Assessment of sulphur demand of crops under permanent fertilization experiment

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ABSTRACT

The aim of the study was to determine plant needs with regard to sulphur fertilization based on the assessments of sulphur in the soil profile carried out in the early spring. The study was founded on the continuous fertilization experiment established in 1985 at the Experimental Station of the Faculty of Agriculture and Biology, Warsaw University of Life Sciences-SGGW, which is located in Skierniewice. Soil samples were collected in the years 2009–2011 in the early spring (February/March) at low soil temperatures. The samples were taken at three soil depths: 0–30, 30–60, 60–90 cm. The content of sulfate sulphur was assessed in fresh soil samples after extraction in 0.01 mol/L $CaCl_2$. The plants cultivated during the study were spring barley and yellow lupine. The amount of sulphur in soil profile was too small and not sufficient to fulfill yellow lupine nutritional needs, thus could be a limiting factor for successful yield production. Regardless the fertilizer treatment, the amount of sulfate sulphur found in 0–60 cm soil layer fully covered nutritional needs of spring barley.

Keywords: sulphur; soil; balance; long-term experiment; barley; lupine

Sulphur deficiency in crops has increasingly been observed at the global scale over the last 50 years (Girma et al. 2005, Schonhof et al. 2007). The underlying reasons for the limited sulphur input to ecosystems include (i) significant reduction of sulphur emission from industrial sources; (ii) widespread use of highly concentrated mineral fertilizers without sulphur; (iii) decreased use of organic fertilizers; (iv) decreased application of sulphur containing plant protection products, and (v) cultivation of abundantly growing new crop varieties (Scherer 2001, Eriksen et al. 2004, Szulc 2008). The input of atmospheric sulphur to farmland was recently estimated not to exceed 10 kg/ha (Hu et al. 2005, Szulc 2008). The latter amount is insufficient to provide for nutrient demand of most crop plants, including grain crops which have the lowest demand with respect to sulphur nutrition. Jamal et al. (2010) reported that in order to produce 1 t of main crop, grain crops need to take up 3–4 kg S/ha (at a variation of 1–6), while leguminous crops – 8 kg S/ha (at a variation of 5–13), and oilseed crops – 12 kg S/ha (at a variation of 5–20). Plants cultured under conditions of sulphur deficiency responded to sulphur supply (Withers et al. 1997, Bloem 1998, Podleśna 2004). On the other hand, no fertilizing effect of sulphur was found in plants cultivated in the sulphur rich soils (Bloem 1998, Haneklaus et al. 1999).

Sulphur is an element whose soil levels vary greatly over the vegetation season. The amounts of sulphate sulphur determined in autumn are significantly higher than those found in the early spring (Goh and Pamidi 2003). Therefore, demand for sulphur supply then shall seemingly be established with respect to a soil sulphur level determined in the early spring. In this regard, we attempted to evaluate sulphur fertilization needs in the crops that have both little and high sulphur demand, based on the long-term fertilizing experiment.

MATERIAL AND METHODS

The study, based on the long-term fertilization experiment, was carried out in the years 2009–2011, at the Experimental Station of the Faculty of Agriculture and Biology, University of Life Sciences-SGGW in Skierniewice latitude 51°58', longitude 20°10'. The experiment was set in 1985 using randomized block design, on Luvisol (FAO 2006) soils of the texture of loamy sand, containing in the 0–30 cm layer the following fractions: sand (> 0.05 mm) – 87%, silt (0.02–0.05 mm) – 5% and clay (< 0.02 mm) – 7%.

The study was conducted on selected objects (fields) varying in the treatment type, including: full mineral fertilization with CaNPK; CaNPK1 with K input in the form of KCl; CaNPK2 with K input in the form of K_2SO_4; CaNKP1 with P input in the form of triple superphosphate and CaNKP2 with P input in the form single of superphosphate. Nitrogen was added in the form of NH_4NO_3. The mineral fertilization was applied in the following rates:

CaNPK: N – 90 kg/ha, P – 26 kg/ha and K – 90 kg/ha
CaNPK1 and CaNPK2: N – 90 kg/ha, P – 26 kg/ha and K – 135 kg/ha
CaNKP1 and CaNKP2: N – 90 kg/ha, P – 39 kg/ha and K – 90 kg/ha

All fields were limed once every four years at a rate of 1.14 t Ca/ha. The input of sulphur varied between the selected experimental treatments (Table 1).

Table 1. Sulphur input with fertilizers (kg/ha) in the long-term fertilizing experiment over the years 1985–2011

Treatment	Annual	1985–2011
CaNPK2	59.4	1425
CaNKP2	23.7	568

Soil was sampled in the early spring (at the turn of February and March) at low soil temperature. Soil samples were taken with the use of soil bore from the three depths, including: 0–30, 30–60 and 60–90 cm. The content of soil sulphate sulphur was determined immediately after sampling, following extraction in 0.01 mol/L $CaCl_2$ (PN-ISO 14255, 2001), and using the inductively coupled plasma atomic emission spectrometry (ICP-AES) (IRYS Advantage ThermoElementar, Cambridge, UK).

