

## Effect of different sources and doses of sulphur on yield, nutrient content and uptake by spring wheat

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### SUMMARY

*The objective of this study was to investigate the effect of two sulphur forms (sulphate and thiosulphate) in combination with three different N:S ratios on the yield of spring wheat and total N- and S-content and uptake by the aboveground biomass on chernozem and sandy soil. In the greenhouse experiment, the effects of two sulphur forms were compared: sulphate ( $\text{SO}_4^{2-}$ ) and thiosulphate ( $\text{S}_2\text{O}_3^{2-}$ ). The sulphate was applied as potassium-sulphate ( $\text{K}_2\text{SO}_4$ ) and thiosulphate as ammonium-thiosulphate ( $(\text{NH}_4)_2\text{S}_2\text{O}_3$ ). Increasing doses of both sulphur forms (24, 60, 120 kg S ha<sup>-1</sup>) were used with the same nitrogen dose (120 kg N ha<sup>-1</sup>) which caused three different N:S ratios background (1:0.2, 1:0.5, 1:1). Nitrogen was supplied in the form of monoammonium-phosphate (MAP), ammonium-nitrate and ammonium-thiosulphate. Plant samples were taken in three different development stages of spring wheat based on the BBCH scale: at the stage of BBCH 30–32 (stem elongation), BBCH 65–69 (flowering) and BBCH 89 (ripening). The total nitrogen and total sulphur content of plant at different development stages and also wheat grain were measured by Elementar Vario EL type CNS analyser. The nutrient uptake by plant and grain was calculated from the yield of spring wheat and the N and S content of plant. The grain yield on chernozem soil ranged between 6.31 and 12.13 g/pot. All fertilised treatments significantly increased the grain yield compared to the control. The highest yield was obtained in the case of the application of 120 kg N ha<sup>-1</sup> and 60 kg S ha<sup>-1</sup> in sulphate form. The grain yield on sandy soil varied from 2.53 to 6.62 g/pot. The fertilised treatments significantly enhanced the yield compared to the control. The highest yield was observed in the case of the application of 120 kg N ha<sup>-1</sup> and 60 kg S ha<sup>-1</sup> in thiosulphate form. On chernozem soil the increasing doses of sulphur (24, 60, 120 kg S ha<sup>-1</sup>) with the same N dose (120 kg N ha<sup>-1</sup>) increased the N-content of spring wheat at all development stages and in the grain. The treatments with different sulphur sources did not cause further changes in the N-content. On sandy soil in the most cases the N-content did not change significantly as a result of increasing sulphur doses. The treatments with sulphate form basically resulted higher nitrogen-content than treatments with thiosulphate form. The treatments with increasing sulphur doses resulted higher S-content on both of chernozem and sandy soil in the case of all development stage. Comparing the effect of the applied sulphur sources on the S-content it can be stated that at the stage of BBCH 30–31 and 65–69 the treatments with sulphate form resulted higher sulphur-content. At the stage of BBCH 89 there was no significant differences in S-content of grain as a result of different sulphur-sources.*

**Keywords:** sulphate; thiosulphate; spring wheat; yield; N-, S-content

### INTRODUCTION

Sulphur is an essential nutrient for plants. Proper sulphur supply has a positive effect on the vegetative growth of plants, increases green weight, modifies protein content, and influences the amount and proportion of protein-forming amino acids (Aula et al., 2019). Nitrogen plays a central role in plant productivity as well because it is a major component of amino acids, proteins, nucleic acids, and chlorophyll. Nitrogen promotes rapid growth, increases leaf size and quality, hastens crop maturity, and promotes seed development (Parsons and Tinsley, 1975). Nitrogen and sulphur are equally important protein components and the correct N:S ratio significantly contributes to grain quality as well as to optimal yield of crop plants (Klikocka et al., 2018).

More and more researchers indicate a positive effect of sulphur fertilisation on cereal crop production (Blake-Kalff et al., 2000; Zhao et al., 2006; Järvan et al., 2008). The positive response of cereal crops to sulphur fertilisation was caused by the fact that the initial levels of sulphur available for plants in soil were low (Olf et al., 2012). Many European countries are facing a problem of low plant-available sulphur levels

in soil due to the decreasing use of superphosphate and sulphate-containing fertilisers and the massive decrease in the inputs of S from atmospheric deposition (Schnug and Haneklaus, 1998; Messick et al., 2005). Insufficient levels of plant available sulphur in soil block the positive effect of nitrogen fertilisation – yield is not increasing, and the excessive amount of nitrogen which was not consumed by plants becomes an environmental pollutant (Jamal et al., 2010).

