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The effect of sulphur fertilisation on yield and technological parameters of spring wheat grain

ABSTRACT. The objective of the present study was to estimate the effect of elementary sulphur and of other sulphur fertilisers on the yield and qualitative parameters of spring wheat. This topic was studied in the form of a pot trial in a vegetation hall in 2003. Each pot was filled with 6 kg of a mixture of fluvisoil and sand, pH 6.9; content of available P 83; K 103 (with additional fertilising to 171); Ca 2058; Mg 184; total water-soluble sulphur 22 and sulphur sulphate 18 mg kg^{-1}. The following variants were applied in the trial: 1. Control. 2. Elementary sulphur applied into the soil. 3. Ammonium sulphate. 4. Pregips H gypsum. 5. Foliar application of elementary sulphur. Basic fertilisation consisted of an application of 0.61 g of nitrogen and 0.24 g of sulphur per pot, with the exception of the last variant, where two foliar doses of elementary sulphur were applied, i.e. 0.026 and 0.019 g of S per pot in DC 31 DC 57, respectively. The results were evaluated by means of variance analysis, and Tukey's test was used for subsequent tests of significance of differences among the variants. The results of the one-year vegetation pot trial where various fertilisers containing sulphur were applied to spring wheat can be summarised as follows: Applications of elementary sulphur resulted in the highest grain yields; In the variant where elementary sulphur was applied to the soil the uptake of nitrogen by the grain was the highest and the exploitation of nitrogenous fertilisers was the best; The content of sulphur in the grain as the requirement for good baking quality was insufficient and the best results were achieved after foliar application of elementary sulphur; Compared to the standard, the content of nitrogenous substances was low, and was the highest in the variant where Pregips H gypsum was applied; The falling number was above 400 s signalising a low specific volume of bakery products and a dry and crumbly crumb; Applications of ammonium sulphate gave the best results in terms of the 1000-grain weight and proportion of grain over 2.5 mm on the sieve; The application of elementary sulphur into the soil did not reduce the soil pH and after harvest provided the highest supply of available sulphur in the soil.

KEY WORDS: spring wheat, fertilisers containing sulphur, elementary sulphur, yields, grain quality

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In the past most of the demands of agricultural crops for sulphur had been covered by atmospheric depositions. However, in 2001 these depositions in the Czech Republic were reduced to 13.6% of the situation in 1990; in 2002 it was only 14.5 kg of S per ha [Czech Statistical Office 2004]. This rapid drop was the main reason why the use of sulphur-containing fertilisers has increased so much.

On a worldwide scale and also in the Czech Republic the most frequently used fertiliser containing sulphur is ammonium sulphate with a 24% content of S [Ceccotti et al. 1998]. An important source of sulphur in the Czech Republic used to be elementary superphosphate, which contained 8–12% of S, and which has now virtually disappeared from the market. Due to its high price also the once used potassium sulphate (18% of S) is now applied only to a limited extent. On the other hand, we see the comeback of gypsum (12-18% of S), which had been recommended as early as the 19th century [Duchoň 1948].

Side by side with conventional mineral fertilisers containing sulphate ions also elementary sulphur (80–99%) is gaining ground. It is an ideal slow-action fertiliser and is not water-soluble; before uptake and utilisation in the plant it has to be oxidised to water-soluble sulphate [Blair 2002]. During foliar application it is also oxidised by bacteria of the genus *Thiobacillus* on the leaf surface or inside the leaf by specific enzymes of chloroplasts [Jolivet 1993]. The condition for its wider use as a fertiliser is based on the reduction of the limit content of sulphur in fuel (binding EU rule of law) from the present 350 mg kg^{-1} to 50 mg kg^{-1} in 2005, and/or 10 mg kg^{-1} in 2008.

The objective of the present study was to estimate the effect of elementary sulphur and other sulphur fertilisers on the yield and qualitative parameters of spring wheat.

METHODS

Sulphur fertilisation and its effect on the yield and technological parameters of grain of spring wheat was explored in 2003 in the vegetation hall of the Department of Agrochemistry and Plant Nutrition, Mendel University of Agriculture and Forestry in Brno. The locality Brno – Černá Pole lies at the altitude of 230 m, latitude 49°13’01’’, longitude 16°36’50’’, mean annual temperature +8.4°C, mean annual precipitation 531 mm and mean sunshine 1860 hours a year. It is a warm region, climate region A3 (warm, moderately dry, with mild winter).

Studies were conducted in the form of a vegetation pot trial. Prior to sowing, Mitscherlich’s pots were filled with 6 kg of a soil mixture from the School Farm in Žabčice (moderately heavy gley fluvisoil) and sand (from Bratčice) in a 2/1 ratio. Table 1 shows the agrochemical properties of the mixture.