Barley cv. Stratus and lupine cv. Dukat were grown under experimental conditions. The fresh mass of herbage was determined after harvest, and subsequently the plant material was dried out at 60°C using drier PREMED (Marki, Poland), then ground and milled using a rotor mill ZM200 Retsch (Haan, Germany), and mineralized following the wet chemistry method using a mixture of acids HNO_3 and $HClO_4$ at a ratio 5:2 (VELP SCIENTIFICA, Usmate, Italy). Plant samples prepared in this way were taken for determination of the total content of sulphur with inductively coupled plasma atomic emission spectrometry (ICP-AES).

The results were statistically analyzed with ANOVA using Statistica PL software (Tulsa, USA).

RESULTS

Under conditions of the experiment the yield of spring barley was not affected by sulphur fertilization while a significant increase was found in the concentration of sulphur in both grain and straw (Table 2). Barczak and Majcherczak (2008) did not observe any effect of sulphur supply on the yield of spring barley. In contrast, a significant effect of sulphur fertilization on barley yield was reported by Togay et al. (2008) who conducted a study on soils with a pH > 8. Divito et al. (2013) and Eriksen et al. (2002) did not show any effect of sulphur fertilization on the yield of grain crops, whereas they determined that there was a significant increase in sulphur content in barley straw.

Sulphur supply led proven to significantly increase of sulphur concentration in lupine straw

Table 2. Yield, sulphur concentration and its uptake by spring barley

Treatment	Yield (t/ha)		Concentration (g/kg)		Uptake (kg/ha)
	grain	straw	grain	straw	
CaNPK	4.01	2.01	2.11^{ab}	1.74^{ab}	11.9^{ab}
CaNPK1	4.11	2.05	1.96^{a}	1.61^{a}	11.3^{a}
CaNPK2	4.05	2.03	2.26^{b}	1.88^{b}	13.0^{b}

Between the treatments marked with different letter are the statistically significant differences at $P < 0.05$

Table 3. Yield, sulphur concentration and its uptake by lupine

Treatment	Yield (t/ha)		Content (g/kg)		Uptake (kg/ha)
	seeds	straw	seeds	straw	
CaNPK	2.23[a]	3.40[a]	5.31	7.43[a]	37.1[a]
CaNKP1	2.20[a]	3.60[a]	5.42	7.77[a]	39.9[a]
CaNKP2	3.26[b]	4.09[b]	5.85	8.38[b]	53.3[b]

Between the treatments marked with different letter are the statistically significant differences at $P < 0.05$

and to significantly affect yields of both seeds and straw of yellow lupine (Table 3). Similar relationships were obtained by Cazzato et al. (2012), who found a significant increase in crop yield due to sulphur fertilization as compared to the reference treatment (control).

Under conditions of a diversified fertilization, soils supplied with potassium sulphate as well as single superphosphate contained a higher level of sulphur as compared to the reference (Table 4). On the other hand, the supply of potassium salt and triple superphosphate resulted in a decrease in sulphur content as compared to the control. Raised sulphur content in the whole soil profile was found in the objects fertilized with potassium sulphate as compared to the objects supplied with single superphosphate. Scherer (2009) found that sulphur availability in soil was enhanced by fertilization with phosphorus. SO_4^{2-} ions are displaced from the soil sorption complex by HPO_4^{2-} ions. In the soils having pH above 6.5, the process of sulphate adsorption does not occur. Under conditions of low humus content and at a high precipitation displaced sulphates are leached from the topsoil down the profile. As was shown in the study by Eriksen et al. (2002), the average amount of 30 kg S/ha may be leached from soil at a high fluctuation ranging from 9 to 40 kg S/ha, depending upon precipitation volume. Similar amounts of sulphur leached from soil (on average 35 kg/ha) were determined by Ercoli et al. (2012).

This study, showed that the amount of sulphate sulphur found in the soil profile does meet the nutrition requirements of spring barley, though it is too low to meet the requirements of yellow lupine (Table 5). However, the amount of sulphur found in the 0–30 cm soil layer, for the treatments with CaNPK and CaNPK1, is too low to meet the requirements of barley. Only the amounts of sulphur found in the deeper layers, i.e. 30–60 cm and 60–90 cm, meet the nutrition requirements of spring barley, whereas, in the treatment with CaNPK2, where potassium sulphate was supplied, the amount of sulphate sulphur in the 0–30 cm layer does sufficiently meet the sulphur nutrition demand of barley. From the study made by Matula

Table 4. The content of sulphur extracted in 0.01 mol/L $CaCl_2$ in soil depending on treatment objects

Treatment	Depth (cm)	(mg S/kg)	Treatment	Depth (cm)	(mg S/kg)
	0–30	1.80[a]		0–30	1.58[a]
CaNPK	30–60	1.51[a]	CaNPK	30–60	1.59[a]
	60–90	2.26[b]		60–90	1.92[b]
	0–30	1.67[a]		0–30	1.00[a]
CaNPK1	30–60	1.54[a]	CaNKP1	30–60	1.17[a]
	60–90	2.31[b]		60–90	1.99[b]
	0–30	4.93[a]		0–30	3.69[c]
CaNPK2	30–60	5.68[b]	CaNKP2	30–60	2.84[b]
	60–90	5.36[b]		60–90	1.71[a]

