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UTILIZATION OF SELECTED PLANT INDICATORS FOR EVALUATING THE SUPPLY OF PLANTS IN SULFUR

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Abstract: Plant indicators are often used at evaluating the level of plant's supply in nutrients. In the case of sulfur, they are: $S_{tot.}$, N:S ratio, S-SO_4 content, and total sulfur to sulfates ratio. Mainly the crop species should determine the selection of the most appropriate indicator. Therefore, the aim of present research was the assessment of a possibility to apply some plant indicators when evaluating the sulfur nutrition of crops grown under conditions of various soil acidity. The study was carried out on a base of two series of strict pot two-year experiments. The soil material was collected from the plough layer of lessive soil with granulometric composition of strong dusty sandy light loam. The experiment was established by means of complete randomization and included 2 variable factors (sulfur dose, calcium dose) at three levels. Sulfur nutrition was applied in a form of Na_2SO_4 while liming as $CaCO_3$ was used only once before experiment setting. The spring rapeseed, followed by spring barley (series I) as well as white mustard and oats (series II) were the test plants. The plant selection was determined by their nutritional needs in respect to sulfur along with their sensitivity to acidification. Results from performed experiments indicated that applied factors affected the values of indicators helpful in assessing the crop's sulfur supply level. Among studied plant indicators, sulfur nutrition caused prominent increase of total and sulfate forms of sulfur, and the increase was much higher in the case of rapeseed and white mustard. Applying Na_2SO_4 was also associated with higher abundance of sulfates as compared with total sulfur, which was reflected as the increase of S-SO_4 : S_{tot} ratio. The reliable indicator for assessing the level of crop's supply with sulfur appeared also to be N:S ratio, that was prominently lower at plants from sulfur-treated objects as compared with values recorded in dry matter of control plants (S_0).

Keywords: plant indicators, total and sulfate sulfur contents, sulfate to total sulfur ratio, N : S ratio

Introduction

Evaluating the level of crop's providing with nutrients is a very important issue from a point of view of their appropriate nutrition. Optimum crop nutrition level has positive

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effects on a yield size and quality. It is also economically and ecologically significant problem, because high fertilization efficiency can be reached under such conditions, and quantities of components transferred out of the root system, are relatively low [1, 2].

Sulfur is one of the nutrients that is necessary for a proper development of living organisms. Taking into considerations the plant's quantitative requirements for sulfur, the element is usually ranked at fourth place after nitrogen, potassium, and phosphorus [3]. It enters many important compounds, the lack of which makes disturbances of plant development and diseases at humans and animals [4, 5]. Various plant indicators are helpful at evaluating the level of plant's supply with sulfur. The most common are: S_{tot}, Nj:jS ratio, $S\text{-}SO_4$ content, and sulfates to total sulfur ratio [6, 7].

However, studies conducted in Poland indicated that the decrease of sulfur deposits from atmosphere and the decrease of the component level introduced along with mineral fertilizers led to sulfur deficiency in plant production [8, 9]. Thus, the lack of sulfur can be suspected namely on lighter – usually acidified – mineral soils localized at some distance from industrial centers [10, 11].

Therefore, the aim of present research was to assess the possibility of applying selected plant indicators for evaluating the sulfur nutrition of crops grown under conditions of various soil acidity.

Material and methods

The study consisted of two series of strict two-year pot experiments. The experiments were carried out on soil material collected from the ploughing layer of lessive soil of granulometric composition of strong dusty sandy light loam. The soil was characterized by very acidic reaction, low level of available phosphorus and sulfates, as well as very low content of available potassium and magnesium.

The experiment was established by means of complete randomization method and included two variable factors (sulfur and calcium doses) at three levels. Sulfur nutrition in a form of Na_2SO_4 and liming as $CaCO_3$ was applied only once before experiment setting in accordance with attached scheme (Table 1).

Table 1

Scheme of the experiment

	Object	Description
1	S_0Ca_0	S_0 – no sulfur nutrition
2	S_1Ca_0	S_1 – nutrition with sulfur as Na_2SO_4 at rate of 0.012 g S · kg^{-1} of soil
3	S_2Ca_0	S_2 – nutrition with sulfur as Na_2SO_4 at rate of 0.024 g S · kg^{-1} of soil
4	S_0Ca_1	Ca_0 – no liming
5	S_1Ca_1	Ca_1 – liming using calcium carbonate according to 0.5 Kh – 0.582 g CaO · kg^{-1} of soil
6	S_2Ca_1	Ca_2 – liming using calcium carbonate according to 1.0 Kh – 1.164 g CaO · kg^{-1} of soil
7	S_0Ca_2	
8	S_1Ca_2	
9	S_2Ca_2	

The experimental series I included the spring rapeseed cv. Lisonne “00”, followed by spring barley cv. Start as test crops. Series II consisted of white mustard cv. Borowska, followed by oats cv. Slawko the following year as test plants. The plant selection was determined by their nutritional needs in respect to sulfur along with their sensitivity to acidification. Plants grew in pots filled with 6 kg of soil. Plants were sown every year at the end of April at amount of 20 seeds per pot. Following the emergence, plants were thinned leaving 7 crucifer and 8 ones in the case of barley and oats, in each pot.

