

Effect of Sulphur Fertilization on Yield and Quality of Wheat Grain

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The influence of sulphur fertilization on plant dry weight, grain yield and quality of wheat grain (var. *Mulan*) was investigated. Wheat was grown in the small plot field experiments conducted in 2011–2012. At the beginning of tillering, the regenerative sulphur fertilization increased dry plant weight and sulphur concentration in dry matter by 28.1–43.2%. Sulphur application reduced the number of unproductive tillers and increased the number of ears per unit area by 10–70%. The highest grain yield was achieved after the application of solid fertilizers YaraBela SULFAN and fertilizer YaraVita Thiotrac applied in the late growing stages. Sulphur fertilization slightly improved the values of grain specific weight, protein content and Zeleny sedimentation volume, but the effect was not significant. The effect of fertilizer application significantly differed between the studied years.

Keywords: *Triticum aestivum* L., sulphur, fertilization, grain, quality

Introduction

Yield and bread-making quality of wheat grain is influenced by the growing conditions, genotype and fertilization (Johansson et al. 2004). Sulphur is an important and essential plant nutrient necessary for plant metabolism, growth and development. The average winter wheat sulphur consumption is about 25–30 kg of sulphur per hectare (Hagel 2005). The main biochemical role of sulphur is to form disulphide bridges between peptide chains and stabilise the protein structures (Hawkesford and De Kok 2006). Sulphur deficiency reduces the efficiency of nitrogen fertilization, increases losses of nitrate and reduces the number of grains per ears (Rasmussen et al. 1977; Mengel 1991; Schnug et al. 1993; Haneklaus et al. 1995; Hřivna et al. 1999; Hřivna and Richter 2002). Deficiency of this element can decrease grain yield and grain bread-making quality (Zhao et al. 1999a, b; Shahsavani and Gholami 2008). Sulphur deficiency is an important factor limiting the crop production in many regions around the world.

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Before the application of sulphur fertilizers it is necessary to define the amount of sulphur required for proper plant growth and development (Dämmgen et al. 1998; Zhao et al. 1999b; Mathot et al. 2008; Zörb et al. 2010). The sulphur deficiency limit in wheat grain is defined as nitrogen:sulphur (N:S) ratio $\geq 17:1$ or as sulphur concentration lower than 0.2% (Zhao et al. 1999a).

The aim of the study was to evaluate the effect of nitrogen and sulphur fertilization on the composition of plant matter, yield and quality of wheat grain.

Material and Methods

Material

The research was carried out on winter wheat var. Mulan. Wheat was grown in small field plots 21.6 m² (ZP Agra Velký Týnec, Czech Republic) in 2011–2012. The plots are located in slightly warm and slightly humid climatic region. The soil can be characterized according to WRB classification as haplic Luvisols (haLV). The pH value and nutrient contents of the soil were determined using Mehlich III method (Zbiral 2002) before the experiments were conducted. The soil characteristics are presented in Table 1.

Table 1. Agrochemical characteristics of soil

Year	pH/CaCl ₂	P	K	Ca	Mg
2011	5.640	38.6	148.4	1997	111.8
2012	7.020	89.2	225.7	2600	107.4

P: Phosphorus; K: Potassium; Ca: Calcium; Mg: Magnesium

Fertilizer application

The fertilizer was applied according to the scheme presented in Table 2. Each variant was grown in four replications.

Table 2. The total applied dose of nitrogen fertilizer and nitrogen fertilizer containing sulphur (kg·ha⁻¹)

Var.	Fertilizer	N	S-Sulfan	S-Thiotrac
1	LAV	174		
2	YaraBela SULFAN	174	30	
3	LAV + YV Thiotrac	174		1.5
4	YaraBela SULFAN + YV Thiotrac	174	30	1.5
5	LAV + YV Thiotrac	174		1.5
6	YaraBela SULFAN + YV Thiotrac	174	30	1.5

