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Agrochemical use of waste elemental sulphur in growing white mustard

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In a one-year pot experiment the effect of waste elementary sulphur on the following parameters was observed: 1. on the chemical composition of mustard plants during the growing season, 2. on the yield of seeds, straw and oil, 3. on the chemical composition of seeds and 4. on the content of the water-soluble sulphur in the soil after the harvest.

Elemental sulphur was obtained as a waste material of petroleum refining and was incorporated into a 15-15-15 NPK fertiliser where it comprised 4%. The experiment had the following variants: 1) control (unfertilised); 2) NPK 1; 3) NPK 2; 4) NPKS 1; 5) NPKS 2. The smaller dose amounted to 3.3 g, the higher one to 6.7 g of the fertiliser per pot (6 kg of soil). Moreover all variants were performed in 2 different soils – a medium soil with neutral pH value and a heavy one with alkali pH value.

At the stage of 6 true leaves, the content of nitrogen in plants increased in accordance with its dose. Simultaneously, sulphur applied in the NPKS fertiliser improved nitrogen utilization. The difference between the variants fertilised with NPK and the variants with NPKS amounted to 38.9% in the neutral medium soil, whereas in the alkali heavy soil it was as low as 1.4%.

The yield of both seed and straw in the fertilised variants was statistically significantly higher than in the unfertilised control variant. However, there were observed no statistically significant differences between the variants with sulphur and the variants without sulphur although both the yield of the seed and straw in the variants with NPKS was higher than in the variants with NPK.

The application of elemental sulphur into the neutral medium soil increased the concentration of both nitrogen and sulphur in the mustard seed in comparison with the variants fertilised with NPK only. The difference between them comprises 1.8% and 9.0% in variants with the small and high dose, respectively. In the heavy soil, the trend was opposite.

The application of sulphur into both soils resulted in the increase of the oil content in comparison with the NPK variants.

Sulphur addition to NPK had a positive impact on the augmentation of the available sulphur content in the soil which can positively affect, particularly the following crops. Still, a drop in the pH value was not confirmed.

Keywords: elemental sulphur, NPK fertiliser, white mustard.

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INTRODUCTION

About 15 years ago, the following problems with the amounts of sulphur dioxide released into the air, particularly in the 1980's and a consequent acid fall-out, the Czech Republic began to desulphurise the main emitters. Recently, after the desulphurisation of thermal power stations firing low-quality lignite and the introduction of gas to towns and villages, the focus has also been on the desulphurisation of fuel during oil refining. The content of sulphur in fuel has gradually decreased from the maximal 2000 $mg \cdot kg^{-1}$ in 1994 to 50 $mg \cdot kg^{-1}$ in 2006; from 2009 only the fuel with no more than 10 $mg \cdot kg^{-1}$ sulphur will be on sale in all EU countries. This process generates a considerable amount of elemental sulphur as waste. The traditional customers, producers of sulphuric acid or the rubber industry, are saturated and so the most convenient exploitation of elemental sulphur is to return it back into the natural cycling, i.e. to use it for the fertilisation of agricultural crops.

When using elemental sulphur for agricultural purposes, however, we must always keep in mind that it can have an acidifying effect in the soil. In weakly acid to acid soils the acidification of the soil environment may pose problems; on neutral and alkali soils it is suitable because other nutrients, particularly phosphorus (Besharati, Rastin, 1999, Falih, 1996) and also microelements (Bayoumi et al., 1999, Chouliaras, Tsadilas, 1998) are more available. In the Czech Republic the acreage of alkali soils is 14.7% of agricultural land and based on long-term monitoring of the Central Control and Testing Agricultural Institute this area is increasing.

The objective of the present study was to establish a one-year vegetation pot experiment and to assess the waste elemental sulphur incorporated into NPKS fertilisers as a potential source of available sulphur for white mustard and at the same time to monitor its effect on the soil reaction on neutral and alkali soil.

MATERIAL AND METHODS

Vegetation pot trials were established on 23 October 2003; vegetation Mitscherlich pots were filled with 6 kg of soil (medium heavy neutral soil – Žabčice near Brno and heavy alkali soil – Čejkovice). Agrochemical properties of both soils are given in Table 1.

