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THE INFLUENCE OF SULPHUR FERTILIZATION AND LIMING ON THE CONTENT OF AVAILABLE FORMS OF PHOSPHORUS, POTASSIUM AND MAGNESIUM IN SOIL

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A b s t r a c t. In the two-year pot experiment on spring rape, spring barley, white mustard, and oats, the influence of sulphur fertilisation and liming on the content of available forms of phosphorus, potassium, and magnesium in soil was evaluated. The results received indicate that in conditions of strong acidification and lack of available sulphur, the uptake of Mg, and especially P and K used in fertilisers by the plants is limited. This is reflected in the increase in the soils richness in the available forms of these elements. The effectiveness of fertilisation with P, K, and Mg increased significantly in sites fertilised with sulphur and limed.

K e y w o r d s: P, K, and Mg available, sulphur fertilisation, liming.

INTRODUCTION

Soil acidification [5,7,8], and recently also the shortage of available sulphur in the environment of plant growth [3,4,12,15,16], may significantly limit their growth, development, and yield. Indirectly, it influences the uptake and usage of basic nutrients by the plants, such as phosphorus, potassium, and magnesium.

In conditions of very acid soil reaction, the uptake of ions by the plants is, on the one hand, limited by active aluminum and manganese, and on the other by their movement into deeper soil horizons [2,6,10,13,14]. The decreased uptake by the plants of the nutrients mentioned may be caused by the negative sulphur balance in the soils. This has been proved by the results of the experiments carried out in the 90's in Western and Northern Europe [1,11]. The authors of those papers point out that the lack of those elements may cause as much as a 50% reduction in plant yield, which stops them from using the N, P, K, and Mg contained in the fertilisers.

The aim of this paper is to determine the range of influence of plant fertilisation with sulphur and the effect of liming on the different content of available forms of phosphorus, potassium, and magnesium in the soil.

MATERIAL AND METHODS

The research was carried out according to two series of strict experiments conducted in pots. These experiments were carried out in the years 1997-98 on soil material taken from the arable layer of the grey-brown podzolic soil of the granulometric composition of light, highly sanded, silty loam. These soils had a very acid reaction, low content of available phosphorus and sulphate sulphur, and very low content of available potassium and magnesium.

The experiment was established using the method of complete randomisation. It included 2 variables (sulphur dose, lime dose) in three levels. Fertilisation with sulphur in the form of Na_2SO_4 and liming in the form of $CaCO_3$ was used once prior to establishing the experiment according to the following scheme:

1. S_0Ca_0	
2. S_1Ca_0	S_0 - no sulphur fertilisation;
3. S_2Ca_0	S_1 - fertilization with sulphur in the form of Na_2SO_4 in the dose of
4. S_0Ca_1	0.012 g S/kg of soil;
5. S_1Ca_1	S_2 - fertilisation with sulphur in the form of Na_2SO_4 in the dose of
6. S_2Ca_1	0.024 g S/kg of soil;
7. S_0Ca_2	Ca_0 - no liming;
8. S_1Ca_2	Ca_1 - liming with calcium carbonate according to 0.5 Hh;
9. S_2Ca_2	Ca_2 - liming with calcium carbonate according to 1.0 Hh.

In the I experimental series, the tested plant in 1997 was spring rape of the Lisonne "OO" variety, and after that - spring barley of the Start variety. In the II series in 1997 white mustard of the Borowska variety was cultivated, and in 1998 - oats of the Sławko variety. During the selection of the plants, their sensitivity to soil acidity was considered and their nutrition needs in relation to sulphur. Pots capable of containing 6 kg of soil were used in the experiment. Each experimental plant was cultivated 6-fold. Collection of the plants was carried out in the flowering phase (2 repetitions) and during the period of full maturity (4 repetitions).