Constant NPKMg fertilization was applied for all experimental objects at the level consistent with crop’s nutritional requirements. Particular nutrients were introduced in forms of: N – NH_4NO_3; P – $Ca(H_2PO_4)_2 \cdot H_2O$; K – KCl; Mg – $MgCl_2 \cdot 6H_2O$. Constant moisture content at the level of 60% of the field water capacity was maintained during the vegetation season.

Every experimental plant was grown in six replicates. Plant harvest was carried out at full blossom (2 replicates) and full ripeness phase (4 replicates).

Determination of chemical properties of the soil used for experiments was made by means of methods commonly applied in chemical-agricultural laboratories. The sulfates were determined in soils samples before experiment and after crop harvest in 1st and 2nd year by means of nephelometry according to Bardsley and Lancaster’s [12]. Also pH in 1 mol KCl was measured in the soil material using glass electrode (potentiometry).

After the plant harvest at blossom phase, plant material was digested in concentrated sulfuric acid with addition of H_2O_2 and then total nitrogen was determined by means of Kjeldahl method.

When plant material was extracted using 2% CH_2COOH with active coal addition, sulfates were determined nephelometrically [13]. Total sulfur was determined applying Butters-Chenery method [14].

All analyses of soil and plant material were done in two replicates of averaged object samples. Attached tables present mean values.

After the plant harvest at full ripeness phase, statistical evaluation of yields (seeds, straw) was performed. The evaluation was made by means of variance analysis for factorial experiments using Tukey confidence intervals.

Results and discussion

Plant indicators are often used at evaluating the level of plant’s providing with nutrients. In the case of sulfur, they are: S_{tot}, N:S ratio, $S\text{-}SO_4$ content, and sulfates to total sulfur ratio. [3, 6, 7, 15–18]. It is difficult to univocally find, which of them is the best. Some authors underline [19] that mainly the crop species, for which the level of sulfur supply is being assessed, should determine the selection of the most appropriate indicator.

The most common sulfur-supply indicators were determined for test plants harvested at blossom phase (Table 2). This can allow for possibly quick intervention in the case of any sulfur deficit during crop production and reduce damages associated with lower yields and their worse quality [3, 15, 20].

Table 2

Influence of sulfur nutrition and liming on selected indicators expressing the sulfur supply of crops harvested at blossom phase

Object	S_{tot} [g · kg^{-1}]	S-SO_4 [g · kg^{-1}]	S-SO_4 : S_{tot}	N_{tot} : S_{tot}
Spring rapeseed				
S_0Ca_0	4.5	2.0	0.44	13.8
S_1Ca_0	8.3	2.5	0.30	7.5
S_2Ca_0	11.5	4.0	0.35	5.7
S_0Ca_1	2.5	1.0	0.40	11.9
S_1Ca_1	5.0	2.4	0.48	5.3
S_2Ca_1	6.3	3.6	0.57	4.2
S_0Ca_2	2.3	0.9	0.39	10.8
S_1Ca_2	4.8	2.0	0.42	5.6
S_2Ca_2	6.1	3.2	0.52	4.9
Spring barley				
S_0Ca_0	2.7	1.2	0.44	16.1
S_1Ca_0	3.3	1.7	0.52	14.0
S_2Ca_0	3.8	2.1	0.55	10.6
S_0Ca_1	2.5	1.2	0.48	15.7
S_1Ca_1	2.8	1.4	0.50	11.9
S_2Ca_1	3.2	1.7	0.53	10.7
S_0Ca_2	1.6	0.9	0.56	19.1
S_1Ca_2	1.9	1.1	0.58	16.1
S_2Ca_2	2.1	1.3	0.62	13.7
White mustard				
S_0Ca_0	7.8	2.6	0.33	X
S_1Ca_0	9.3	3.5	0.38	X
S_2Ca_0	10.0	3.6	0.36	X
S_0Ca_1	4.1	0.5	0.12	8.6
S_1Ca_1	6.4	1.5	0.23	5.2
S_2Ca_1	8.8	3.1	0.35	4.2
S_0Ca_2	4.5	0.8	0.18	8.7
S_1Ca_2	6.5	1.9	0.29	5.9
S_2Ca_2	7.6	2.9	0.38	4.2
Oats				
S_0Ca_0	2.3	1.1	0.48	14.7
S_1Ca_0	3.0	1.6	0.53	11.9
S_2Ca_0	3.7	2.1	0.57	9.5
S_0Ca_1	1.6	0.8	0.50	17.7
S_1Ca_1	1.6	0.8	0.50	17.4
S_2Ca_1	2.4	1.4	0.58	11.8
S_0Ca_2	1.7	0.9	0.53	16.8
S_1Ca_2	1.8	1.0	0.56	15.4
S_2Ca_2	2.3	1.4	0.61	12.6

X – not determined due to lack of material.