Table 1. Agrochemical properties of the soils

Place	Type of soil	pH/KCl	$mg.kg^{-1}$					
			P	K	Ca	Mg	$S_{watersol.}$	S_{SO4}
Žabčice	medium heavy soil	5.8	104	237	3713	360	21.6	18.3
Čejkovice	heavy soil	7.3	176	407	7189	639	31.6	25.0

Table 2. Pattern of the trial

Variant	Pattern of trial	soil	Variant	Pattern of trial	soil
1	control	medium heavy neutral soil – Žabčice	6	control	heavy alkali soil – Čejkovice
2	NPK 1		7	NPK 1	
3	NPK 2		8	NPK 2	
4	NPKS 1		9	NPKS 1	
5	NPKS 2		10	NPKS 2	

Fertilisers (NPK 15-15-15 and NPKS 15-15-15-4) were first of all sieved and pellets smaller than 4 mm were used to distribute small amounts of fertilisers in the vegetation pots evenly. Proper application was conducted on 21 November 2003 to a depth of ca 2 cm according to the pattern given in Table 2.

Each variant was established in 8 replications; white mustard was sown in 5 of them, 3 remained unsown. Of the five sown pots, one in each variant was used for sampling the plant matter at the stage of six true leaves.

Fertiliser doses were based on the optimal dose of nitrogen applicable with regard to the demands of the plants and also the nitrate directive in autumn, as the basic fertilisation. With a lower dose (NPK 1 or NPKS 1) we applied 0.665 g of fertiliser per pot and with a higher dose (NPK 2 or NPKS 2) 1.330 g of fertiliser. With lower doses of NPKS we added 26.6 mg S per pot or 4.43 mg S for 1 kg of soil and with a higher dose 53.2 mg S per pot or 8.86 mg S for 1 kg of soil.

In spring, on 16 April 2004, before sowing mustard we fertilised to a total level of 0.5 g of nitrogen or 1.0 g N per pot, that means that we applied 2.668 g NPK or NPKS with the lower dose and 5.337 g NPK, or NPKS with the higher dose.

Each variant was established in 5 replications; one pot remained unsown. After thinning 3 mustard plants were left in the sown pots. For watering we used de-mineralised water and standard disease and pest control was applied. During vegetation the mustard plants were sampled at the stage of 6 leaves (17 May) for chemical analysis. The dry matter weight of one plant and the content of N, P, K, Ca, Mg a S v % in the dry matter was determined in each experimental variant.

The plants were harvested on 3 August at full maturity. Seed and straw yields were monitored and the contents of N, P, K, Ca, Mg and S in the products were assessed by chemical analysis. The content of oil in the seeds was recorded as a qualitative parameter.

After harvesting, soil samples were taken from all the variants (sown and unsown pots) and the soil reaction was determined (current – pH/H_2O and exchangeable – pH/$CaCl_2$) as well as the content of water-soluble sulphur.

All the results were evaluated statistically by multiple factorial analyses of variance using the Statistica 6.0 software and the effect was assessed of adding elemental sulphur to the NPK fertiliser or the effect of sulphur and other nutrients on the monitored parameters.

RESULTS AND DISCUSSION

Tab. 3 shows the dry matter weight of one plant and the concentration of nutrients in the aboveground part of mustard plants at the stage of six true leaves. The results showed poor emergence, especially of the variants grown in heavy alkali soil from Čejkovice. Owing to this fact we

Table 3. The results of the analysis of the aboveground mass of plants at the stage of 6 true leaves