Constant fertilisation with NPKMg was used each year in all the study sites. The following doses of those elements, reduced to 1 kg of soil, were introduced into the soil under the cereals and mustard: N - 0.16 g N; P - 0.055 g P; K - 0.16 g

K; Mg - 0.01 g Mg. The doses of NPKMg, reduced to 1 kg of soil, applied under the rape were higher: N - 0.32 g N; P - 0.08 g P; K - 0.22 g K; Mg - 0.013 g Mg. The dose of nitrogen was divided into two parts. Half of that element was applied while establishing the experiment and the other half after collecting some of the plants, until an appropriate number of them remained. Phosphorus, potassium, and magnesium were fully applied prior to sowing. Particular nutrients were applied in the following forms: N - NH_4NO_3; P - $Ca(H_2PO_4)_2 \cdot H_2O$; K - KCl; Mg - $MgCl_2 \cdot 6H_2O$. During the vegetation period a constant humidity was maintained at 60% of the field water capacity.

The following features were measured in the soil samples before and after the 2-year experiment: the content of available phosphorus and potassium according to Egner-Riehm DL (extraction with a lactate buffer); the content of available magnesium with the Schachtschabel method (extraction with 0.0125 mol/dm^3 $CaCl_2$).

The analysis of the soil material, post-experiment, was carried out as an average of the object trials. The evaluation of the soil in terms of the available forms of the measured elements was done according to the Polish limiting numbers [17].

RESULTS AND DISCUSSION

The content of the available forms of phosphorus, potassium, and magnesium in the soil taken after the experiment was clearly differentiated (Tables 1-3). Those differences were influenced by the dose of sulphur and lime, the species of the cultivated plant, and the period, in which the soil samples were taken.

The highest content of available phosphorus (Table 1) was found in the soil of the control objects (S_0Ca_0) after harvesting the plants that were sensitive to the acid environment (rape, barley) and had high sulphur requirements (rape) [1,5,11]. In this experimental series, after the experiment, the soil contained large amounts of that element. A high content of available phosphorus occurred also in the soil samples after harvesting the mustard and oats at the flowering phase in the limed series not fertilised with sulphur. The addition of sulphur to the environment of plant growth and the liming of the soil caused an immediate decrease in the content of available P. As a result, the soil of those sites after the experiment contained modest amounts of the element under analysis, and in some cases it reached the initial, i.e. low content of that nutrient. The received data indicates that the necessary condition for the effective uptake of phosphorus by plants is to provide optimum conditions for growth. In this research the factors that had significantly

Table 1. The influence of sulphur fertilization and liming on the content of available forms of phosphorus in soil (mg P/kg)

Plant / Object	Ca_o			Ca_1			Ca_2		
	S_o	S_1	S_2	S_o	S_1	S_2	S_o	S_1	S_2
After barley harvesting - florescence period	66.3	60.2	63.3	57.6	57.6	70.3	52.4	52.4	53.7
Abundance class*	h	m	m	m	m	h	m	m	m
After barley harvesting - full maturity period	71.6	64.1	71.1	59.8	56.3	50.2	51.0	43.2	40.1
Abundance class	h	m	h	m	m	m	m	l	l
After barley harvesting - florescence period	49.3	48.0	58.0	63.7	43.6	58.5	74.2	53.2	62.0
Abundance class	m	m	m	h	l	m	h	m	m
After barley harvesting - full maturity period	53.2	48.4	56.3	40.6	34.9	35.8	46.2	40.1	32.7
Abundance class	m	m	m	l	l	l	m	l	l
Before the experiment					24.0				
Abundance class					l				

*l - low; m - medium; h - high.

T a b l e 2. The influence of sulphur fertilization and liming on the content of available forms of potassium in soil (mg K/kg)

Object / Plant	Ca_o			Ca_1			Ca_2		
	S_o	S_1	S_2	S_o	S_1	S_2	S_o	S_1	S_2
After barley harvesting - florescence period	218.3	249.1	259.8	189.3	102.1	106.3	103.8	78.9	37.3
Abundance class*	vh	vh	vh	h	l	m	l	l	vl
After barley harvesting - full maturity period	293.1	225.0	215.8	154.4	70.6	58.9	39.8	16.6	21.6
Abundance class	vh	vh	vh	m	l	vl	vl	vl	vl
After barley harvesting - florescence period	146.9	164.4	208.4	106.3	54.0	77.2	105.4	66.4	83.8
Abundance class	h	m	vh	m	vl	l	m	l	l
After barley harvesting - full maturity period	100.4	87.2	87.2	58.1	35.7	33.2	24.1	25.7	19.7
Abundance class	m	l	l	vl	vl	vl	vl	vl	vl
Before the experiment					56.0				
Abundance class					vl				

*vl - very low; l - low; m - medium; h - high; vh - very high.