Table 1. Agrochemical properties of the soil/sand mixture

Mixture of soil/sand	pH KCl	Content of available elements					
		P	K	Ca	Mg	S in water-soluble	SO_4-S
		mg kg^{-1}					
2/1	6.9	83	103	2058	184	21.6	18.3

The exchangeable soil reaction was assessed in the extract 0.2 mol KCl and the content of P, K, Ca and Mg using the Mehlich III method [Zbíral 1995]. The resulting values showed that the soil reaction was neutral, the supply of available P and K satisfactory, the supply of available Mg good and of available Ca high.

The purpose of mixing soil with sand was to reduce the content of available nutrients, particularly phosphorus and potassium. Their supply was additionally modified to the lower limit of category "good" [Annex No. 5 of the Regulation of the Czech Ministry of Agriculture No. 275/1998 of the Collection of Laws of the Czech Republic], i.e. 81 mg kg^{-1} of P and 171 mg kg^{-1} of K, for medium soil by basic pre-sowing fertilisation with 68.2 mg kg^{-1} of potassium in a KCl solution. Phosphorus on the lower limit of category "good" had been reduced after dilution of the soil with sand.

Basic fertilisation also included an application of nitrogen in DAM 390 and fertilisation with sulphur in various forms, but in a uniform dose of 40 mg of S per 1 kg of soil (Tab. 2), with the exception of variant 5.

Spring wheat cultivar 'Aranka', was sown out on 23 April 2003, i.e. 30 kernels per pot; on 12 May the pots were thinned to 20 plants per pot.

In variant No. 5 the micronised elementary sulphur was applied on two dates, on 23 May in the stage of the first nodule (DC 31) and on 13 June in the stage of heading (DC 57), in the form of spraying 8 kg ha^{-1} (0.026 g of S per pot) and 6 kg ha^{-1} (0.019 g of S per pot), respectively, according to the instructions of the manufacturer.

Table 2. Chart of the trial

Variant No.	Design	Dose of N g pot^{-1}
1	Control	0.61
2	Elementary sulphur	0.61
3	Ammonium sulphate (AS)	0.4 (0.21 already in AS)
4	Pregips H	0.61
5	Foliar elementary sulphur	0.61

Note: Elementary sulphur – sublimed sulphur (99.8% S). Ammonium sulphate (21% N, 24% S). Pregips H – gypsum (14% S, 18% Ca). Foliar application of elementary sulphur – dispersed microgranulate of elementary sulphur forming a suspension (80% S).

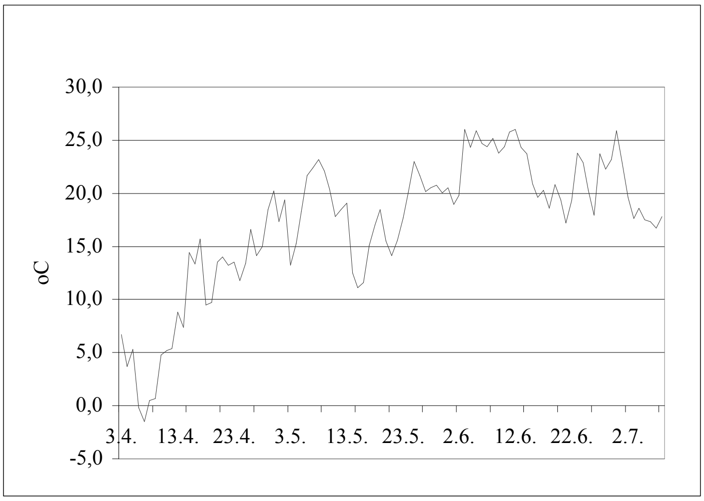

Figure 1. Course of mean daily temperatures during spring barley vegetation in 2003 (Brno–Černá Pole)

The trial pots were weed-free; regular watering to ca 60% of the maximal water capacity provided sufficient moisture of the soil/sand mixture. In terms of the weather conditions the vegetation of spring wheat was most affected by the temperature (Fig. 1).

On 19 May the stand was treated with the Falcon 460 EC fungicide against *Erysiphe graminis* , *Puccinia* and *Septoria nodorum* and on 28 May and 5 June with the Karate 2,5 WG insecticide against *Lema, Oscinella frit* and *Aphidoidea* .

The plants were harvested on 18 July in the stage of full maturity. After complete drying the aboveground matter was weighed, the ears were separated from the stems and the grain was threshed on the KMP 2 spike laboratory thresher. At harvest the number of productive shoots, i.e. the number of ears, grain and straw yields, was evaluated. The following grain parameters were evaluated: the starch content according to Ewers, the protein content according to Kjeldahl, the sulphur content, proportion of grain above 2.5 on the sieve (Steinecker's screen), the falling number and 1000-grain weight. The total uptake of nitrogen by grain and straw and the effectiveness of nitrogenous fertilisation were evaluated. After harvest the value of exchangeable soil reaction in the soil/sand mixture was explored and also the content of available nutrients, particularly sulphur. Multi-factor analysis of variance was used to evaluate the yield and technological parameters of the grain, applying Unistat version 5.1 software; successive tests were performed with Tukey's test of significance of differences using the programme Statgraphics version 4.0.