Variant	Pattern of trial	Type of soil	Dry matter weight of 1 plant (g)	% in dry matter					
				N	P	K	Ca	Mg	S
1	control	Medium heavy neutral soil - Žabčice	0.64	3.11	0.54	2.83	1.99	0.21	0.60
2	NPK 1		0.73	3.23	0.47	2.62	1.78	0.21	0.53
3	NPK 2		0.99	3.88	0.53	3.30	2.04	0.23	0.61
4	NPKS 1		0.78	5.81	0.49	2.66	1.94	0.21	0.57
5	NPKS 2		0.86	5.84	0.51	2.98	2.03	0.21	0.55
Average variant of 2, 3			0.86	3.56	0.50	2.96	1.91	0.22	0.57
Average variant of 4, 5			0.81	5.83	0.50	2.82	1.99	0.21	0.56
6	control	Heavy alkali soil - Čejkovice	0.99	4.31	0.55	3.82	1.88	0.25	0.67
7	NPK 1		0.70	4.37	0.52	3.71	2.05	0.28	0.59
8	NPK 2		1.10	5.54	0.56	4.23	2.40	0.34	0.61
9	NPKS 1		0.98	4.53	0.48	3.75	1.84	0.26	0.63
10	NPKS 2		0.71	5.52	0.52	4.20	2.10	0.31	0.63
Average variant of 7, 8			0.85	4.96	0.54	3.97	2.23	0.31	0.60
Average variant of 9, 10			0.85	5.03	0.50	3.98	1.97	0.29	0.63

had one third fewer plants for chemical analysis at different stages of growth and development.

In the variants where higher doses of NPK or NPKS were applied the weight of one plant increased, with the exception of variant 10 (NPKS 2 and alkali soil). There was no response to sulphur.

The nitrogen content increased with increasing N doses; at the same time its better utilisation was due to sulphur applied in NPKS. Between the variants with NPK and NPKS it increased by 38.9% and 1.4% in soils from Žabcice and Čejkovice, respectively.

The contents of other macro-elements (P, K, Ca, Mg) were relatively balanced. There were no significant differences in sulphur concentrations in the plants either; they ranged between 0.53 and 0.67%.

Higher stages of vegetation are illustrated in Figs. 1 and 2. In the former we can see the plants of the respective variants in the stage of the onset of flowering (1 June). Stronger and darker plants indicate a higher content of nitrogen. The plants supplied with sulphur from NPKS were also seen to enter the stage of flowering earlier.

The other figure shows taller plants in all the fertilised variants compared to the control and again darker, stronger and better leafed plants in variants where higher doses of nitrogen, and partly also sulphur, were applied.

In terms of harvest we monitored the number of branches, capsules, seed yields and straw yields (Tab. 4). In the fertilised variants all the monitored parameters showed a statistically significant increase compared to the unfertilised control. The differences between the variants with sulphur and those without were not statistically significant; however, branching was lower in the sulphur variants than in the NPK variants without sulphur and at a lower dose also fewer capsules (Tab. 5). These trends were not reflected in the yields and both seed and straw yields were higher in the NPKS variants than in the variants with NPK. In concrete terms with the lower doses the seed yields after sulphur application increased by 20.3% and with higher fertiliser doses by 12.2%. Likewise, the straw yields increased with NPKS 1 compared to NPK 1 by 4.7% and with NPKS 2 by 9.1% compared to NPK 2. Comparisons of the yield parameters in the different soils showed that the number of branches and capsules of plants grown in the Čejkovice soil slightly decreased compared to Žabčice (by 3.9% and 2.0%, respectively); on the contrary the seed and straw yields increased by 1.8% in the Čejkovice soil compared to Žabičce, 8.4%.

Table 4. Basic yield parameters

Variant	Pattern of trial	Soil type	Number of branches	Number of capsules	Seed yields (g/pot)	Straw yields (g/pot)
1	control	Medium heavy neutral soil - Žabčice	9.0 ± 1.0	194.3 ± 21.2	3.55 ± 0.54	10.71 ± 1.56
2	NPK 1		24.0 ± 1.6	513.8 ± 17.2	10.56 ± 0.67	32.63 ± 1.17
3	NPK 2		39.8 ± 4.0	614.8 ± 19.0	14.23 ± 1.28	45.21 ± 2.88
4	NPKS 1		25.5 ± 2.4	476.5 ± 12.2	12.34 ± 0.42	36.14 ± 2.00
5	NPKS 2		31.0 ± 1.8	652.0 ± 24.1	15.25 ± 1.36	48.91 ± 3.07
6	control	Heavy alkali soil - Čejkovice	10.0 ± 0.9	171.3 ± 10.3	3.43 ± 0.45	13.15 ± 0.92
7	NPK 1		24.8 ± 1.9	480.8 ± 18.9	8.99 ± 0.71	36.12 ± 3.19
8	NPK 2		33.0 ± 3.9	650.8 ± 28.4	14.64 ± 2.68	49.81± 4.59
9	NPKS 1		23.0 ± 3.7	465.0 ± 48.9	12.17 ± 0.69	35.86 ± 1.95
10	NPKS 2		33.5 ± 2.6	635.0 ± 33.7	17.57 ± 0.56	54.63 ± 1.85

