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EFFECT OF DIFFERENT RATES AND FORMS OF SULPHUR ON CONTENT OF AVAILABLE PHOSPHORUS IN SOIL

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Abstract

A three-year field experiment was conducted in Byszwałd near Lubawa in 2000-2002. The aim of this study has been to determine the influence of increasing rates of sulphur on the dynamics of available phosphorus in soil at two horizons: 0-40 and 40-80 cm. The trial was set up on acid brown soil of the granulometric composition of heavy loamy sand. The initial soil had the following properties: $pH_{(KCl)}$ = 5.30, mineral nitrogen 24.0, sulphate sulphur 4.10, available phosphorus 34.5 and potassium 110.0 mg kg^{-1} of soil.

Three levels of sulphur fertilization were applied: 40, 80 and 120 $kg \cdot ha^{-1}$ in the sulphate form ($S\text{-}SO_4$) and as elementary sulphur ($S\text{-}S^0$). During the whole duration of the field trials, the results demonstrating the effect of fertilization with different forms and rates of sulphur on the content and transfer of available phosphorus in soil were inconsistent. Only the dose of 120 $kg \cdot ha^{-1}$ $S\text{-}SO_4$ caused a significant increase in the concentration of available sulphur in soil in the 0-40 and 40-80 cm layers. All the rates of elementary sulphur as well as 40 and 80 $kg \cdot ha^{-1}$ sulphate sulphur caused little less but an increasing tendency in the content of phosphorus in soil. The effect of elementary sulphur became apparent as late as the third year of the trials. The effect of the doses of 40 and 80 $kg \cdot ha^{-1}$ of sulphur on properties of soil depended on the form of sulphur, duration of the experiment.

Key words: fertilization, sulphate sulphur, elementary sulphur, available phosphorus, soil.

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WPŁYW RÓŻNYCH DAWEK I FORM SIARKI NA ZAWARTOŚĆ PRZYSWAJALNEGO FOSFORU W GLEBIE

Abstrakt

W latach 2000-2002, w Byszwałdzie, w pobliżu Lubawy, przeprowadzono 3-letnie doświadczenie polowe. W doświadczeniu badano wpływ nawożenia siarką na dynamikę przyswajalnego fosforu w glebie w dwóch poziomach: 0-40 cm i 40-80 cm. Eksperyment założono na glebie brunatnej, kwaśnej o składzie granulometrycznym piasku gliniastego mocnego. Gleba wyjściowa miała nstępujące właściwości: $pH_{(KCl)}$=5,30, azot mineralny 24,0, siarka siarczanowa 4,10, przyswajalny fosfor 34,5, potas 110,0 $mg \cdot kg^{-1}$ gleby. Zastosowano 3 poziomy nawożenia siarką: 40, 80 i 120 $kg \cdot ha^{-1}$ w formie siarczanowej ($S\text{-}SO_4$) i elementarnej ($S\text{-}S^0$). W ciągu całego okresu badań otrzymano niejednoznaczne wyniki dotyczące wpływu nawożenia różnymi formami i dawkami siarki na zawartość i przemieszczanie się przyswajalnego fosforu w glebie. Jedynie dawka 120 $kg \cdot ha^{-1}$ $S\text{-}SO_4$ przez cały okres badań wpływała na uruchamianie i migrację fosforu glebie oraz spowodowała istotne zwiększenie zawartości przyswajalnego fosforu w glebie w warstwie 0-40 cm i 40-80 cm. Wszystkie dawki siarki elementarnej oraz 40 i 80 kg siarki siarczanowej powodowały jedynie tendencję zwyżkową. Wpływ siarki elementarnej uwidocznił się dopiero w trzecim roku doświadczenia. Działanie dawek 40 i 80 $kg \cdot ha^{-1}$ siarki na właściwości gleby zależało od formy siarki oraz czasu trwania doświadczenia.

Słowa kluczowe: nawożenie, siarka siarczanowa, siarka elementarna, przyswajalny fosfor, gleba.