The S-containing fertilisers are available mostly in three chemical forms: sulphate ( $\text{SO}_4^{2-}$ ), elemental S ( $\text{S}^0$ ) and thiosulphate ( $\text{S}_2\text{O}_3^{2-}$ ) (Germida and Janzen, 1993; McGrath et al., 1996). Of these, the sulphate and elemental sulphur forms have received much more attention in terms of their chemical reactions in soils and availability of S to crops. Thiosulphate, especially ammonium thiosulphate can be used as sulphur fertiliser materials. Ammonium thiosulphate has the benefit of supplying both sulphur (26%) and nitrogen (12%) (Dick, 2008). However, thiosulphate reactions in soil have been slightly researched. A pot experiment by Janzen and Bettany (1986) presented that oxidation of  $\text{S}_2\text{O}_3^{2-}$  fertiliser was almost complete in 25 day, but because of the involvement of microorganisms in the process, some of the oxidised S was immobilised,



making it less available than the same amount of  $\text{SO}_4^{2-}$  in the short term. Most of the studies concerning  $\text{S}_2\text{O}_3^{2-}$  focus on its inhibitory effects on nitrification, urea hydrolysis and potential improvement of N efficiency (Janzen and Bettany, 1986; Sullivan and Havlin, 1992; Saad et al., 1996).

The objective of this study was to investigate the effect of two sulphur forms (sulphate and thiosulphate) in combination with three different N:S ratio (1:0.2, 1:0.5, 1:1) on the yield of spring wheat and total N- and S-content and uptake by the aboveground biomass on chernozem and sandy soil.

**MATERIALS AND METHODS**

The greenhouse pot experiment was conducted on two different soils: calcareous chernozem soil of Debrecen-Látókép and sandy soil with humus content of Pállag. The main parameters of experimental soils are shown in the *Table 1*.

*Table 1. The main parameters of experimental soils*

	Chernozem soil (Debrecen-Látókép)	Sandy soil (Pállag)
pH (KCl)	5.68	5.38
Hu%	3.11	1.00
K <sub>A</sub>	39	30
AL-P <sub>2</sub> O <sub>5</sub> (mg kg <sup>-1</sup> )	263.6	248.2
AL-K <sub>2</sub> O (mg kg <sup>-1</sup> )	180.0	278.0
KCl-SO <sub>4</sub> <sup>2-</sup> (mg kg <sup>-1</sup> )	4.98	6.43

The chernozem soil was well supplied with N, very well with P and poorly with K. The sandy soil was moderately supplied with N, adequate with P and very well with K. According to Brook (1979); Tiwari et al. (1985); Balanagaudar and Satyanlyana (1990) 10 mg kg<sup>-1</sup> in KCl extract is widely reported as critical limit for plant available sulphur in the soil. Based on these studies the sulphur content of our experimental soils is not sufficient for the plant development.

To establish the experiment, 10 kg of air dry soil was measured into the experimental pots. The indicator plant was the Stanga variety of spring wheat. The moisture content of soils was set up to 60% of the water holding capacity of the field. Pots were weighed daily and the missing water was supplemented with ion exchange water.

In the experiment, the effects of two sulphur forms were compared: the sulphate ( $\text{SO}_4^{2-}$ ) and the thiosulphate ( $\text{S}_2\text{O}_3^{2-}$ ). The sulphate was applied as potassium-sulphate ( $\text{K}_2\text{SO}_4$ ) and thiosulphate as ammonium-thiosulphate ( $(\text{NH}_4)_2\text{S}_2\text{O}_3$ ). Increasing doses of both sulphur forms (24, 60, 120 kg S ha<sup>-1</sup>) were used with the same nitrogen dose (120 kg N ha<sup>-1</sup>) which caused three different N:S ratios background (1:0.2, 1:0.5, 1:1). Nitrogen was supplied in the form of monoammonium-phosphate (MAP), ammonium-nitrate and ammonium-thiosulphate. The phosphorus and potassium needs of wheat were added MAP, KCl and  $\text{K}_2\text{SO}_4$ . The solid phase fertilisers were applied at the same time with sowing. There were 7 treatments with three replications and the treatment plan of the experiment is shown in the *Table 2*.