n number of monitorings

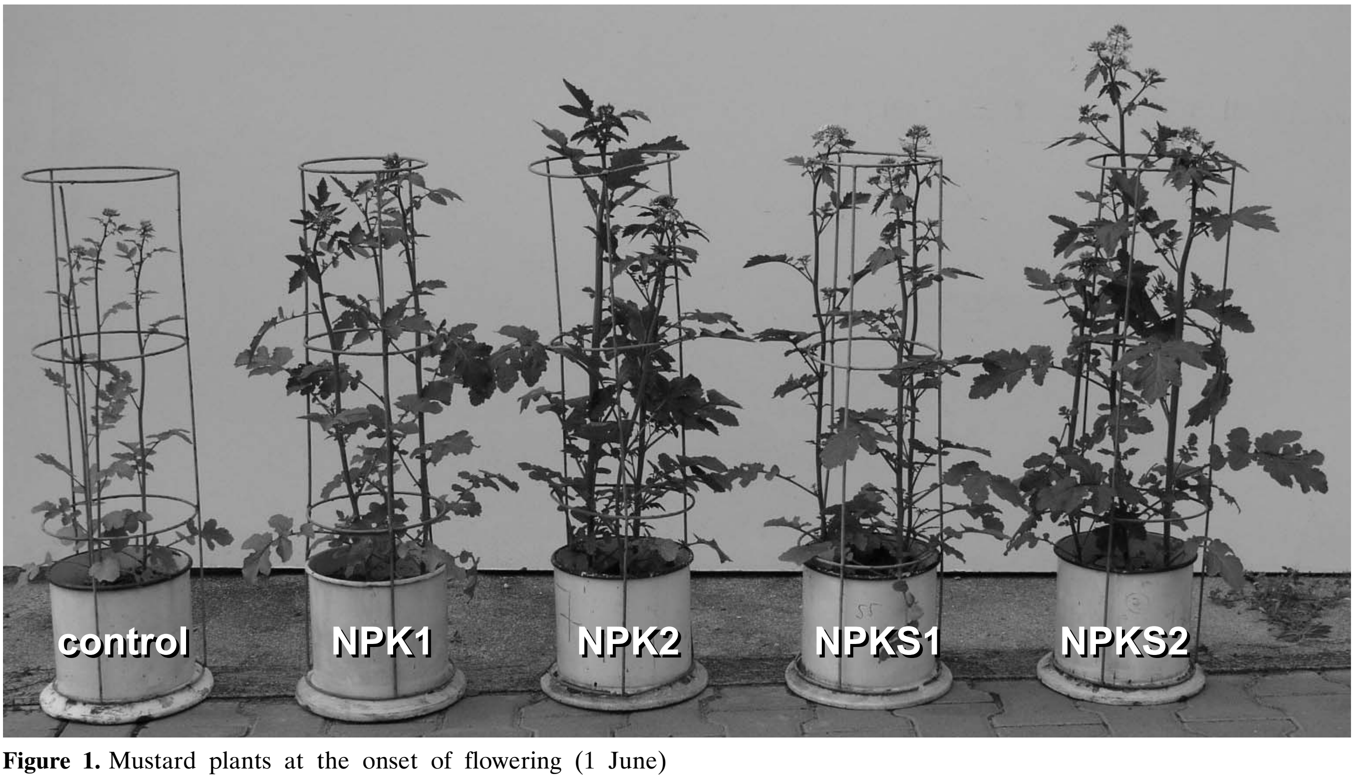

Figure 1. Mustard plants at the onset of flowering (1 June)