INTRODUCTION

Sulphur deficit in Europe becomes evident not only in high sulphur demanding crops but has already become a problem for farmers growing cereals (Schung et al. 1993, Zhao et al 1996, Scherer 2001). At present, there is a growing interest in sulphur as a component of fertilisers, especially in non-industrialised areas situated far from large cities, where deficient quantities of sulphur in plants are detected (Kaczor and Brodowska 2002). Phosphorus metabolism in soil is important for both agriculture and environment as different forms and levels of phosphorus play a decisive role in plant production and eutrophication of water bodies (Sharpley 1995). The results of studies on the effect of sulphur on fluctuations in concentrations of available sulphur in soil are inconsistent. Motowicka-Terelak and Terelak (1998) demonstrated that sulphur, by binding aluminium sulphate, reduced phosphorus fixation in soil, while excessive amounts of sulphates may result in incomplete utilization of phosphorus supplied with fertilizers, as they inhibit the growth of crops. In contrast, Lindemann et al. (1991) did not determine such a relationship. In soils fertilized with elementary sulphur, access of plants to available sulphur is improved (Jaggi et al. 2005).

The purpose of the present study has been to determine the effect of fertilization with increasing rates of sulphur applied in the form of sulphates and as elementary sulphur on the content of available phosphorus forms in soil the 0-40 and 40-80 cm layers.

MATERIAL AND METHODS

A three-year field experiment was conducted from 2000 to 2002, in Byszwałd near Lubawa. The village is distant from larger industrial plants which emit sulphur compounds and lies far from any big cities. As a result, any changes in the concentration of sulphur in the soil were not caused by human pressure.

The trial was set up on acid brown soil of the granulometric composition of heavy loamy sand. The initial soil had the following properties: $pH_{(KCl)}$ = 5.30, mineral nitrogen 24.0, sulphate sulphur 4.10, available phosphorus 34.5 and potassium 110.0 mg kg^{-1} of soil. The annual rates of sulphate sulphur ($S\text{-}SO_4$) and elementary sulphur ($S\text{-}S^0$) were: S_1 – 40, S_2 – 80 and S_3 – 120 kg ha^{-1}.

The permanent experiment was established in a random block design and consisted of eight fertilisation objects with four replications: 1) 0, 2) NPK, 3) NPK + $S_1\text{-}SO_4$, 4) NPK + $S_2\text{-}SO_4$, 5) NPK +$S_3\text{-}SO_4$, 6) NPK +$S_1\text{-}S^0$, 7) NPK +$S_2\text{-}S^0$, 8) NPK +$S_3\text{-}S^0$. The NPK rates depended on the crop species and soil fertility (Table 1). The design of the experiment is presented in Tables 2-4. The following fertilisers were applied: nitrogen – ammonium nitrate or ammonium sulphate, phosphorus – triple superphosphate, potassium – potassium chloride 60% or potassium sulphate, sulphur – potassium sulphate and, as a supplement, ammonium sulphate; in addition, elementary sulphur was applied on the objects where this form of sulphur was tested.

Table 1

NPK rates applied in the trials

Crops	Year	($kg \cdot ha^{-1}$)		
		N	P	K
Head cabbage	2000	200.0	52.5	180.0
Common onion	2001	160.0	60.0	183.0
Spring barley	2002	90.0	80.0	111.0

Soil samples were collected from each plot, at 0-40 and 40-80 cm depths, prior to the establishment of the trials, after each harvest and before sowing the consecutive crop. There was one exception to the routine – in spring 2001, due to prolonged rains, soil samples were taken only from the 0-40 cm horizon. Available phosphorus was determined with Enger Riehm's method (DL) (the ratio between soil and extraction 1:50).

The concentrations of available phosphorus in soil were processed statistically using analysis of variance for two-factor experiments in a random-block design, assuming the form of sulphur as factor a and rate of sulphur

Table 2

Effect of different rates and forms of sulphur on the content of available phosphorus in soil at 0-40 cm depth (mg·kg^{-1} soil)

Treatments	2000 autumn	2001 spring	2001 autumn	2002 spring	2002 autumn
	soil at 0-40 cm depth				
0	34.8	34.1	57.0	44.1	27.4
NPK	41.0	31.6	53.1	41.0	37.5
NPK+ S_1-SO_4	50.1	38.6	91.3	43.8	47.7
NPK+ S_2-SO_4	45.2	32.1	68.0	38.5	40.3
NPK+ S_3-SO_4	35.6	33.5	91.3	43.4	49.2
NPK+S_1-S^0	39.7	33.5	55.3	35.1	38.0
NPK+S_2-S^0	48.6	33.2	56.0	35.4	39.3
NPK+S_3-S^0	45.1	33.6	66.4	42.4	44.7
NIR-*p*-0.05					
a	n.s.*	n.s.	n.s.	2.25	1.64
b	2.44	n.s.	1.68	3.19	2.32
a x *b*	n.s.	n.s.	2.38	4.51	3.29

SO_4 – sulphate sulphur; S^0 – elementary sulphur; S_1 – 40 kg·ha^{-1}, S_2 – 80 kg·ha^{-1}, S_3 – 120 kg·ha^{-1}
a – form of sulphur; *b* – dose of sulphur; *a* x *b* – interaction
* n.s. – non-significant difference

as factor b. Additional statistical analyses were performed with the software package Statistica 6.0 PL, to carry out analysis of regression with Duncan's tests in order to determine statistical differences between sets of data.