*Table 2. Rates of fertilisers applied in the pot experiment*

Number of treatment	N:S ratio	Sulphur forms	Nitrogen doses (g/10kg)	Sulphur doses (g/10kg)
1.	control	–	–	–
2.	1:0.2	SO <sub>4</sub> <sup>2-</sup>	0.4	0.08
3.	1:0.5	SO <sub>4</sub> <sup>2-</sup>	0.4	0.2
4.	1:1	SO <sub>4</sub> <sup>2-</sup>	0.4	0.4
5.	1:0.2	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	0.4	0.08
6.	1:0.5	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	0.4	0.2
7.	1:1	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	0.4	0.4

Plant samples were taken in three different development stages of spring wheat based on the BBCH scale: at the stage of BBCH 30–32 (stem elongation), BBCH 65–69 (flowering) and BBCH 89 (ripening).

Harvested plants were dried and dry biomass weights of wheat were determined. Dry samples were milled for the analysis. The total nitrogen and total sulphur content of plant at different development stages and also wheat grain were measured by Elementar Vario EL type CNS analyser. The nutrient uptake by plant and grain was calculated from the yield of spring wheat and the N and S content of plant.

For statistical analysis of experimental results IBM SPSS Statistics 22 and Microsoft Excel 2016 programs were used. The mean values of each treatment group were subjected to comparisons analysis using the One-Way ANOVA (significance level of p<0.05) with post hoc comparisons using Tukey test.

**RESULTS AND DISCUSSION**

**The dry biomass of spring wheat at different development stages**

On chernozem there were no significant effects on dry biomass of different sulphur forms and different N:S ratios (*Table 3*) at the stage of BBCH 30–32.



On sandy soil, greater biomass growth was observed compared to the biomass value of chernozem soil. On sandy soil, significantly higher biomass production was detected due to the treatments 2 (24 kg S ha<sup>-1</sup>) and 3 (60 kg S ha<sup>-1</sup>) compared to the control treatment. Analysing the effect of different sulphur

forms on biomass, the treatments with sulphate form tended to increase the dry biomass compared to the tiosulphate treatments. There were no significant variances between the different N:S ratio treatments, but there were visible some tendencies to the yield decrease with increasing S rate.

Table 3. The changes of dry biomass at different development stages of spring wheat

Treatment number	Sulphur forms	N:S ratio	BBCH 30–32 g/2 plants	BBCH 65–69 g/2 plants	BBCH 89 grain (g/pot)
<b>Chernozem soil</b>					
1.	–	control	0.24a	0.61a	6.31a
2.	SO <sub>4</sub> <sup>2-</sup>	1:0.2	0.30a	0.80a	12.04b
3.	SO <sub>4</sub> <sup>2-</sup>	1:0.5	0.25a	0.83a	12.13b
4.	SO <sub>4</sub> <sup>2-</sup>	1:1	0.26a	0.72a	10.53b
5.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:0.2	0.34a	0.71a	10.03b
6.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:0.5	0.29a	0.93a	10.53b
7.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:1	0.28a	0.69a	10.01b
<b>Sandy soil</b>					
1.	–	control	0.17a	0.27a	2.53a
2.	SO <sub>4</sub> <sup>2-</sup>	1:0.2	0.54c	0.64ab	6.10b
3.	SO <sub>4</sub> <sup>2-</sup>	1:0.5	0.51bc	0.60ab	6.24b
4.	SO <sub>4</sub> <sup>2-</sup>	1:1	0.40abc	0.63ab	5.37ab
5.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:0.2	0.35abc	0.80b	6.45b
6.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:0.5	0.28ab	0.72ab	6.62b
7.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:1	0.22a	0.62ab	6.31b

Note: Data marked with the same letter is not significantly different at the significant level of  $p < 0.05$

At the stage of BBCH 65–69, the treatments with different N:S ratio and the applied sulphur sources did not cause any significant differences in the dry biomass on chernozem soil.