RESULTS

Table 3 and Table 4 summarise the statistically processed yield and qualitative parameters of spring wheat. The first shows the analysis of variance, i.e. the significance of application of various sulphur fertilisers, the other shows the mean values of the parameters in the respective variants of fertilisation and the significance of differences.

One of the essential yield-forming elements, the number of ears, was not markedly influenced by the applied fertilisers. The spring wheat produced virtually no tillers and so the numbers of ears per pot were almost the same as the number of plants.

The grain and straw yields were not significantly affected by the variants of fertilisation either. Grain yields were the highest in the variant fertilised with elementary sulphur in the soil; in the case of straw yields in the variant of foliar applications of elementary sulphur. Nuttall et al. [1993] also studied the positive effect of elementary sulphur on the yields of spring wheat grain. Similarly, Kuligod et al. [1994] proved that yields increased by 18% after the application of 30 kg of elementary S per ha. On the basis of field trials with ammonium sulphate, elementary sulphur and gypsum, Mitchell and Mullins [1990] recommended foliar applications of at least 22 kg of S per ha at the end of the tillering stage (DC 29). The conclusions of Griffiths et al. [1995] correspond with our results; after foliar application of elementary sulphur they did not achieve a significant effect on grain yields.

Apart from the results of yields it is interesting to explore the uptake, and/or utilisation of nitrogen after the application of various sulphur fertilisers. The uptake of nitrogen alone does not show significant differences among the respective variants; the highest values were achieved in the variant where elementary sulphur was applied in the soil. When expressing the uptake of nitrogen by grain and straw we can deduct the efficiency of the applied nitrogenous fertilisation 0.61 g of N per pot (Tab. 5).

The table shows that N uptake by grain and straw was higher in the sulphur-applied variants and that the utilisation of applied nitrogen increased to 96.8% in the elementary sulphur variant. These results correspond with the conclusions of Schnug et al. [1993]; see Table 6, and Tandon [1992], who reported that a sufficient dose of S increased N utilisation.

Sulphur does not affect only nitrogen utilisation and grain quality, but it also plays an important part in the formation of the baking quality [Wrigley et al. 1984; Rendig 1986; Laurent et al. 1992]. Sulphur deficit may result in harder grain; the dough made from such grain is usually stuff and is not elastic [Moss et

Table 3. Variance analyses of the respective parameters

Source of variability	ddf	Mean square									
		Number of ears per pot	Grain yields g pot^{-1}	Straw yields g pot^{-1}	Content of N-substances %	Falling number s	Starch content %	Thousand-grain weight g	Proportion of full grain >2.5 mm %	S content in grain %	N uptake by grain g pot^{-1}
Variant of experiment	4	0.55 ns	5.49 ns	2.17 ns	0.19 ns	530.4 **	0.42 ns	10.43 **	9.36 ns	$2.74 \cdot 10^{-5}$ ns	$8.81 \cdot 10^{-4}$ ns
Error	15	0.20	3.53	3.31	0.12	18.2	0.14	1.48	6.23	$1.97 \cdot 10^{-5}$	$8.62 \cdot 10^{-4}$
Total	19										

Note: ns not significant, *$\alpha \leq 0.05$, ** $\alpha \leq 0.01$

Table 4. Mean and significance of differences between the variants

Variant of experiment	n	Number of ears per pot	Grain yields g pot^{-1}	Straw yields g pot^{-1}	Content of N-substances %	Falling number s	Starch content %	Thousand-grain weight g	Proportion of full grain >2.5 mm %	S content in grain %	N uptake by grain g pot^{-1}
Control	4	20.25 a	27.58 a	29.45 a	9.39 a	449.0 b	72.45 a	35.78 a	92.15 a	0.110 a	0.454 a
Elementary sulphur	4	20.25 a	28.74 a	28.29 a	9.63 a	450.5 b	71.84 a	38.20 ab	94.33 a	0.112 a	0.485 a
Ammonium sulphate	4	19.75 a	26.97 a	29.45 a	9.82 a	457.0 b	72.08 a	39.70 b	96.76 a	0.111 a	0.465 a
Pregips H	4	20.75 a	25.51 a	29.20 a	9.98 a	457.0 b	71.68 a	38.08 ab	94.57 a	0.114 a	0.446 a
Foliar applications of elementary S	4	20.50 a	26.89 a	30.35 a	9.65 a	425.0 a	71.49 a	36.15 a	92.94 a	0.116 a	0.455 a

Note: Different letters indicates significant different between mean at $\alpha \leq 0.05$

al. 1981]. Therefore, the content of S in the grain is crucial. In the analysed grain the content ranged between 0.11 and 0.12%, and according to McGrath et al. [1993], and Schnug and Haneklaus [1998] in this case the content of sulphur was insufficient. The S content was the highest (0.116%) in the variant where foliar applications of elementary sulphur were provided.