LAV: Ammonium nitrate with limestone (27% N, 20% CaCO₃), YaraBela SULFAN (24% N + 6% S + 7% CaO), YV Thiotrac (YaraVita Thiotrac) 300 g S, 200 g N in 1 L

Plant analysis

Plant matter characteristics were tested during the growing period, according to the scheme shown in Table 3. The total nitrogen content was determined using the Dumas method (Zbiral et al. 2005). The plant was treated with the mixture of H₂O₂ and HNO₃ before the determination of other nutrient characteristics. The samples were subsequently analysed according to Zbiral et al. (2005) using optical emission spectrometry with inductively coupled plasma ICP-OES. The harvested grain was subjected to analysis.

Table 3. Plant sampling during wheat growing stages

Variant	Applied fertilizer	BBCH 28–30	BBCH 39–43	BBCH 65–70
1	LAV	+	+	+
2	YaraBela SULFAN	+	+	+
3	LAV + YV Thiotrac		+	+
4	YaraBela SULFAN + YV Thiotrac		+	+
5	LAV + YV Thiotrac			+
6	YaraBela SULFAN + YV Thiotrac			+

YV Thiotrac: YaraVita Thiotrac

Grain quality

Specific weight was assessed according to ISO 7971-2 (1995). It was measured as weight of grain per unit volume and the results were expressed in kg·hl⁻¹. The proportion of front grain was determined using Czech technical standard ČSN 461011-7 (1988). Wheat grains were ground into wholemeal on a laboratory mill MILL 120 (Perten Instr). Hagberg falling number (ISO 3093 2004) was measured as the total time, in seconds, required to activate a viscometer stirrer and allow it to fall a predetermined distance through an aqueous gel prepared by heating a mixture of wholemeal and water in a viscometer tube. Protein content in dry matter was assessed using the Dumas combustion method according to ICC Standard no. 167 (2000). The total content of crude protein in dry matter was calculated as the nitrogen content multiplied by 5.7 and expressed in percent (w/w). Zeleny sedimentation volume was determined according to ISO 5529 (2007).

Each laboratory test was carried out on two test portions simultaneously or rapidly one after the other. The arithmetic mean of two determinations was taken as a result, if the conditions of repeatability given by standards were satisfied. If the absolute difference between two independent single test results, obtained using the same method on identical test material in the same laboratory by the same operator using the same equipment with a short interval of time was outside of standard limits, two determinations were carried out again.

Statistical analysis

Statistical data analysis was tested by two-factor analysis of variance followed by Tukey's test. Data were evaluated using STATISTICA 10.0 (StatSoft, Inc.).

Results

The application of fertilizer YaraBela SULFAN containing sulphur had a positive effect on the values of plant weight and sulphur content in plant (Table 4). The apparent differences between the variants were observed 14 days after fertilization during BBCH 28–30 growing stages. The total sulphur uptake per plant was increased by 28.1 to 43.2% compared with the control sample.

The application of solid and liquid fertilizers containing sulphur improved the plant characteristics in the BBCH 39–43 growing stages in 2012 (Table 5). The effect of sulphur fertilization was lower in 2011. Only the sulphur application in the form of solid fertilizer (var. 4) increased plant sulphur uptake. The total amount of sulphur intake per plant (variants 2, 3) was lower than in control variant (var. 1). The highest uptake was observed during both years in var. 4. The application of YaraVita Thiotrac fertilizer also positively influenced plant characteristics after spraying fertilizer on leaves during the first productive fertilization. The sulphur content in wheat plants increased by 3.1% to 38.5% compared with the control variant (var. 1).

Lower effect of sulphur fertilizer application was observed in plant matter during the BBCH 65–70 growing stages (Table 6). The highest sulphur content in plant matter was found in variants 4 and 6 in 2011 after the application of YaraBela SULFAN and YaraVita Thiotrac fertilizer, while the uptake was highest in variants 5, 6. In 2012, sulphur content were significantly affected by the precipitation deficit, which occurred in May. The lack of water reduced leaching of sulphate anions outside the wheat root zone, which positively affected sulphur uptake found in the most of the variants.