For spring rapeseed harvested at blossom phase, the quantity of total sulfur in plant dry matter oscillated within quite wide range (2.3–11.5) g · kg^{-1}. Plants from control objects (S_0Ca_0, S_0Ca_1, S_0Ca_2), to which sulfur nutrition was not applied, were characterized by the lowest content of discussed sulfur form. Nevertheless, when comparing the total sulfur in analyzed objects, it is prominent that levels of this sulfur form at plants from S_0Ca_0 object is almost twice as high as those found in S_0Ca_1 and S_0Ca_2 objects. It probably results from the "component's concentrating effect", since plants could not find any beneficial conditions for growth and development in analyzed object. Such conclusion could be confirmed by the yield size of plants harvested at full ripeness phase (Table 3). Crops from here discussed object produced the lowest seed and straw yields.

Table 3

Influence of sulfur nutrition and liming of soil acidity [pH_{KCl}]

Soil	Object								
	Ca_0			Ca_1			Ca_2		
	S_0	S_1	S_2	S_0	S_1	S_2	S_0	S_1	S_2
After rapeseed harvest – blossom phase	4.3	4.3	4.3	4.9	5.2	5.0	6.1	5.9	5.9
After barley harvest – blossom phase	4.2	4.6	4.5	4.7	4.9	4.2	5.4	5.4	5.1
After mustard harvest – blossom phase	4.5	4.4	4.4	5.4	5.2	5.3	6.4	6.5	6.3
After oats harvest – blossom phase	4.2	4.3	4.1	4.9	4.9	5.0	5.8	5.7	5.7
After rapeseed harvest – full ripeness phase	4.1	4.2	4.1	4.7	4.8	4.7	5.8	5.8	5.8
After barley harvest – full ripeness phase	3.9	3.8	3.8	4.0	4.1	4.1	5.6	5.6	5.7
After mustard harvest – full ripeness phase	4.1	4.1	4.1	4.9	5.1	4.9	6.2	6.3	6.1
After oats harvest – full ripeness phase	4.1	4.1	4.1	4.5	4.6	4.6	5.7	5.7	5.6
Before experiment	3.85								

Unlike control objects, the lowest total sulfur content characterized crops grown with sulfur addition at the rates of 0.012 gS · kg^{-1} and 0.024 gS · kg^{-1} of soil, although soil acidification associated with lack of liming (Ca_0) was the factor that limited the yield size (Table 3). In analyzed objects, total sulfur level due to "component concentrating effect" [21] amounted (8.3–11.5) g · kg^{-1}. It is often underlined in numerous literature references that besides fertilization using various nutrients, liming greatly determines the amount of produced biomass during cultivation of crops, namely those sensitive to low pH [22].

In the case of objects, where liming was done, a clear dependence between total sulfur and seed and straw yields of spring rapeseed can be observed (Table 4). The increase of sulfur dose applied was accompanied by the increase of total sulfur amount determined in dry matter of plants harvested at blossom phase and the increase of yield size of generative and vegetative parts of analyzed crop. Numerous studies upon the impact of nutrition on quality and size of yields for crops often underlined that there is some regularity indicating that plants utilize nutrients more effectively when they are applied in proportions adjusted to crop's nutritional requirements [23]. Referring to spring rapeseed as a plant species particularly sensitive to sulfur deficits in an environment, higher sodium sulfate (0.024 gS · kg^{-1} of soil) appeared to be the most appropriate.

Table 4

Influence of sulfur nutrition and liming on crop yielding [g d.m. · pot^{-1}]