On sandy soil, the fertilised treatments tended to increase the dry biomass production, but only at treatment 5 was achieved statistically higher value compared to the control treatment. In addition, there was no significant effect in the case of application of the sulphur forms or the different N:S ratio treatments.

Analysis of the results of Table 3 showed a significant beneficial effect of N and S fertilisation on the grain yield of spring wheat on both of chernozem and sandy soil.

The grain yield on chernozem soil ranged between 6.31 and 12.13 g/pot. All fertilised treatments significantly increased the grain yield compared to the control. The highest yield was obtained in the treatment 3, in the case of the application of 120 kg N ha<sup>-1</sup> and 60 kg S ha<sup>-1</sup>. In a study by Podleśna (2013), S fertilisation of winter wheat at a rate of 60 kg S ha<sup>-1</sup> led to a significant increase as well in grain yield. A study led by Fotyma (1990) on fertilisation of spring wheat with S showed too that the application of 60 kg S ha<sup>-1</sup> increased grain yield. He claims that S indirectly increases crop yield by influencing N transformation in the plant. Comparing the effect of sulphur forms on grain yield, a little bit higher yield was observed in the case of application of sulphate. Sangwan et al. (2018) came to the similar conclusion, in their study the yield-

enhancing effect of K<sub>2</sub>SO<sub>4</sub> was observed. The different N:S ratio treatments did not cause significant effect on grain yield.

The grain yield on sandy soil varied from 2.53 to 6.62 g/pot. The fertilised treatments significantly enhanced the yield compared to the control. The highest yield was observed in the case of the application of 120 kg N ha<sup>-1</sup> and 60 kg S ha<sup>-1</sup> in thiosulphate form. However, there were no significant differences between the treatments with different sulphur forms, but a slight increment was observed due to the treatment with tiosulphate form. Furthermore, the applied N:S ratios did not cause any significant differences in the grain yield.

On both the chernozem and sandy soil, a grain yield-reducing effect was observed in the case of application of the highest sulphur doses (120 kg S ha<sup>-1</sup>).

#### The changes of total N and total S content of spring wheat at different development stages

Based on the result of Table 4, the total N-content of spring wheat at the stage of BBCH 30–31 on chernozem soil varied from 3.607% to 4.404%. Very similar values were determined in spring red wheat by Reussi et al. (2008), in their experiment the N-content of plant at the stage of BBCH 30–31 ranged from 3.72% to 4.61%. Analysing the effect of the two sulphur forms, the sulphate form slightly increased the N% compared to treatments with the tiosulphate.

Statistically proved differences between the applied N:S ratios were not found, however the increasing sulphur doses tended to increase the N%.

The total S-content of spring wheat ranged between 0.358% and 0.543%. The maximum S-value was observed in control treatment. In this development stage the fertilised treatment decreased the S%, which

can be explained by the phenomenon as the effect of dilution. Considering the different sulphur forms, significantly higher S-concentration was determined in the case of treatment with sulphate form application. There were no significant differences between the studied N:S ratio treatments, but a slight increment was observed as a result of the increasing sulphur doses.

Table 4. Total N and total S content of spring wheat at different development stages

Treatment number	Sulphur forms	N:S ratio	BBCH 30–31 whole plant		BBCH 65–69 leaves		BBCH 89 grain	
			N%	S%	N%	S%	N%	S%
<b>Chernozem soil</b>								
1.	–	control	4.211b	0.543d	1.701a	0.369cd	1.824ab	0.153a
2.	SO <sub>4</sub> <sup>2-</sup>	1:0.2	4.050ab	0.446bc	2.165b	0.296bc	1.732a	0.159a
3.	SO <sub>4</sub> <sup>2-</sup>	1:0.5	4.332b	0.490cd	2.260b	0.437de	1.885b	0.164a
4.	SO <sub>4</sub> <sup>2-</sup>	1:1	4.404b	0.494cd	2.219b	0.456e	2.020c	0.172a
5.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:0.2	3.607a	0.358a	2.300b	0.198a	1.915bc	0.169a
6.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:0.5	3.952ab	0.376ab	2.368b	0.219ab	1.920bc	0.176a
7.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:1	4.013ab	0.392ab	2.399b	0.297bc	1.941bc	0.180a
<b>Sandy soil</b>								
1.	–	control	2.139a	0.475d	1.209a	0.214ab	2.232a	0.204ab
2.	SO <sub>4</sub> <sup>2-</sup>	1:0.2	3.433b	0.358a	1.888c	0.246b	2.275ab	0.220abcd
3.	SO <sub>4</sub> <sup>2-</sup>	1:0.5	4.079d	0.439c	1.682bc	0.355c	2.711c	0.244d
4.	SO <sub>4</sub> <sup>2-</sup>	1:1	4.218e	0.452cd	1.636bc	0.403c	2.648bc	0.229bcd
5.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:0.2	4.017cd	0.344a	1.567b	0.180a	2.127a	0.198a
6.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:0.5	3.990c	0.367a	1.614bc	0.189a	2.212a	0.214abc
7.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:1	4.000cd	0.392b	1.630bc	0.220ab	2.463abc	0.234cd