Sulphur application increased the number of ears in 2011 and 2012. The highest number of ears was obtained in variants 5 and 6 in 2011. Sulphur fertilization increased the number of ears by 23% to 170% compared with the control variant. The highest numbers of ears found in the variants 5 and 6 in 2011 increased dry weight per plant.

Grain yield significantly differed in wheat harvested in 2011 and 2012 (Table 7). The highest grain yield was recorded in 2011 ($10.5\text{--}11.4\text{ t}\cdot\text{ha}^{-1}$). In 2011 and 2012, the greatest effect of fertilization on grain yield occurred in var. 6 after the application of YaraBela SULFAN fertilizer and YaraVita Thiotrac sprayed in the late stages of vegetation (Table 7). The lowest grain yields were recorded in 2011 after YaraVita Thiotrac application (var. 3 and var. 4) during tillering phase.

Proportion of front grain significantly varied between 2011 and 2012. In 2011, specific weight values ($76.1\text{--}76.9\text{ kg}\cdot\text{hl}^{-1}$) were decreased due to rainy weather. The total rainfall in May 2011 was higher by 52 mm compared to May 2012. The sulphur fertilization had no effect on specific weight values (Table 7). Similarly, no effect of sulphur fertilization on Hagberg falling number was recorded. Protein content was slightly increased by the combination of YaraBela SULFAN and YaraVita Thiotrac fertilization, but differences among variants were not significant. Higher differences were found in Zeleny sedimentation volume, but the values also did not significantly differ among variants (Table 7).

Table 4. Chemical composition of plant dry matter and sulphur uptake per plant during BBCH 28–30 growing stages

Year	Var.	H1SR g	N %	P %	K %	Ca %	Mg %	S %	Sulphur uptake per plant mg
2011	1	0.910 ^b	3.747 ^a	0.488 ^a	3.790 ^a	0.443 ^a	0.129 ^a	0.294 ^a	2.675 ^a
	2	1.197 ^b	3.570 ^a	0.519 ^b	4.084 ^b	0.491 ^a	0.144 ^b	0.320 ^a	3.830 ^b
2012	1	0.586 ^a	5.071 ^b	0.482 ^a	4.908 ^b	0.609 ^b	0.121 ^a	0.417 ^b	2.444 ^a
	2	0.691 ^a	4.965 ^b	0.522 ^b	5.254 ^b	0.671 ^b	0.134 ^b	0.453 ^b	3.130 ^b

H1SR – dry weight per plant; values in one column labelled with various letters significantly differ on $p < 0.05$

Table 5. Chemical composition of plant dry matter and sulphur uptake per plant during BBCH 39–43 growing stages

Year	Var.	H1SR g	N %	P %	K %	S %	Sulphur uptake mg	Number of ears per 1 m ²
2011	1	4.717 ^d	2.202 ^a	0.290 ^b	2.765 ^a	0.188 ^a	8.868 ^c	3.7 ^d
	2	3.816 ^b	2.533 ^c	0.328 ^d	3.160 ^c	0.213 ^b	8.128 ^b	3.3 ^c
	3	3.037 ^a	2.610 ^d	0.318 ^c	2.855 ^b	0.190 ^a	5.770 ^a	2.7 ^a
	4	4.233 ^c	2.370 ^b	0.274 ^a	2.778 ^a	0.216 ^b	9.143 ^d	3.1 ^b
2012	1	1.829 ^a	2.877 ^c	0.260 ^b	3.312 ^a	0.296 ^a	5.414 ^a	2.1 ^c
	2	2.193 ^c	2.561 ^a	0.294 ^c	3.686 ^d	0.298 ^a	6.535 ^c	1.7 ^a
	3	1.917 ^b	2.623 ^b	0.269 ^b	3.571 ^c	0.296 ^a	5.674 ^b	1.8 ^b
	4	2.568 ^d	2.610 ^b	0.234 ^a	3.442 ^b	0.292 ^a	7.498 ^d	1.7 ^a

