1})									
0	7.03	7.45	7.24	8.07	6.55	7.31	7.55	7.00	7.28
20	8.67	8.60	8.64	7.85	6.58	7.22	7.76	7.59	7.68
40	8.83	7.34	8.09	6.78	7.27	7.03	7.81	7.31	7.56
60	9.46	7.98	8.72	9.47	9.15	9.31	9.47	8.57	9.02
Mean	8.50	7.84	8.17	8.04	7.39	7.72	8.15	7.62	
$LSD_{0.05}$: A-0.29; C-0.34; AxC-0.23									

Based of the response to sodium fertilization, plants are often divided into sodium-loving and non-sodium-loving (Khan and Mazid, 2011). Lupin is considered to represent the latter group, which is seen from the low contents of sodium in its seeds; an average of 0.15 g·kg^{-1} (Table 6). The ionic form of sulphur had a significantly more favourable effect than the elemental form on the sodium content and uptake; on average the respective differences accounted for, 14.3% and 2.4%.

The higher the sulphur rates of applied sulphur, the greater the sodium uptake of potassium was. The rate which resulted in the highest increase in the sodium uptake, by an average of 13.9% as compared with the control, was 60 kg S·ha^{-1}.

Table 6. Content and uptake of sodium in narrow-leaf lupin

Dose of sulphur kg·ha^{-1} (C)	Method of sulphur application (A)						Form of sulphur (B)		Mean
	Foliar fertilizer			Soil fertilizer			Siarkol	Na_2SO_4	
	Siarkol	Na_2SO_4	Mean	Siarkol	Na_2SO_4	Mean			
Content of sodium (g·kg^{-1})									
0	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
20	0.13	0.16	0.14	0.15	0.16	0.16	0.14	0.16	0.15
40	0.14	0.15	0.15	0.16	0.16	0.16	0.15	0.15	0.15
60	0.13	0.16	0.15	0.16	0.17	0.16	0.15	0.17	0.16
Mean	0.14	0.15	0.15	0.15	0.16	0.16	0.14	0.16	0.15
$LSD_{0.05}$: B-0.01; AxB-0.01									
Uptake of sodium (kg·ha^{-1})									
0	3.82	3.89	3.86	3.83	3.75	3.79	3.83	3.82	3.82
20	4.03	4.60	4.31	4.10	3.86	3.98	4.06	4.23	4.14
40	4.33	4.70	4.51	3.90	4.05	3.98	4.12	4.37	4.24
60	4.40	4.81	4.61	4.33	3.86	4.09	4.36	4.33	4.35
Mean	4.15	4.50	4.32	4.04	3.88	3.96	4.09	4.19	4.14
$LSD_{0.05}$: A-0.18; B-0.05; C-0.05; AxB-0.17; AxC-0.16									

Although narrow-leaf lupin is not considered a sulphur-loving species, the present research demonstrated a clear effect of sulphur, irrespective of the factors studied, on the content and uptake of nutrients with its yield. The foliar application of sulphur demonstrated a more favourable effect than when applied into soil on the content and uptake of most elements determined; however, it is difficult to show its definitely optimal form for the mineral composition of lupin seeds. The application of 40 kg S·ha^{-1} resulted, in general, in a significant increase in the uptake of the macroelements determined, as compared with the control. Since sulphur fertilization enhanced not only the content of macroelements in narrow-leaf lupin seeds but also, due to the yield-forming effect, their uptake, it seems indispensable to consider it in the crop management practises for this species.

CONCLUSIONS

The present research showed a clear effect of sulphur, irrespective of the factors studied, on the content in the seeds and the uptake of nutrients with the yield of narrow-leaf lupin seed and straw.

As for the content of most macroelements assayed and their uptake, the foliar fertilization with sulphur was more favourable than its application into soil.

It is difficult to demonstrate a clear-cut optimal form of that nutrient to enhance the mineral lupin seed composition.

In general, the use of 40 kg S·ha^{-1}, significantly increased the uptake of nitrogen, potassium, magnesium and sodium with the yield of lupin seeds and straw, as compared with the control.

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