Note: Data marked with the same letter is not significantly different at the significant level of p<0.05

The N-content of spring wheat on sandy soil, as expected, was lower than N-content of plant on chernozem soil, its value ranged between 2.139% and 4.218%. All fertilised treatment significantly increased this value. Analysing the effect of different sulphur forms, higher N-concentration was observed in the case of application of sulphate form with higher sulphur rates (treatment 3, 4). Comparing the effect of treatment with different N:S ratio, significantly higher N-content was measured with increasing sulphur doses, but this increment was observed only by using the sulphate form.

The variations of sulphur content of spring wheat on sandy soil (0.344–0.475%) showed the same tendencies as the changes on the chernozem soil.

The nitrogen-content of plants ranged between 1.701 and 2.399% in all treatments at the stage of BBCH 65–69 on chernozem soil. The fertilised treatments significantly increased the N-content of spring wheat compared to the control. Analysing the effect of the applied sulphur forms and the treatments with different N:S ratios, there were no further changes in the N-content.

The total sulphur-content of spring wheat varied from 0.198 to 0.456% in all treatments. At this development stage, the treatments with sulphate form resulted significantly higher sulphur-content than treatments with thiosulphate form. The treatments with

increasing sulphur doses had also significant effect on sulphur-content, higher sulphur-content was observed with higher sulphur rates.

On sandy soil, the total N-content ranged between 1.567 and 1.888%. Significant enhancement in N-content was found in all fertilised treatments. The treatments with sulphate form resulted higher N-content than the treatments with thiosulphate S-source. The applied N:S ratios did not change significantly these values, however the increasing sulphur doses of the used sulphur forms influenced the N-content differently, which means the increasing doses of sulphate form decreased, while the increasing level of thiosulphate form slightly increased the N-content.

The total sulphur content varied from 0.180 to 0.403%. In general, the increasing sulphur doses enhanced this value. Examining the differences between the applied sulphur sources it can be established that the treatments with sulphate form resulted significantly higher sulphur-content.

The concentration of total N in wheat grain on chernozem soil varied from 1.732 to 2.020%. Klikocka et al. (2017) estimated higher values (2.54–2.88%) in their experiment with spring wheat. Similar values (2.33–2.88%) were obtained by Reussi et al. (2011), who also conducted experiments with spring wheat to determine sulphur deficiency. In our experiment the highest value was found after the application of 120 kg



S ha<sup>-1</sup> in sulphate form (treatment 4). The effect of increasing sulphur doses on N-content prevailed only in the case of application of sulphate forms. In studies of Martin (1997) and Reussi et al. (2011), the increasing level of sulphur increased noticeably the N content in grains of wheat.

The total sulphur-content of spring wheat grain ranged between 0.153% and 0.180%. In studies of Klikocka et al. (2017), lower sulphur content of spring wheat grain was measured (0.124–0.140). In our experiment, the sulphur content of grain was all similar and not significantly different from the unfertilised control. However, several works carried on different crops, determined increase in grain S concentration by S fertilisation (Moss et al., 1981; Prystupa et al., 2006; Zhao et al., 2006). The lack of response at fertilised treatments, which by the way showed yield increase by S addition, could be explained by the late contribution of S through mineralization, thus enabling right S concentrations at crop.