Crop Object	Series I				Series II			
	Spring rapeseed		Spring barley		White mustard		Oats	
	Seeds	Straw	Grain	Straw	Seeds	Straw	Grain	Straw
S_0Ca_0	0.62	9.32	b.n.	1.61	b.n.	0.31	18.21	23.30
S_1Ca_0	1.79	16.80	b.n.	1.73	b.n.	0.64	18.98	24.05
S_2Ca_0	2.39	24.85	b.n.	1.94	b.n.	1.04	20.31	24.99
S_0Ca_1	1.29	54.12	4.80	11.34	6.99	39.15	20.20	25.40
S_1Ca_1	18.33	63.25	10.37	16.40	9.62	41.65	20.80	26.86
S_2Ca_1	22.55	65.10	13.58	17.71	9.82	41.57	20.92	26.87
S_0Ca_2	2.11	80.45	19.86	29.51	10.19	46.95	22.64	28.79
S_1Ca_2	25.42	83.57	23.65	29.52	10.81	47.92	25.82	30.41
S_2Ca_2	35.46	91.15	25.65	33.14	11.19	49.95	28.21	30.45
LSD (p = 0.01)								
S	0.71	2.27	1.36	1.19	0.42	1.15	1.24	1.34
Ca	0.71	2.27	1.06	1.19	0.33	1.15	1.24	1.34
S · Ca	1.34	4.33	1.54*	2.26	0.66	2.19	2.35	n.i.

* – differences significant only at the level of p = 0.05; b.n. – lack of material; n.i. – insignificant differences.

Changes in total sulfur content in dry matter of spring rapeseed harvested at blossom phase were also accompanied by alterations of S-SO_4 level. Like for total sulfur, the highest sulfate concentration was recorded at plants from objects, where liming was given up. Due to unfavorable conditions for growth and development, crops produced much lower seed and straw yields.

Plants from series limed according to 1.0 HA (hydrolitic acidity) were characterized by the lowest sulfate content, which was reflected in the amount of sulfates recorded in the soil after the plant harvest (Table 5) as well as seed and straw yields determined after rapeseed harvest at full ripeness phase (Table 4).

Applying the sodium sulfate also contributed to changes of S-SO_4 to S_{tot} proportions in spring rapeseed dry matter. Sulfur nutrition caused the increase of this ratio in limed objects. Better plant providing with sulfur usually makes the decrease of the component incorporation within organic compounds [24], while on the other hand, higher sulfate contents in crop's biomass means that they were insufficiently provided with sulfur [25].

The N : S ratio in dry matter of rapeseed harvested at blossom phase ranged within 4.2–13.8. Some authors underline that this indicator is better for assessing the level of plant's supply with sulfur rather than total sulfur and sulfates concentrations [19]. Under conditions of present experiment, the N : S ratio reached the highest values in objects, where sulfur nutrition was not applied at all. Nitrogen to sulfur ratio is somehow disturbed at sulfur deficiency, which in consequence may diminish the nitrogen utilization and leading to lower size and quality of crop's yields [22]. In the case of spring rapeseed, plants produced the lowest seed and straw yields at N : S ratio of 10.8–13.8, which may indicate that sulfur deficit could be the factor that limited the yielding.

Table 5

Influence of sulfur nutrition and liming on sulfates content in the soil [mg · kg^{-1}]

Soil	Object								
	Ca_0			Ca_1			Ca_2		
	S_0	S_1	S_2	S_0	S_1	S_2	S_0	S_1	S_2
After rapeseed harvest – blossom phase	17.0	27.8	26.6	11.2	9.0	8.3	4.8	7.4	10.4
After barley harvest – blossom phase	19.6	28.4	37.6	19.2	25.0	22.0	17.6	24.3	24.1
After mustard harvest – blossom phase	21.8	25.4	49.9	11.6	7.9	15.4	4.8	4.7	10.4
After oats harvest – blossom phase	22.2	28.8	36.0	24.7	22.5	28.0	26.4	27.4	23.6
Before experiment	19.7								

Objects treated with sulfur at the level of S_2 revealed the N : S ratio 1.2–1.3-fold lower as compared to values recorded after sulfur nutrition at S_1 rate. Higher rapeseed seed and straw yields were the effects of better crop supply with sulfur, namely in limed objects. It is also confirmed by literature data [3, 19, 26] pointing out that the N:S value is quite good indicator of rapeseed providing with sulfur.

In the case of spring barley, that is a plant species with relatively modest nutritional requirements in respect to sulfur [23, 27], the level of the element supply might determine the size and quality of yields, because appropriate crop providing with sulfur has beneficial influence on photosynthesis, protein biosynthesis, and nucleic acids contents, and in consequence, necessary technological value of yield [22].

Contents of S_{tot} and S-SO_4 in spring barley dry matter harvested at blossom phase prominently depended both on sulfur nutrition level and soil acidification (Table 3). Plants from objects where liming was not applied (Ca_0) were characterized by the highest concentration of analyzed sulfur forms. In those objects, quantity of total sulfur was at the level of 2.7–3.8 g · kg^{-1}, while that of sulfates 1.2–2.1 g · kg^{-1}. Such large amount of sulfur may be attributed to the "component concentrating effect", which was reflected by barley grain and straw yields harvested at full ripeness phase. Crops produced minimum grain yields and low (1.61–1.94 g · pot^{-1}) straw yield in objects, where liming was not done. Also the concentration of sulfates left in the soil after the crop harvest (Table 5) may indicate that mainly soil acidification was the factor limiting the plant yielding in objects without liming (Ca_0) (Table 3). It is frequently emphasized that sulfur availability for plants greatly depends on the soil acidity. Alkaline reaction of the soil accelerates the organic matter decomposition and sulfur release, whereas low pH values intensify the sulfates adsorption on hydrated iron and aluminum oxides, as well as kaolinite, which reduces the sulfur availability for plants [28].