Between the treatments marked with different letter are the statistically significant differences at $P < 0.05$

Table 5. Sulphur balance under conditions of permanent fertilization experiment

	Treatment	Depth (cm)	S content in soil	S content in the profile	Uptake	Balance
			(kg S/ha)			
Barley	CaNPK	0–30	8.1	25.1[a]	11.9	+13.2
		30–60	6.8			
		60–90	10.2			
	CaNPK1	0–30	7.5	24.8[a]	11.3	+13.5
		30–60	6.9			
		60–90	10.4			
	CaNPK2	0–30	22.2	71.8[b]	13.0	+58.8
		30–60	25.5			
		60–90	24.1			
Lupine	CaNPK	0–30	7.1	22.8[a]	37.1	–14.3
		30–60	7.1			
		60–90	8.6			
	CaNKP1	0–30	4.5	18.7[a]	39.9	–21.2
		30–60	5.3			
		60–90	8.9			
	CaNKP2	0–30	16.6	39.5[b]	53.3	–13.8
		30–60	12.7			
		60–90	10.2			

Between the treatments marked with different letter are the statistically significant differences at $P < 0.05$

(2004) it follows that the optimal soil sulphur content adequately safeguarding the nutrition needs of barley fluctuates within the limits of 6–10 mg S/kg of soil. In this study, the content of sulphur in soil, depending on varying sulphur supply, was significantly lower in the treatments with CaNPK1 and CaNPK2 and oscillated within a range of 1.67–4.93 mg S/kg of soil in the 0–30 cm layer (Table 4). At the treatments CaNKP1 and CaNKP2 sulphur content was still much lower and attained 1.00 and 3.69 mg S/kg of soil, respectively. Such low sulphur contents may not be sufficient to meet nutrition requirements of barley, in particular when the yields are high. Leguminous crops take up much higher sulphur amounts as compared to the grain crops. In the case of yellow lupine the amounts of sulphur found in the entire soil profile are not adequate for covering its nutrition demand regardless the type of the treatment applied. In that case sulphur may be a limiting nutrient for obtaining a high level of lupine yield.

Similar relationships were reported by Eriksen et al. (2002), who conducted a study on light soils and found the negative sulphur balance in a range of 8–22 kg S/ha for grain crops. Likewise, a negative sulphur balance for cultured plants was reported by Ercoli et al. (2012). The positive balance was found only with high sulphur supply at a level 120 kg S/ha. In the course of the above mentioned study it was also established that dividing of rates had positive effects on utilisation of sulphur supply from fertilization, as with such treatment one can obtain a positive balance of sulphur.

Diagnosing sulphur fertilization needs is backed upon tests using both soils and plants. Sulphur is an element which causes analytical problems due to the fact that it occurs in numerous oxidation states, and in addition, it is found in soil in various forms, which undergo many dynamical changes during the vegetation season. Due to a high variability of sulphur amounts extracted from soil and low coefficients of correlation between the content of sulphate sulphur in soil and plant indicators (contents, uptake and yield) the soil tests are often criticized. Significant inter-relationships between sulphur content in plants and plant yield were corroborated by the plant tests. However, the above tests were also subject to criticism which concentrated above all on the timing of plant material sampling and on the correct selection of indicatory part of a plant. Under conditions prevailing in Poland, the soil tests are more frequently used for diagnostic purposes than the plant tests. That is why a preliminary study was carried out in order to select the proper soil test and to establish the timing of soil sampling for determination of sulphur available to plants under conditions in the country (Szulc 2008). It was found that the test using extraction with 0.01 mol/L $CaCl_2$ shows the most significant correlation with sulphur content in plants. At the same time, it was found that the turn of February and March is a critical period when the lowest amounts of sulphate sulphur are normally detected in soil. In this period there is a lack of microbial activity which mobilizes sulphur from organic compounds, thus the amounts of sulphates occurring in autumn decrease due to leaching from soil in autumn and early spring. In the regions where sulphur deficiency is commonplace, diagnosing of the demand for sulphur supply is made using soil tests based on weak extracting solutions (Brennan and Bolland 2006, Rego et al. 2007). The latter authors are of the opinion that there is a need to supply sulphur if the level of soil sulphate sulphur is below 10 mg S/kg.

Under the conditions of long-term fertilization with sulphur in the form of potassium sulphate and superphosphate, a significant increase was found over the entire soil profile, in the content of sulphur extracted with 0.01 mol/L solution of $CaCl_2$ relative to the reference objects not treated with sulphur. The comparison of the amounts of sulphur taken by plants with soil sulphur concentrations determined in early spring has shown that nutrition requirements of spring barley may only be met with the amount of sulphur found at the soil level of 0–60 cm. The nutrition requirements of yellow lupine cannot be satisfactorily covered by the amounts of sulphur determined in the whole soil profile. The results obtained point out that under conditions prevailing in the Central Poland there is a need to apply sulphur fertilization to crop plants.

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Received on December 20, 2013
Accepted on February 12, 2014

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