DISCUSSION OF THE RESULTS

In 2000, the amount of available phosphorus in the 0-40 cm soil layer was varied, ranging between 34.8 and 50.1 mg P·kg^{-1} of soil (Table 2). NPK as well as NPK+S fertilization caused significant increase in the concentration of available phosphorus versus the control and initial soil. When a single rate of sulphate sulphur was applied, the concentration of available phosphorus in soil increased versus the NPK fertilized object. The application of 120 kg·ha^{-1} S-SO_4 caused a significant decline in the amount of available phosphorus in soil relative all the remaining fertilization objects. This decrease could have been due to several factors, for example transfer of phosphorus to the deeper soil layer 40-80 cm (Table 3). In the 40-80 cm soil horizon, the other sulphur rates had little effect on the dynamics of available phosphorus. As the rates of sulphate sulphur applied as a fertilizer rose,

Table 3

Effect of different rates and forms of sulphur on the content of available phosphorus in soil at 40-80 cm depth (mg kg^{-1} soil)

Treatments	2000 autumn	2001 spring	2001 autumn	2002 spring	2002 autumn
	soil at 40-80 cm depth				
0	36.2	-	36.2	36.2	36.7
NPK	33.0	-	33.0	33.0	32.4
NPK+ S_1-SO_4	34.3	-	34.3	34.3	28.3
NPK+ S_2-SO_4	29.0	-	29.0	29.0	22.0
NPK+ S_3-SO_4	37.6	-	37.6	37.6	49.9
NPK+S_1-S^0	33.5	-	33.5	33.5	32.2
NPK+S_2-S^0	35.7	-	35.7	35.7	35.1
NPK+S_3-S^0	33.8	-	33.8	33.8	41.3
NIR-*p*-0.05 a *b* *a* x *b*	 1.48 2.09 * n.s.	-	 1.48 2.09 n.s.	 1.48 2.09 n.s.	 2.25 3.18 4.50

SO_4 – sulphate sulphur; S^0 – elementary sulphur; S_1 – 40 kg·ha^{-1}, S_2 – 80 kg·ha^{-1}, S_3 – 120 kg·ha^{-1}
a – form of sulphur; *b* – dose of sulphur; *a* x *b* – interaction
* n.s. – non-significant difference

a tendency towards decreasing concentration of available phosphorus in soil appeared. However, the application of elementary sulphur resulted in less regular changes.

In the second year of the experiment (2001), the concentration of available phosphorus in the 0-40 cm soil layer was uniform and independent of the sulphur fertilization (Table 2).

In autumn (2001), the level of phosphorus in soil was evidently higher in all the objects fertilized with sulphur than in the NPK fertilized object, especially after all the increasing rates of sulphate sulphur as well as a triple dose of elementary sulphur had been applied. It is most likely that the process of elementary sulphur oxidation was initiated or else increasing rates of S-SO_4 were observed to be followed by a decreasing uptake of phosphorus by onion plants Skwierawska et al (2008). In the 40-80 cm soil layer, sulphur fertilization had an ambiguous influence on the amount of available phosphorus. This form of phosphorus occurred in increased quantities in the objects which had received 120 kg·ha^{-1} S-SO_4 and 80 kg·ha^{-1} S-S^0 (Table 3). Other authors, e.g. KRÓL et al. (1986), MOTOWICKA-TERELAK (1989), JAGGI et al. (2005) have also noticed that the content of available phosphorus in soil under the influence of sulphur tends to increase. The sulphur fertilization applied in the second year of the experiment increased the amounts of avail-

Table 4

Significance of differences in the content of available phosphorus in soil between particular objects according to Duncan's test.
Differences statistically significant at ($p \leq 0.05$)