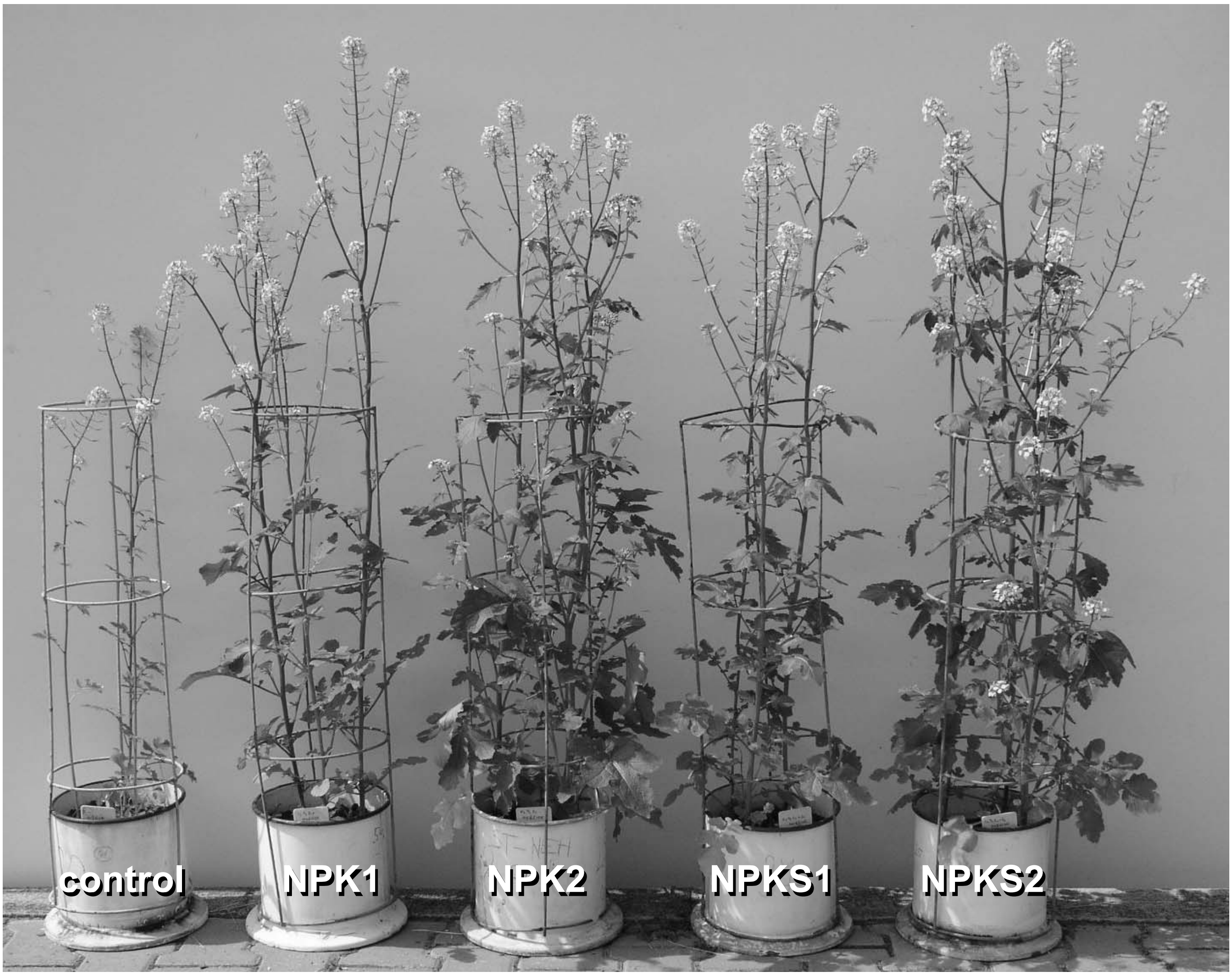

Figure 2. Mustard plants in the stage of full flowering (10 June)

Table 5. Averages and the significance of differences in yield parameters according to Tuckey