H1SR: dry weight per plant; values in one column labelled with various letters significantly differ on $p < 0.05$

Discussion

Sufficient sulphur supply during the growing period is necessary for the production of high quality grain. The most suitable are solid fertilizers containing sulphur in SO_4^{2-} anion forms in mixture with nitrate ions (Richter and Hlušek 1994). The positive effect of applied fertilizers was demonstrated by the results of plant analysis during BBCH 28–30 growing stages. Sulphur content in plant matter was increased after the application of sulphur fertilizer. Sulphur content present in the plant was relatively high (0.294–0.453%) and recorded values are consistent with findings published by Fageria (2008) and Sahota (2006).

Dry weight per plant also increased after sulphur application, which corresponds with the conclusions published by Haneklaus and Schnug (1994). Sulphur uptake per plant increased only in var. 4 in 2011 while in 2012 the sulphur uptake per plant was coherent with the fertilizer application scheme. The application decreased the number of tillers and consequently the number of the unproductive tillers during late stages of vegetation (BBCH

Table 6. Chemical composition of plant dry matter and sulphur uptake per plant during BBCH 65–70 growing stages

Year	Var.	HISR g	N %	P %	K %	Mg %	S %	Sulphur uptake mg	Number of ears per 1 m ²
2011	1	7.169 ^d	1.919 ^d	0.25 ^c	2.001 ^{bc}	0.109 ^b	0.122 ^c	8.746 ^c	690 ^a
	2	5.875 ^b	1.444 ^a	0.208 ^a	1.87 ^a	0.103 ^a	0.103 ^a	6.051 ^a	725 ^b
	3	6.325 ^c	1.729 ^c	0.224 ^b	2.045 ^d	0.125 ^c	0.111 ^b	7.021 ^b	730 ^b
	4	5.686 ^a	1.614 ^b	0.229 ^c	2.122 ^c	0.112 ^b	0.126 ^d	7.164 ^b	700 ^a
	5	9.693 ^f	1.659 ^b	0.224 ^b	1.965 ^b	0.102 ^a	0.111 ^b	10.76 ^c	750 ^c
	6	7.625 ^e	1.664 ^b	0.238 ^d	2.032 ^{cd}	0.102 ^a	0.128 ^c	9.76 ^d	735 ^b
2012	1	4.82 ^c	1.914 ^c	0.211 ^c	1.69 ^c	0.161 ^c	0.211 ^c	10.17 ^c	442 ^a
	2	7.169 ^d	1.919 ^d	0.25 ^c	2.001 ^{bc}	0.109 ^b	0.122 ^c	8.746 ^c	690 ^a
	3	5.875 ^b	1.444 ^a	0.208 ^a	1.87 ^a	0.103 ^a	0.103 ^a	6.051 ^a	725 ^b
	4	6.325 ^c	1.729 ^c	0.224 ^b	2.045 ^d	0.125 ^c	0.111 ^b	7.021 ^b	730 ^b
	5	5.686 ^a	1.614 ^b	0.229 ^c	2.122 ^c	0.112 ^b	0.126 ^d	7.164 ^b	700 ^a
	6	9.693 ^f	1.659 ^b	0.224 ^b	1.965 ^b	0.102 ^a	0.111 ^b	10.76 ^c	750 ^c

HISR: dry weight per plant; values in one column labelled with various letters significantly differ on $p < 0.05$