T a b l e 3. The influence of sulphur fertilization and liming on the content of available forms of magnesium in soil (mg Mg/kg)

Plant / Object	Ca_o			Ca_1			Ca_2		
	S_o	S_1	S_2	S_o	S_1	S_2	S_o	S_1	S_2
After barley harvesting - florescence pe-	43.1	39.2	43.1	41.3	29.4	30.1	38.3	39.2	27.3
riod	1	1	1	1	vl	1	1	1	vl
Abundance class*	75.1	63.2	31.3	46.2	31.2	24.4	21.4	20.3	21.3
After barley harvesting - full maturity period	h	m	1	1	1	vl	vl	vl	vl
Abundance class									
After barley harvesting - florescence period	36.1	42.2	45.1	45.2	38.3	45.5	37.3	47.1	30.2
Abundance class	1	1	1	1	1	1	1	1	1
After barley harvesting - full maturity period	41.3	43.2	32.1	29.2	28.2	33.4	24.1	24.3	24.1
Abundance class	1	1	1	vl	vl	1	vl	vl	vl
Before the experiment					28.0				
Abundance class					vl				

*vl - very low; 1 - low; m - medium; h - high.

limited the use of phosphorus included in the fertilisers were the acid reaction of the soil and the lack of sulphur in the environment, which was reflected in the yield harvested [9].

The experimental factors used, differentiated the content of available potassium (Table 2) and magnesium (Table 3) even more. In the cases of those elements - depending on the degree of supply to the plants with sulphur and the dosage of calcium carbonate - the soil ranged from a very low to a very high content of them. A very high content of available K and Mg were found in all the soil samples taken from the sites limed with a higher dose of $CaCO_3$ after harvesting the barley and oats during the period of full maturity. This proves that in conditions of optimum soil reaction (Ca_2) the tested plants accepted the full amount of potassium and magnesium contained in the used fertilisers. The uptake of K and Mg did not, therefore, depend on the dose of sulphur applied at the beginning of the research. The amount of the used sulphur at the beginning of the experiment had an effect on the formation of the content of available potassium and magnesium in the soil taken from the series limed with a lower dose of calcium carbonate (Ca_1). In the sites described, the lowest content of potassium and magnesium was to be found in soil fertilised with the double dose of sodium sulphate (S_2).

The highest content of available potassium was found in soil samples taken after barley harvesting from the non-limed series. This content was noted at both harvest periods of this plant on all three levels of sulphur used. In the experimental series II, after harvesting the oats in the sites with no lime, an increase in the sulphur dose caused a decrease in the content of available potassium in the soil. Therefore, one can suppose that in cases where plants are less sensitive to the acid reaction of the soil, the fertilising activity of sulphur in such conditions is not significantly limited and indirectly affects its uptake of potassium.

The content of available magnesium in the non-limed soil was low in most of the sites - regardless of the amount of sodium sulphate used. In the case of this element, in the sites investigated in the two-year research cycle, the content of available magnesium in the soil changed from very low to low.

The results received prove the frequently emphasised fact that the effective use of the basic nutrients by the plants is highly dependent on measures previously aimed at bringing the soil reaction to a state close to the optimum [5-7]. They also indicate that the factor which limits the uptake and use of those nutrients could also be the shortage of sulphur in the soil. Therefore, it can be stated that in the cultivation of plants which have great sulphur requirements, this element should be considered while determining their fertilisation needs.

CONCLUSIONS

1. The acid reaction of the soil and the shortage of sulphur in the environment limits the uptake of magnesium, potassium, and phosphorus by the plants. This is indicated by the significant growth of the content of available forms of those elements in the soil.

2. The greatest limitation of the uptake of P, K, and Mg occurs in the case of plants which are sensitive to acidification (rape, barley) and which have high requirements in terms of sulphur (rape).

3. The optimum conditions for the uptake of phosphorus, potassium, and magnesium by the plants occurred after the application of sulphur and bringing the soil reaction to the optimum value.

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