Factor	Level	n	Number of branches	Number of capsules	Seed yields (g/pot)	Straw yields (g/pot)
Variant	Control	8	9.5 ± 0.7 a	182.8 ± 11.7 a	3.5 ± 0.3 a	11.9 ±1.0 a
	NPK 1	8	25.1 ± 1.4 bc	497.3 ± 13.4 bc	9.8 ± 0.5 b	34.4 ± 1.7 bc
	NPK 2	8	36.4 ± 2.9 de	632.8 ± 17.2 de	14.4 ± 1.4 cd	47.5 ± 2.7 de
	NPKS 1	8	23.5 ± 1.9 bc	470.8 ± 23.4 bc	12.3 ± 0.4 bc	36.0 ± 1.3 bc
	NPKS 2	8	32.3 ± 1.5 bcd	643.5 ± 19.4 de	16.4 ± 0.8 de	51.8 ± 2.0 de
Soil	Medium heavy neutral soil - Žabčice	20	25.9 ± 2.5 a	490.3 ± 37.8 a	11.2 ± 1.0 a	34.7 ± 3.2 a
	Heavy alkali soil - Čejkovice	20	24.9 ± 2.3 a	480.6 ± 41.4 a	11.4 ± 1.2 a	37.9 ± 3.5 a

Note: If the same letters are given, the differences in the averages of the respective variants are not significant.
n – number of monitorings

Chemical analysis of the harvested seeds provided the information about the contents of the basic macro-elements and the oil content (see Tab. 6). The contents of phosphorus, potassium, calcium and magnesium did not differ considerably, regardless of the variant and soil. The concentrations of nitrogen and sulphur were higher in Žabčice after the application of elemental sulphur in NPKS compared to the variants without sulphur, i.e. by 1.8% and 9.0%, respectively. The trends were opposite in the variants on heavy alkali soil from Čejkovice where the N and S contents dropped after NPKS fertilisation by an average of 6.2% and 8.9%, respectively.

A visible trend can be seen in fat contents (Tab. 6); in both soils the fat content expressed in percentage increased after sulphur application in NPKS, i.e. in Žabičce 6.2%

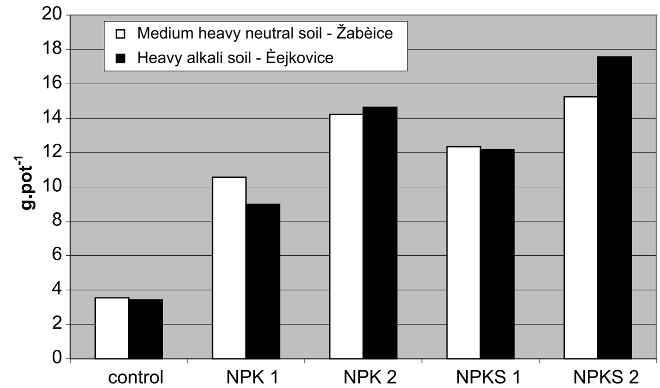

Figure 3. The yields of the mustard seed

Table 6. The results of mustard seed analysis

Variant	Pattern of trial	Soil type	% in dry matter						
			N	P	K	Ca	Mg	S	oil
1	Control	Medium heavy neutral soil - Žabčice	3.88	0.95	1.06	0.62	0.32	0.91	19.90
2	NPK 1		3.62	0.88	1.01	0.68	0.31	1.03	22.10
3	NPK 2		3.97	0.85	1.05	0.60	0.31	0.99	21.70
4	NPKS 1		3.74	0.96	1.04	0.62	0.33	1.12	22.30
5	NPKS 2		4.00	0.89	1.00	0.66	0.33	1.10	24.40
Average of Variants 2 and 3			3.80	0.87	1.03	0.64	0.31	1.01	21.90
Average of Variants 4 and 5			3.87	0.92	1.02	0.64	0.33	1.11	23.35
6	Control	Heavy alkali soil - Čejkovice	3.90	0.92	1.00	0.60	0.32	0.92	19.60
7	NPK 1		3.75	0.88	1.00	0.60	0.34	1.07	21.50
8	NPK 2		3.99	0.85	1.02	0.64	0.32	1.17	19.20
9	NPKS 1		3.53	0.89	1.00	0.60	0.34	1.09	22.00
10	NPKS 2		3.72	0.86	1.00	0.60	0.33	0.95	21.60
Average of Variants 7 and 8			3.87	0.87	1.01	0.62	0.33	1.12	20.35
Average of Variants 9 and 10			3.63	0.88	1.00	0.60	0.34	1.02	21.80