The nitrogen-content of wheat grain on sandy soil (2.127 and 2.711%) was higher than on chernozem soil, which can be describe as a result of higher biomass

production on chernozem soil. The content of N in the spring wheat grain significantly increased by the rate of 60 kg S and 120 kg S ha<sup>-1</sup> in the case of application of sulphate form, however the highest content of N was found after the application of 60 kg S ha<sup>-1</sup> (treatment 3). In general the increasing sulphur doses resulted higher N-content and the treatments with sulphate increased the N-content compared to the treatments with thiosulphate form.

On sandy soil, the sulphur content of grain ranged between 0.198% and 0.244% Significantly higher value was observed at the treatment 3 (60 kg S ha<sup>-1</sup>). The effect of increasing sulphur doses prevailed only in the case of application of thiosulphate form, where the increasing sulphur levels enhanced the sulphur content of grain.

**The changes of N- and S-uptake by spring wheat at different development stages**

The N- and S-uptake by spring wheat (Table 5) at the stage of BBCH 30–31 on chernozem soil did not change significantly with the application of different treatments.

Table 5. The changes of uptake of N and S by spring wheat at different development stages

Treatment number	Sulphur forms	N:S ratio	BBCH 30–31 whole plant (mg/2plants)		BBCH 69 leaves (mg/2plants)		BBCH 89 grain (mg/pot)	
			N-uptake	S-uptake	N-uptake	S-uptake	N-uptake	S-uptake
<b>Chernozem soil</b>								
1.	–	control	10.23a	1.33a	10.21a	2.22abc	114.8a	9.75a
2.	SO <sub>4</sub> <sup>2-</sup>	1:0.2	12.08a	1.38a	17.32ab	2.37abc	208.6b	18.97b
3.	SO <sub>4</sub> <sup>2-</sup>	1:0.5	10.84a	1.23a	18.86ab	3.67c	228.7b	19.91b
4.	SO <sub>4</sub> <sup>2-</sup>	1:1	11.31a	1.20a	15.27ab	3.16bc	212.1b	18.24b
5.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:0.2	12.17a	0.94a	16.10ab	1.39a	193.0b	16.82b
6.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:0.5	11.44a	1.32a	21.97b	2.03ab	202.2b	18.52b
7.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:1	11.25a	1.11a	16.87ab	2.07abc	194.2b	17.94b
<b>Sandy soil</b>								
1.	–	control	3.69a	0.82a	3.11a	0.56a	56.5a	5.16a
2.	SO <sub>4</sub> <sup>2-</sup>	1:0.2	18.40cd	1.91cd	11.84b	1.55ab	138.4b	12.37b
3.	SO <sub>4</sub> <sup>2-</sup>	1:0.5	20.83d	2.25d	10.61b	2.24bc	168.8b	12.57b
4.	SO <sub>4</sub> <sup>2-</sup>	1:1	17.01bcd	1.82bcd	10.27b	2.54c	140.9b	12.33b
5.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:0.2	13.94bcd	1.19abc	12.37b	1.45ab	137.1b	13.50b
6.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:0.5	11.37abc	1.05abc	11.28b	1.19a	146.7b	14.20b
7.	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	1:1	8.72ab	0.85ab	10.70b	1.40b	154.7b	14.69b

Note: Data marked with the same letter is not significantly different at the significant level of p<0.05

On sandy soil, greater variations were observed in the N- and S-uptake by spring wheat. Application of N and S fertilisers increased the N- and S-uptake by the plant. In the case of both nutrient uptakes, the lowest value was found in the control treatment and the maximum uptake was calculated in treatment 3 (120 kg N and 60 kg S ha<sup>-1</sup>). In the treatments with sulphate form, higher N-and S-uptake were detected than in the treatments with thiosulphate. The increasing doses of sulphur had no significant effect on the nutrient uptake.

At the stage of BBCH 65–69 on chernozem soil, the N- uptake by wheat was tended to be higher in all fertilised treatments, however, the highest uptake of N by wheat was found after the application of 120 kg N and 60 kg S ha<sup>-1</sup> (treatment 6). Furthermore, no significant differences were determined on uptake by N as effect of N and S addition.

In the case of uptake of sulphur, the maximum value was determined as a result of 120 kg N and 60 kg S ha<sup>-1</sup> addition (treatment 3). The treatments with sulphate form resulted higher sulphur-uptake by spring



wheat than treatments with thiosulphate form. In addition, there were no significant differences between the applied N:S ratio treatments.