The S-SO_4 : S_{tot} ratio is also worth mentioning among discussed indicators of spring barley providing with sulfur. Studies conducted upon the sulfur utilization level by crops [19] revealed that sulfate to total sulfur ratio is quite constant during the whole vegetation season and is more suitable for assessing the plant supply with sulfur than total sulfur or sulfates concentration.

When comparing value of S-SO_4 : S_{tot} in dry matter of barley harvested at blossom phase, it is noticeable that sodium sulfate application resulted in relatively larger increase of sulfates than organic sulfur contents. It was proven by the increase of S-SO_4 : S_{tot}, namely in objects, where sulfur was introduced at the amount of 0.024 gS · kg^{-1} of soil. It was probably due to the fact that better plant supply with sulfur causes that those plants incorporate that nutrient into organic compounds to a lesser degree [24, 25]. In addition, increased sulfates content in plant biomass means that crops were sufficiently provided with the element, which was confirmed by presented pot experiment. Value of S-SO_4 : S_{tot} ratio in dry matter of barley from objects treated with sulfur was about 1.1–1.3-fold higher in reference to levels recorded at plants, to which sulfur was not introduced. Better supply of these plants with sulfur resulted also in the increase of grain and straw yields observed after the barley harvest at full ripeness phase.

Ratio N:S also seems to be a reliable indicator of spring barley providing with sulfur. Literature references underline that the ratio should amount to 17 : 1 at optimum grasses supply with sulfur. For spring barley harvested at blossom phase, that value oscillated around 10.6–19.1. Some prominent decrease of N:S ratio was recorded for plants, to which sulfur nutrition was applied. It was probably associated with the influence of sodium sulfate on total sulfur content increase and decrease of total nitrogen concentration at plants from those objects. Perhaps, sulfur treatment improved crop providing with the nutrient [19], which in turn affected the increase of barley grain and straw yields determined at full ripeness phase.

White mustard – as similar as spring rapeseed – is a plant species with particularly large nutritional requirements for sulfur. The plant produces specific sulfur compounds (fatty acids, bitter oils, etc.), its utility value depends on [29, 30].

When considering the influence of sodium sulfate nutrition on total sulfur and sulfate concentrations in dry matter of white mustard harvested at blossom phase, it can be observed that plants from objects without liming were characterized by the highest contents of analyzed sulfur forms. It was probably associated with the "component concentrating effect" and was also reflected in seed and straw yield size determined after mustard harvest at full ripeness phase (Table 4). In objects of series Ca_0 (no liming), plants did not produce seeds at all. Quantity of sulfates found in the soil under series Ca_0 determined after white harvest at blossom phase (Table 5) may suggest that the plant species strongly reacted towards low soil pH (Table 3) and did not utilize available sulfur forms in full. It is somehow surprising reaction, since white mustard is considered as a plant of light soils, thus not counted to particularly sensitive to soil acidification [30].

At plants from analyzed objects, amount of total sulfur was at the level of (7.8–10.0) g · kg^{-1}, which about 1.1–1.9-fold exceeded total sulfur content found at crops of series with liming according to 0.5 Kh (Ca_1) and 1.3–1.7-fold in reference to plants of series Ca_2. It was more obvious in the case of sulfates, for which their amount was 1.2–5.2

times higher in dry matter of plants of series Ca_0 as compared with values recorded at plants of series Ca_1 and 1.2–3.3 times higher in relation to series Ca_2.

Comparing both above indictors that describe the mustard supply with sulfur with sulfur to total sulfur ratio, it is prominent that also plants of series Ca_0 were characterized by the highest values of the proportion. In analyzed objects, the $S\text{-}SO_4 : S_{tot}$ was at the level of 0.33–0.36, which was 1.3–2.8-fold higher as compared with data recorded at plants from other objects. High values of the proportion may indicate that besides sulfur nutrition of the test crop, also soil liming might play some important role. When the soil is of improper acidity, nutrients are worse utilized by plants and their uptake is often disturbed. Not only the yields of generative parts is decreased then, but its technological value is worsened as well [20, 22].