The criteria of the quality of wheat grain for food are limited by the Czech standard [ČSN 461100-02]. An important indicator of the quality is the content of protein, or N-substances. Due to the unfavourable course of temperatures during grain formation (Fig. 1), to nitrogen nutrition applied merely in the form of basic fertilisation and due to the stress of plants grown in vegetation pots, the limits of this standard, i.e. a minimum of 12% of N-substances, were not achieved. Under relative comparisons there was no significant effect of the fertilisation on the content of N substances; the highest value, i.e. 9.98%, was achieved after the application of the Pregips H gypsum.

Table 5. The effect of sulphur application on nitrogen utilisation

Variant No.	Design	N uptake		Net use of fertiliser N %
		grain	straw	
		g pot^{-1}		
1	Control	0.444	0.104	89.8
2	Elementary sulphur	0.485	0.105	96.8
3	Ammonium sulphate	0.464	0.105	93.3
4	Pregips H	0.446	0.108	90.8
5	Foliar elementary sulphur	0.455	0.106	92.0

Table 6. The effect of sulphur application on nitrogen utilisation [Schnug et al. 1993]

Design	N uptake		Net use of fertiliser N %
	grain	straw	
	kg ha^{-1}		
Control	107	26.4	67
Elementary sulphur	114	28.5	72
Sulphate sulphur	125	31.1	79

Another criterion of the standards is the falling number. In the present experiment this number ranged between 425 s and 457 s and was significantly the lowest after foliar application of elementary sulphur. All the values soared above the minimum value specified in the standard, i.e. 160 s, or 240 s. At the same time, however, they exceeded 400 s and bakery products made from such grain would have a lower specific volume and the crumb would be dry and crumbly [Fencík 1998].

Along with the amylolytic activity of the grain given by the falling number, also the absolute content of starch was evaluated; the values were balanced.

The last qualitative parameter was the 1000-grain weight and the proportion of full grain above 2.5 mm on the sieve. The significantly highest 1000-grain weight was achieved after the application of ammonium sulphate. This variant also had the highest proportion of grain larger than 2.5 mm on the sieve (96.76%) but this result was not statistically significant.

Table 7. Agrochemical soil properties after harvest of spring wheat

Variant No.	Design	pH $CaCl_2$	Element					
			P	K	Ca	Mg	S in water-solub.	SO_4-S
			kg ha^{-1}					
1	Control	7.06	79.1	136.8	2533	209.3	41.4	30.0
2	Elementary sulphur	7.11	80.9	104.3	2383	203.1	62.2	48.3
3	Ammonium sulphate	7.10	79.1	130	2649	225.4	55.3	46.7
4	Pregips H	7.20	76.3	122.9	2771	224.5	50.1	38.3
5	Foliar elementary sulphur	7.18	75.4	126.2	2161	192.5	30.3	30.0

In connection with the application of elementary sulphur a number of authors [Finck 1982; Eriksen et al. 1998; Richter et al. 1999] reported a marked decrease in the soil reaction. From Table 7 it is evident that the value of exchangeable soil reaction (pH in $CaCl_2$) was not considerably affected and ranged between 7.06 in the controls to 7.20 in the variant where the Pregips H gypsum was applied.

When evaluating the content of available S (total water-soluble S or only sulphate) it can be concluded that the supply of sulphur available for the successive crop was the highest in the variant where elementary sulphur was applied into the soil and in the variant where ammonium sulphate was applied. By contrast, the lowest amount of sulphate sulphur was available in the control variant and in the variant with foliar application of S.

CONCLUSION

1. The highest grain yield was achieved after the application of elementary sulphur.

2. The variant with elementary sulphur applied to the soil resulted in the highest uptake of nitrogen by the grain and the best utilisation of nitrogenous fertilisers.

3. The content of sulphur in the grain, as a condition of good baking quality, was insufficient and the highest values were achieved after foliar application of elementary sulphur.

4. Compared to the standard the content of nitrogenous substances was low and the highest value was achieved in the variant where Pregips H was applied.

5. The falling number ranged above 400 s, signalising a low specific volume of the bakery products and a dry and crumbly crumb.

6. The best 1000-grain weight and proportion of full grain above 2.5 mm over the sieve was achieved in the variant applying ammonium sulphate.

7. The application of elementary sulphur into the soil did not reduce the soil reaction and produced the highest supply of available sulphur in the soil after harvest.

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