Table 7. Parameters of wheat grain quality

Year	Var.	Yield t·ha ⁻¹	FG %	SW kg·hl ⁻¹	FN s	Protein %	SEDI ml
2011	1	11.2 ^{fg}	49.8 ^{bc}	76.9 ^a	259 ^a	12.0 ^a	50 ^{bc}
	2	11.1 ^{fg}	49.0 ^b	76.5 ^a	257 ^a	11.9 ^a	49 ^b
	3	10.5 ^d	49.5 ^{bc}	76.5 ^a	263 ^a	12.1 ^{ab}	50 ^{bc}
	4	10.6 ^{dc}	54.3 ^d	76.1 ^a	229 ^a	12.2 ^{ab}	54 ^d
	5	11.0 ^{ef}	53.0 ^{cd}	76.4 ^a	238 ^a	12.0 ^a	53 ^{cd}
	6	11.4 ^e	50.0 ^{bc}	76.2 ^a	264 ^a	12.2 ^{ab}	50 ^{bc}
2012	1	7.7 ^a	43.0 ^a	81.7 ^b	336 ^b	12.5 ^{bc}	43 ^a
	2	7.8 ^{ab}	44.0 ^a	81.2 ^b	330 ^b	12.7 ^d	44 ^a
	3	8.0 ^{bc}	43.3 ^a	81.3 ^b	341 ^b	12.7 ^d	43 ^a
	4	7.7 ^a	41.0 ^a	81.6 ^b	326 ^b	12.6 ^{cd}	41 ^a
	5	8.1 ^{bc}	42.0 ^a	81.7 ^b	332 ^b	12.7 ^d	42 ^a
	6	8.3 ^c	43.3 ^a	81.6 ^b	316 ^b	12.7 ^d	43 ^a

FG: proportion of front grain; SW: specific weight; FN: Hagberg falling number; Protein: protein content in dry matter; SEDI: Zeleny sedimentation volume; values in one column labelled with various letters significantly differ on $p < 0.05$

65–70). The positive effect of applied sulphur on the number of productive tillers is in agreement with the results of Eriksen et al. (2001). The application of sulphur fertilizer increased the average number of ears per unit area by 14.0% and the average number of grains per ear by 18.6%.

The application of sulphur fertilizers YaraBela SULFAN and YaraVita Thiotrac improved the plant nutrition demonstrated by greater grain quality. The grain yield was year

dependent. In 2012, grain yield was decreased due to frost damage. The results confirmed the significant effect of weather conditions on grain quality previously described by Ducsay and Ložek (2004).

On haplic Luvisols (haLV), sulphur is known to increase the average yield by 21.7% (Järvan et al. 2012a). It was confirmed the time of fertilizer application is of a significant importance. The highest yield was obtained after the application of YaraBela SULFAN and YaraVita Thiotrac fertilizers in later stages of plant growth.

The proportion of front grain harvested in 2011 reached around 92% of the values measured in 2012. The proportion of front grain is in close relation with specific weight. The values of specific weight were decreased by high rainfall during the grain ripening in 2011. In 2012, grain specific weight was higher, but the differences between variants were not significant. The specific weight reached the values required ($78 \text{ kg}\cdot\text{hl}^{-1}$) for wheat grain with high bread-making quality (Horáková 2010). The effect of sulphur fertilization on Hagberg falling number and protein content is not obvious. The values of Hagberg falling number significantly differed between 2011 and 2012. Hagberg falling number is known to be dependent on weather during the grain ripening and harvest (Perten 1964). Even if the difference between the values of Hagberg falling number were not significant, sulphur application decreased the values of Hagberg falling number with is in general agreement with the findings published by Schnug et al. (1993). Sulphur fertilization had a slight positive effect on grain protein content. The relation between fertilization, protein content and Hagberg falling number has been previously described. If the nitrogen obtained in the fertilizer is not incorporated into peptide chain the values of Hagberg falling number can be decreased (Randall and Wrigley 1986; Zhao et al. 1999a; Seling et al. 2006). This hypothesis is partially supported by the lower values of the Hagberg falling number obtained in 2012, variants 2, 4, 6. Contrarily, some papers (Schnug et al. 1993; Richter et al. 2001) described reverse correlation.

Even if sulphur fertilization slightly increased the values of protein content and Zeleny sedimentation volume, the effect was not significant which is not in agreement with the conclusions published by Randall and Wrigley (1986), Zhao et al. (1999a) and Hoel (2011).

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