Object	0	NPK	I-S-SO_4	II-S-SO_4	III-S-SO_4	I-S-S^0	II-S-S^0	III-S-S^0
0								
NPK	0.400789							
S_1-SO_4	0.002371	0.025297						
S_2-SO_4	0.938754	0.411004	0.002652					
S_3-SO_4	0.000667	0.010226	0.697388	0.000779				
S_1-S^0	0.772696	0.285048	0.000969	0.733427	0.000241			
S_2-S^0	0.192724	0.588087	0.075883	0.200051	0.036888	0.125709		
S_3- S^0	0.071181	0.293166	0.195560	0.075410	0.112098	0.041239	0.561581	
$\overline{x}$*	3.578	3.798	4.392	3.597	4.487	3.507	3.931	4.074

*$\overline{x}$ – average content of available phosphorus in soil in particular objects for the years 2000-2003 (mg·kg^{-1} soil); SO_4 – sulphate sulphur, S^0 – elementary sulphur, S_1 – 40 kg ha^{-1}, S_2 – 80 kg ha^{-1}, S_3 – 120 kg·ha^{-1}

able phosphorus in soil at the depths of 0-40 cm and 40-80 cm compared to the results obtained during the first year of the trials.

In the spring of 2002, the content of available phosphorus in soil sampled at 0-40 cm and 40-80 cm depth was smaller than in autumn 2001 (Tables 2,3), and ranged 29.0 and 44.1 mg P·kg^{-1} of soil.

In the autumn of 2002, all the fertilization rates of sulphate sulphur and elementary sulphur caused an increase in the amount of available phosphorus in soil sampled at 0-40 cm depth, which was particularly high after the triple sulphate sulphur dose. The increase was observed versus the control objects (Table 2). The fertilization with sulphate and elementary sulphur increased the concentration of available phosphorus in the 0-40 cm soil layer compared to the soil tested in spring, whereas the objects fertilized without sulphur became less abundant in phosphorus. At the soil depth of 40-80 cm, the concentration of available phosphorus decreased following the application of 40 and 80 kg·ha^{-1} of either sulphur form. It was only when 120 kg·ha^{-1} of S-SO_4 or S-S^0 was used that the soil was enriched with available phosphorus, which was also demonstrated in the earlier years of the trials.

During the whole duration of the field trials, the results demonstrating the effect of fertilization with different forms and rates of sulphur on the content and transfer of available phosphorus in soil were inconsistent. Only one rate of phosphorus, 120 kg·ha^{-1} S-SO_4 initiated mobilization and migration of phosphorus in soil throughout the whole period of the field trails.

The effect produced by elementary sulphur depended on the rate of its oxygenation in soil and its dose, which finds confirmation in studies reported by Germid and Janzen (1993) as well as Watkinson and Lee (1994) and Zhou (2002). This is proven by that fact that the concentration of available phosphorus in soil increased as late as the third year of our experiment and only in the object fertilized with 120 kg·ha^{-1} S-S^0. Lindemann et al. (1991) did not find any increase in available phosphorus in soil following fertilization treatments with elementary sulphur, even though the soil pH was lowered and the amount of the sulphate form in soil increased. According to Jagii et al. (2005), addition of elementary sulphur improves the availability of phosphorus in cultivated soils, irrespective of the soil initial pH.

The available references contain diverse interpretation of the influence of sulphur on the dynamics of available phosphorus in soil. The differences stem from changes in soil pH, competition among sulphate ions, mineralization of phosphorus organic forms (Jaggi et al. 1999, 2005) as well as liberation of aluminium and iron ions, which by reacting with sulphates bind fewer phosphate ions. Besides, the presence of free sulphur acid in sulphur-rich soils creates favourable conditions for the release of phosphorus from compounds which are hardly soluble (Gądor, Motowicka-Terelak 1986b). According to Kaczor (1996), application sulphur acid during three years cause decreasing concentration of available phosphorus in soil.

The computation of the level of significance of the differences performed with Duncan's test (Table 4) showed statistically significant differences between particular objects during the three years of the experiment. The object fertilized with the triple dose of sulphate sulphur was the most distinct one as the average content of available phosphorus determined in its soil was the highest and significantly different from the values established in the other fertilization objects.

CONCLUSIONS

1. The application of 120 kg·ha^{-1} of S-SO_4 caused significant increase in the content of available phosphorus in soil in the layers at 0-40 and 40-80 cm depth. All rates of elementary sulphur as well as those of 40 and 80 kg·ha^{-1} of sulphate sulphur produced only an increasing tendency in the soil concentration of phosphorus.

2. The effect of elementary sulphur on mobilization of phosphorus in soil revealed itself as late as the third year of the experiment.

3. The effect of the doses of 40 and 80 $kg \cdot ha^{-1}$ of sulphur on properties of soil depended on the form of sulphur, duration of the experiment.

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