On sandy soil, the nutrient uptake by plant was lower than on chernozem soil. All fertilised treatments increased the N- and S-uptake by spring wheat compared to the unfertilised pots, but in the case of N-uptake there was no further effect between the applied treatments. At treatments 3, 4 and 7, significant increase in S-uptake was determined as a result of N and S addition. Analysing the effect of two sulphur sources, the treatments with sulphate form were more effective than the treatments with thiosulphate and the effect of increasing sulphur doses only prevailed in the case of application of sulphate form.

The uptake of N and S by the wheat grain on chernozem soil significantly increased together with the S and N application and were the highest following the application of 120 kg N and 60 kg S ha<sup>-1</sup> (treatment 3). Howarth et al. (2008) observed this effect, too, namely that S fertilisation increased uptake of S by grain. The various sources of sulphur did not show any significant improvement in sulphur and nitrogen uptake by wheat grain, however a little bit higher uptake of nutrients was recorded in the case of application of sulphate form. Sangwan et al. (2018) investigated the effect of different sulphur forms (elemental sulphur, gypsum, potassium sulphate and pyrite) on the nutrient uptake of wheat in a pot experiment and they came to similar conclusion, too. In their experiment, the treatments with potassium sulphate resulted the highest uptake of sulphur and nitrogen. The uptake of sulphur and nitrogen was not significantly influenced by the increasing level of sulphur.

The interaction between the increasing sulphur level and the applied S- sources resulted significant increase in sulphur and nitrogen uptake by spring wheat grain on sandy soil as well. However, further variances between the fertilised treatments were not observed, but there were visible some tendencies. In the case of N-uptake, the highest value was observed in the treatment 3 (120 kg N and 60 kg S ha<sup>-1</sup>), and it can also be observed that the treatments with sulphate form resulted a little bit higher nitrogen-uptake. In contrast, the sulphur uptake was tended to be higher in the case of application of thiosulphate form and with increasing level of thiosulphate higher sulphur uptake was observed.

## CONCLUSIONS

In the greenhouse pot experiment the effects of fertilisation with two sulphur sources (sulphate and

thiosulphate) with different N:S ratio background were investigated on yield and nutrient content and uptake by spring wheat on chernozem and sandy soil. It is clearly prevailed that different sources and rates of S application all affect seed yield, nutrient content and uptake by spring wheat.

On both chernozem and sandy soil, the maximum yield was observed in the case of application of 120 kg N and 60 kg S ha<sup>-1</sup> with N:S=1:0.5 background. On chernozem soil, this effect was achieved with sulphate-S form and on sandy soil with thiosulphate form.

In general, it can be concluded that on chernozem soil the increasing doses of sulphur (24, 60, 120 kg S ha<sup>-1</sup>) with the same N dose (120 kg N ha<sup>-1</sup>) increased the N-content of spring wheat at all development stages and in the wheat grain. The treatment with different sulphur sources did not cause further changes in the N-content.

On sandy soil, in the most cases the N-content did not change significantly as a result of increasing sulphur doses. The treatments with sulphate form basically resulted higher nitrogen-content than treatments with thiosulphate form.

The treatments with increasing sulphur doses resulted higher S-content on both of chernozem and sandy soil in the case of all development stage. Comparing the effect of the applied sulphur sources on the S-content, it can be stated that at the stage of BBCH 30–31 and 65–69 the treatments with sulphate form resulted higher sulphur-content, because at these development stages the thiosulphate may not have been available yet to the plant (thiosulphate should be oxidised first to be taken up by plant). However, at the stage of BBCH 89 there were no significant differences in S-content of grain as a result of different sulphur-sources.

At the stage of BBCH 30–31, the applied treatments influenced the N-and S-uptake by wheat only on sandy soil. The treatments with sulphate form resulted higher nutrient uptake, but the increasing sulphur doses had no effect on these values. At the stage of BBCH 65–69 on both of chernozem and sandy soil, the fertilised treatments did not influence significantly the N-uptake by wheat. The S-uptake was higher as a result of treatments with sulphate form, but the treatments with increasing sulphur doses did not change the uptake by sulphur.

On both chernozem and sandy soil, there was no significant differences in the nutrient uptake by wheat grain as a result of increasing doses of sulphur and the different sulphur sources.

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