However, it is worth underlining that in the case of majority of objects, namely those of series Ca_1 and Ca_2, the increase of sodium sulfate dose caused obvious increase in $S\text{-}SO_4$ to S_{tot} value of white mustard dry matter, which may indicate that the crop utilized sulfur better from directly available forms. It is reflected in the amount of sulfates found in the soil of these objects, analyzed when mustard was harvested at blossom phase (Table 5).

The total nitrogen to total sulfur ratio, that is frequently used for evaluating the crop providing with sulfur, appeared to be the least reliable indicator in the case of white mustard harvested at blossom phase. Its value oscillated within 4.2–8.6 for plants of series Ca_1 and around 4.2–8.7 of dry matter of mustard from objects, where liming was applied according to 1.0 Kh.

Oat was another crop subject to evaluate the level of supply with sulfur. The species is from the plant group with relatively low nutritional requirements for sulfur; nevertheless, it is often emphasized that the requirements and reaction towards sulfur addition into the environment can increase at higher levels of nutrition using other nutrients, namely nitrogen and phosphorus [31].

Plants from series Ca_0 were characterized by the highest concentrations of total sulfur and sulfates. Dry matter of plants from above objects contained 1.4–1.9-fold more total sulfur than those of series Ca_1 and 1.4–1.7-fold more as compared with plants growing after liming according to 1.0 Kh (Ca_2). Similar situation was observed in the case of sulfates, the quantity of which at plants of series Ca_0 was 1.2–2 times higher as compared with the contents recorded in dry matter of oats from other experimental objects. It is worth noticing that sodium sulfate application caused slightly larger increase of sulfate in relation to organic sulfur content, which was confirmed by the increase of $S\text{-}SO_4 : S_{tot}$ value. The increase of sulfate content in plant biomass may indicate that they were sufficiently provided with sulfur [25].

The highest value of $S\text{-}SO_4 : S_{tot}$ ratio was recorded for oat biomass from objects, where liming was applied in accordance to 1.0 Kh. In these objects, the value was at the level of 0.53–0.61, which was 1.1-fold higher than for plants of series Ca_1 and Ca_0. It was also confirmed by the biomass of plants produced after oats harvest at full ripeness, because in series Ca_2, the crops produced significantly higher grain and straw yields.

The N:S ratio also seems to be quite good indicator of oat supply with sulfur. It is often underlined in literature references that total sulfur content may decrease during the plant's growth and development, hence the N:S ratio should be the most proposed indicator taken into consideration at evaluating the grass providing with sulfur [16].

Under conditions of presented pot experiment, value of N:S ratio ranged within 9.5–16.8. Both at plants from limed series, as well as series Ca_0, prominently lower levels of N : S ratio were recorded at plants treated with higher sulfur dose (S_2). It may indicate the high degree of sulfur from sources that were directly available for crops and finds its reflection in grain and straw yields of oats harvested at full ripeness phase. In analyzed objects, namely series Ca_2, plants produced considerably higher yields of vegetative and generative parts as compared with oats fertilized with higher sulfur rate as well as to those from control series (S_0). High value of N : S ratio in objects with no sulfur treatment, may suggest sulfur deficit within oats environment. Despite of the fact that oat is a species with relatively low sulfur requirements, the N:S ratio can be disturbed at sulfur deficits and nitrogen excess. In consequence, it leads to lower nitrogen utilization and may contribute to the decrease of plant's size and quality of yields [22].

Conclusions

Results from studies aiming at evaluating the possibilities of utilization of some plant indicators taken into consideration during evaluating the level of crop's providing with sulfur under various soil acidity, allow for drawing following conclusions:

1. Applied experimental factors exerted significant influence on values of analyzed indicators for evaluating the level of test crop's supply with sulfur.

2. Sulfur nutrition cause the increase of total sulfur and sulfate contents in dry matter of test plants. The increase was much higher in the case of rapeseed and white mustard, *ie* crops with high requirements for the component. It might indicate that these plants reacted towards sulfur deficiency within their growth environment the most clearly.

3. Unlike sulfur nutrition, calcium carbonate applying affected the decrease of analyzed sulfur forms concentration in biomass of all test crops.

4. Application of sodium sulfate also contributed to higher increase of sulfates in relation to total sulfur, which was proved by value of $S\text{-}SO_4 : S_{tot}$ ratio, and it means that test plant species were sufficiently provided with sulfur.

5. The N:S ratio also appeared to be quite good indicator of plant's supply with sulfur. As an effect of sulfur nutrition, that value was prominently lower as compared with values found at plants from the control series, which indicates that crops treated with sulfur were better provided with the nutrient.

6. Results from presented studies allow for concluding that every analyzed indicator may be used to evaluate the level of crop's supply with sulfur, and the selection of the best one should be determined mainly by the species of cultivated crop.