Table 7. The results of the analysis of mustard straw

Variant	Pattern of trial	Soil type	% in dry matter					
			N	P	K	Ca	Mg	S
1	Control	Medium heavy neutral soil - Žabčice	0.37	0.09	1.22	1.61	0.11	0,25
2	NPK 1		0.39	0.09	1.44	1.61	0.11	0,24
3	NPK 2		0.45	0.08	1.78	1.57	0.11	0,21
4	NPKS 1		0.32	0.08	1.37	1.38	0.11	0,29
5	NPKS 2		0.46	0.08	1.69	1.36	0.12	0,27
Average of Variants 2 and 3			0.42	0.09	1.61	1.59	0.11	0.23
Average of Variants 4 and 5			0.39	0.08	1.53	1.37	0.12	0.28
6	Control	Heavy alkali soil - Čejkovice	0.37	0.08	1.20	1.55	0.16	0,33
7	NPK 1		0.37	0.08	1.43	1.48	0.16	0,24
8	NPK 2		0.43	0.05	1.73	1.38	0.15	0,22
9	NPKS 1		0.35	0.06	1.51	1.32	0.13	0,36
10	NPKS 2		0.41	0.06	1.74	1.24	0.15	0,29
Average of Variants 7 and 8			0.40	0.07	1.58	1.43	0.16	0.23
Average of Variants 9 and 10			0.38	0.06	1.63	1.28	0.14	0.33

Table 8. The current and exchangeable soil reaction and the content of available sulphur in the unsown variants (20 may)

Variant	Soil	Pattern of trial	pH/H_2O	$pHCaCl_2$	$S_{water-soluble}$ ($mg.kg^{-1}$)
1	Medium heavy neutral soil - Žabčice	Control	6.47	7.06	34.50
2		NPK 1	6.28	6.80	33.20
3		NPK 2	6.23	6.67	28.00
4		NPKS 1	6.21	6.74	40.00
5		NPKS 2	6.07	6.63	36.90
6	Heavy alkali soil - Čejkovice	Control	7.61	8.01	67.60
7		NPK 1	7.53	8.03	35.50
8		NPK 2	7.51	7.98	46.00
9		NPKS 1	7.57	8.10	45.80
10		NPKS 2	7.55	8.02	60.80

and in Čejkovice 6.7%. Similar results were discovered in field conditions when the fertiliser was applied in a small-plot experiment (Ryant, 2006). At the same time it was confirmed that with an increasing N dose the oil content decreases, as Richter et al. (2001) reported.

The trends in concentrations of phosphorus, potassium, calcium and magnesium in straw were not unambiguous and the sulphur contents in variants with both types of soil were always higher after fertilising with sulphur in NPKS; i.e. in Žabčice by 17.9% and in Čejkovice by 20.3%.

The value of the current (pH/H_2O) and exchangeable ($pH/CaCl_2$) soil reaction and the content of available sulphur were monitored in all the variants during the year (20 May) in the unsown pots and after harvesting the crops. We could divide the monitoring into the effect of sowing, two soil types and the individual fertilisation variants (unfertilised variant and two doses of NPK or NPKS).