References

[1] Beaton J, Hasegawa H, Keng J. Some aspects of plant nutrition, soil fertility management to consider in maximum yield research. Proc Symp on "Maximum yield research". Kyoto, Japan; 1990:131-152.

[2] Bednarek W, Tkaczyk P, Dresler S. Siarka w niektórych roślinach uprawnych Lubelszczyzny. Acta Agrophys. 2008;11(3):575-587.
[3] Scherer HW. Sulphur in crop production – invited paper. Europ J Agronom. 2001;14:81-111.
[4] Tańska M, Rotkiewicz D. Wpływ różnych czynników na jakość nasion rzepaku. Rośl Oleis. 2003;29:595-616.
[5] Wielebski F, Wójtowicz M. Problemy nawożenia rzepaku siarką w Polsce i na świecie. Rośl Oleis. 2000;21(2):449-463.
[6] Bloem EM. Schwefel-Bilanz von Agrarökosystemem unter besonderer Berücksichtigung hydrologischer und bodenphysikalischer Standorteigenschaften. Landbauforschung Völkenrode, Sonderheft; 1998;192:1-156.
[7] Mc Grath SP, Zhao FJ. Sulphur uptake, yield responses and the interactions between nitrogen and sulphur in winter oilseed rape (Brassica napus). J Agricult Sci. 1996;126:53-62.
[8] Krauze A, Bowszys T. Wpływ terminu nawożenia siarką rzepaku jarego Star na plon nasion oraz zawartość siarki i tłuszczu. Rośl Oleis. 2001;21(2):285-290.
[9] Motowicka-Terelak T, Terelak H. Siarka w glebach Polski – stan i zagrożenia. Warszawa: PIOŚ; Bibl Monit Środow. 1998.
[10] Kaczor A, Kozłowska J. Wpływ nawożenia siarką i wapnowania na ogólną zawartość tłuszczu i skład kwasów tłuszczowych w nasionach roślin krzyżowych. Zesz Probl Post Nauk Roln. 2002;482:245-250.
[11] Lipiński W, Motowicka-Terelak T, Terelak H. Sulphur concentration in the agricultural soils of the Lublin region and Poland. Acta Agrophys. 2001;52:161-165.
[12] Boratyński K, Grom A, Ziętecka M. Badania nad zawartością siarki w glebie. Cz I. Rocz Glebozn. 1975;26(3):121-139.
[13] Grzesiuk W. Nefelometryczne oznaczanie siarki siarczanowej w roślinach. Rocz Glebozn. 1968;19(1):167-173.
[14] Butters B, Chenery EM. A rapid method for the determination of total sulphur in soil and plants. Analyst. 1959;84:239-245.
[15] Luo C, Branlardt G, Griffin WB, Mc Neil DL. The effect of nitrogen and sulphur fertilisation and their interactions with genotype on wheat glutenins and quality parameters. J Cereal Sci. 2000;31:185-194.
[16] Mathot M, Thčlier-Huchč L, Lambert R. Sulphur and nitrogen content as sulphur deficiency indicator for grasses. Europ J Agronom. 2009;30:172-176.
[17] Pyś JB, Pucek T. Wartość pokarmowa roślin pastewnych uprawianych w rejonie składowisk siarki kopalni "Jeziórko". Cz II. Zawartość siarki i azotu oraz stosunek N:S w roślinach. Arch Ochr Środow. 1993;1/2:163-212.
[18] Zhao FJ, Mc Grath SP, Salmon SE, Shewry PR, Quayle R, Withers PJA, et al. Optimising sulphur inputs for breadmaking quality of wheat. Aspec Appl Biol. 1997;50:199-205.
[19] Mc Grath SP, Zhao FJ, Withers PJA. Development of sulphur deficiency in crops and its treatment. Fertil Soc. 1996:3-47.
[20] Kocoń A. Nawożenie jakościowej pszenicy jarej i ozimej a plon i jakość ziarna. Pamięt Puław. 2005;139:55-64.
[21] Nowak GA, Ciećko Z. Wykorzystanie fosforu z nawozów w warunkach stosowania gnojowicy oraz popiołu z węgla kamiennego. Zesz Nauk AR Szczec. 1996;172(62):397-403.
[22] Gondek K. Ocena wpływu siarki wprowadzanej do gleby z nawożeniem mineralnym oraz odpadem po produkcji siarczanu magnezu na jej zawartość w pszenicy jarej (Triticum aestivum L). Acta Agrophys. 2010;15(2):269-280.
[23] Kaczor A, Łaszcz-Zakorczmenna J. Wpływ nawożenia siarką i potasem na plonowanie i zawartość różnych form siarki w jęczmieniu jarym. Acta Agrophys. 2003;1(2):239-244.
[24] Blake-Kalff MMA, Harrison KR, Hawkesford MJ, Zhao FJ, Mc Grath SP. Distribution of sulfur within oilseed rape leaves in response to sulfur deficiency during vegetative growth. Plant Physiol. 1998;118:1337-1344.
[25] Marschner H. Mineral nutrition of higher plants (sec. edit.). Cambridge: Academic Press, M; 1995.
[26] Fismes J, Vong PC, Guckert A, Frossard E. Influence of sulphur on apparent N-use efficiency, yield and quality of oilseed rape (Brassica napus L) grown on a calcareous soil. Europ J Agronom. 2000;12:127-141.
[27] Zhao FJ, Fortune S, Barbosa VL, Mc Grath SP, Stobart R, Bilsborrow PE, et al. Effects of sulphur on yield and malting quality of barley. J Cereal Sci. 2006;43:369-377.