Tab. 8 shows the values obtained from the soil samples in unsown pots on 20 May. In the neutral medium heavy soil from Žabčice the values of relevant and exchangeable

Table 9. The current and exchangeable soil reaction and the content of available sulphur in the soil after harvesting mustard

Variant	Soil	Pattern of trial	pH/H_2O		pH/$CaCl_2$		$S_{water-soluble}$ (mg.kg^{-1})	
			sown	unsown	sown	unsown	sown	unsown
1	Medium heavy neutral soil - Žabčice	Control	7.24	7.07	6.47	6.36	33.00	55.80
2		NPK 1	7.31	6.72	6.63	6.12	28.80	45.20
3		NPK 2	7.33	6.28	6.62	5.88	20.30	45.40
4		NPKS 1	7.21	6.59	6.56	6.13	38.20	65.00
5		NPKS 2	7.08	6.13	6.45	5.91	44.50	75.00
6	Heavy alkali soil - Čejkovice	Control	8.31	8.14	7.66	7.44	49.00	43.70
7		NPK 1	8.29	8.06	7.65	7.53	26.20	36.50
8		NPK 2	8.24	8.00	7.61	7.51	20.80	34.00
9		NPKS 1	8.25	8.13	7.65	7.55	37.20	45.70
10		NPKS 2	8.26	7.90	7.63	7.54	35.40	73.80

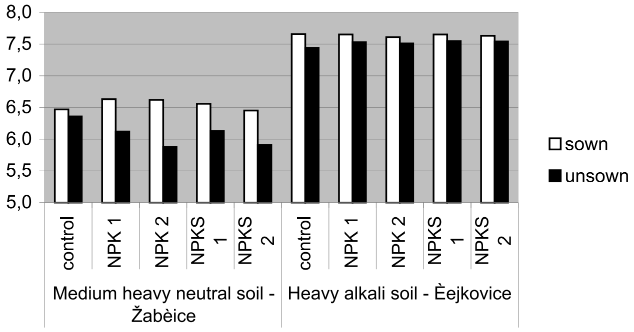

Figure 4. The exchangeable soil reaction after mustard harvest

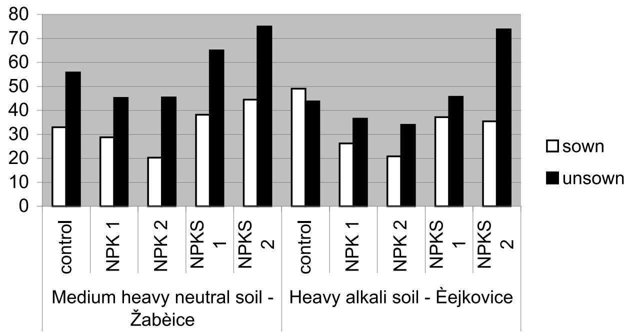

Figure 5. The content of water-soluble sulphur (mg.kg^{-1}) after mustard harvest

soil reaction slightly decreased, at the same time the content of available sulphur increased by 17.0% and 24.1% with lower and higher fertiliser doses, respectively. In heavy alkali soil from Čejkovice its strong buffer ability was seen and that is why the values of current soil reaction in the variants with elemental sulphur (both NPKS 1 and NPKS 2) decreased only slightly compared to the unfertilised control, and the values of exchangeable soil reaction were balanced.

Tab. 9 gives the results of the current and exchangeable soil reaction and the content of available sulphur after harvesting mustard, showing that the values of the current and exchangeable soil reaction slightly decreased after fertiliser application. The differences between the variants are statistically insignificant and the effect of elemental sulphur on soil acidification is negligible. The acidification effect of elemental sulphur reported e.g. by Finck (1982) was not confirmed, but we must also take into account the relatively low content of elemental sulphur in the applied fertiliser. A more detailed evaluation revealed that the decrease appeared particularly in the neutral medium heavy soil of Žabčice, while the values of the alkali heavy soil of Čejkovice were balanced, including the unsown variants.

CONCLUSION

The following conclusions can be drawn from the results of the vegetation pot experiment with mustard and NPK fertilising with elemental sulphur:

– Sulphur applied in NPKS increased nitrogen utilisation resulting in its higher concentration in plants at the stage of 6 true leaves.

– The number of branches and partly also capsules decreased in the variants where sulphur was applied in NPKS.

– Seed and straw yields were higher after fertilising with sulphur contained in NPKS, although the increase was not statistically significant.

– The oil content in seeds increased after the application of NPKS in both fertiliser doses.

– The addition of elemental sulphur in the NPK fertiliser was positive and increased the content of available sulphur in the soil with no parallel reduction in soil reaction, particularly on heavy alkali soil.

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