[28] Gajewska J, Olejnik K, Parzydeł M, Rastawicka M, Szulc W, Borkowski A. Charakterystyka morfologiczna i fizjologiczna glebowych bakterii utleniających związki siarki. Zesz Nauk UP we Wrocławiu, Rolnictwo. 2006;546:65-70.
[29] Ahmad A, Khan I, Anjum NA, Abrol YP, Iqbal M. Role of sulphate transporter systems in sulphur efficiency of mustard genotypes. Plant Sci. 2005;169:842-846.
[30] Sawicka B, Kotiuk E. Gorczyce jako rośliny wielofunkcyjne. Acta Sci Pol. Agricult. 2007;6(2):17-27.
[31] Bona L, Baligar VC, Bligh DP, Purnhauser L. Soil acidity effects on concentration of mineral elements in common and durum wheat. IXth International colloquium for the optimization of plant nutrition. Prague, Czech Republic; 1996:279-282.

MOŻLIWOŚĆ WYKORZYSTANIA WYBRANYCH WSKAŹNIKÓW ROŚLINNYCH W OCENIE STOPNIA ZAOPATRZENIA W SIARKĘ ROŚLIN UPRAWNYCH

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Abstract: Przy ocenie stopnia zaopatrzenia roślin w składniki pokarmowe często wykorzystywane są wskaźniki roślinne. W przypadku siarki jest to: zawartość S ogółem, stosunek N:S, zawartość S-SO_4 oraz stosunek siarczanów do siarki ogółem. O wyborze najbardziej właściwego wskaźnika powinien w pierwszej kolejności decydować gatunek uprawianej rośliny. Stąd celem podjętych badań była próba oceny możliwości wykorzystania niektórych wskaźników roślinnych w ocenie stopnia odżywienia siarką roślin, uprawianych w warunkach zróżnicowanego odczynu gleby. Badania wykonano na podstawie dwóch serii ścisłych, dwuletnich doświadczeń wazonowych. Materiał glebowy pobrano z warstwy ornej gleby płowej o składzie granulometrycznym gliny lekkiej silnie spiaszczonej pylastej. Doświadczenie założono metodą kompletnej randomizacji i obejmowało ono 2 zmienne czynniki (dawka siarki, dawka wapna) na trzech poziomach. Nawożenie siarką w formie Na_2SO_4 i wapnowanie w postaci $CaCO_3$ zastosowano jednorazowo przed założeniem doświadczenia. Roślinami testowymi był rzepak jary, a po nim jęczmień jary (I seria doświadczalna) oraz gorczyca biała i owies (II seria doświadczalna). Przy doborze roślin brano pod uwagę ich potrzeby pokarmowe w stosunku do siarki oraz wrażliwość na zakwaszenie. Wyniki przeprowadzonych badań wskazują, że zastosowane czynniki doświadczalne wpływały na wartość wskaźników oceniających stan zaopatrzenia roślin w siarkę. Wśród rozpatrywanych wskaźników roślinnych, nawożenie siarką powodowało wyraźny wzrost zawartości siarki ogółem oraz siarczanowej, przy czym wzrost ten był znacznie wyższy w przypadku rzepaku i gorczycy. Aplikacja Na_2SO_4 wiązała się również z większym przyrostem ilości siarczanów w stosunku do siarki ogółem, co znalazło odzwierciedlenie we wzroście wartości proporcji S-SO_4 : $S_{og.}$. Miarodajnym wskaźnikiem, oceniającym stan zaopatrzenia roślin w siarkę, okazał się również stosunek N : S, który w roślinach z obiektów nawożonych siarką był wyraźnie mniejszy w porównaniu z wartościami stwierdzonymi w suchej masie roślin z serii kontrolnej (S_0).

Słowa kluczowe: wskaźniki roślinne, zawartość siarki ogółem i siarczanowej, stosunek siarczanów do siarki ogółem, stosunek N : S