Barley response to the soil reserve of sulphur and ammonium sulphate in short-term experiments under controlled conditions of cultivation

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ABSTRACT

The objective of the paper was to determine an appropriate concentration of available sulphur in soil for the initial growth of plants. Based on previous researches two methods of soil extraction were used to acquire information on the soil reserve: water extraction (H_2O 1:5, w/v) and extraction in 0.5M ammonium acetate with addition of NH_4F (KVK-UF soil test). Spring barley was used as a test crop to determine the soil reserve of sulphur and its response to sulphur addition to the soil. A collection of 48 samples of topsoil from agriculturally important localities in the CR was made up for this purpose and the parameters of the nutrient status of the soil were remarkably different. A set of soils was used to establish short-time vegetation experiments in a plant growth chamber according to the scheme: A) control – without sulphur application and B) response variant with application of 30 mg S/kg of soil in the form of $(NH)_4SO_4$; nitrogen in variant A was adjusted by application of NH_4Cl. Index of nutrient efficiency (IE = Y/N where Y = yield and N = nutrient concentration in the plant) and boundary lines of the point field were used to evaluate the efficiency of barley nutrition with sulphur. The efficient soil reserve of sulphur for the soil test H_2O (1:5) when the ICP analytical technique was used was indicated in the range of 8–11 mg S/kg; 6–10 mg S/kg for sulphate detection on a SKALAR analyser. The efficient utilisation of sulphur by barley plants for the KVK-UF soil test was in the range of 7–12 mg S/kg. The conversion of the KVK-UF S-test to the index of soil reserve of sulphur by adding up a variable portion of the CEC value to the value of sulphur determined by the soil test (0.0167CEC + 9.1667) improved the closeness of the relationship between soil and plant.

Keywords: sulphur; soil testing; barley

Although sulphur is an important main nutrient, no appropriate attention has been paid to the need of sulphur fertilization until recently. It was assumed that the supply of sulphur to the soil with a ballast component of many ordinary fertilizers, pesticides and from air pollutants from combustion of fossil fuels in thermal power plants was sufficiently high. Production of concentrated fertilizers of NPK type (so called ballast-free ones), ecological pressures to reduce the generation of emissions by the power industry, intensification of farm crop yields and potential high losses of sulphates from the soil by leaching contribute to sulphur negative recycling in field plant production.

Similarly like for the other main nutrients, a rational fertilization system should be conceived for sulphur to avoid the unnecessary depreciation of the complex of other inputs into plant production through apparent or latent sulphur deficiency. It should be based on prevention: soil tests should provide basic information prior to the vegetation of the crop in the field. It is too late for subsequent fertilization practices to be fully efficient that were carried out after plants had shown symptoms of apparent sulphur deficiency or after latent sulphur deficiency was diagnosed by plant analysis during vegetation. As for the use of soil tests for sulphur diagnosis, many researchers are rather sceptical (Schnug and Haneklaus 1998). The scepticism is based on the fact that the main portion of sulphur in the soil is a part of the soil's organic matter, therefore its transformations could markedly change the soil reserve of sulphur available to plants in a short time, similarly like in the case of nitrogen.

Sulphates that are not sorbed in the soil with current pH values of cultivated soil are the main form of sulphur intake for plants. This fact makes it difficult to specify the capacity characteristic of the reserve of available sulphur in the soil, complicating the agronomic interpretation of soil tests.

Results of research conducted in Denmark (Eriksen et al. 1995, 1998) documented that the participation of soil organic matter and animal fertilizers in the renewal of the soil reserve of mineral sulphur is hardly important in practice. These conclusions are

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in agreement with our research on possibilities of renewing labile forms of sulphur from soil organic matter in the critical period after winter. Moreover, considerable immobilization of labile sulphur was observed in our set of 47 soils that was increased by applications of nitrogenous fertilizers. These findings support the use of preventive soil tests to estimate the nutrient status of soil for sulphur and document the suitability of simultaneous application of sulphur and nitrogen in the critical spring period of increased requirements for crop nutrition (Matula et al. 2000). Further information on the parent material and hydropedology of soil profile in the field will obviously contribute to the correct interpretation of S-soil test. The utility value of soil test is based on an assumption that laboratory-determined values are in agreement with the actual availability of nutrients to plants. If it is so, it is reasonable to carry out agronomic interpretations of laboratory results.

Sulphates – an inorganic form – are the most easily available form of sulphur to plants. Hence the soil test should identify only that fraction of organic sulphur that can easily be transformed into sulphates. The analytical technique ICP (inductively coupled plasma) atomic emission spectroscopy for sulphur determination provides the total content of (inorganic and organic) sulphur in the extract. The extracting agent of soil test should release only that part of organic sulphur from the soil that could participate in plant nutrition. In this context Matula (1999) verified a possibility of including sulphur in currently used and envisaged multi-nutrient soil tests. Based on the obtained results the set of extraction techniques for further experimentation was reduced to two: extraction of nutrients from soil to water and to 0.5M ammonium acetate (Matula and Pirkl 1988, Matula 1996).

The objective of this paper was to determine an appropriate concentration of sulphur in the soil reserve for the initial growth of plants by help of test plant barley in a variegated set of soils from agriculturally important localities of the CR.

MATERIAL AND METHODS

Forty-eight soil samples were selected from the collection of soil samples obtained by a survey of the nutrient status of soils at 28 localities of the CR to encompass the widest range possible of the reserve of sulphur labile forms for different soil texture classes that were derived from CEC values (Table 1). Two techniques of soil extractions were used: extraction in 0.5M ammonium acetate with NH_4F addition – soil test KVK-UF (Matula and Pirkl 1988, Matula 1996) and water extraction at a 1:5 ratio (w/v). An ICP-OES Trace SCAN apparatus (Thermo Jarrell Ash) was used for the total sulphur determination while sulphates in water extract were determined on a Sun Plus System SKALAR analyser.

The set of 48 samples was divided into four subgroups of 12 soils each respecting the capacity of a plant growth chamber. Short-term (18-day) vegetation trials were established on each soil with spring barley cv. Akcent as a test plant using this scheme:

A – control variant, without sulphur application (NH_4Cl was applied to adjust the nitrogen rate to variant B).

B – response variant, with the application of 3 mg S/100 g of soil in the form of $(NH_4)_2SO_4$. Sulphur application and nitrogen adjustment in variant A were carried out before the test plant was sown.

Each variant had four replications. Vegetation pots 6 cm in diameter was filled with 100 g of soil that was mixed with 80 g of coarse-grained quartz sand. Fifteen barley seeds (after their washing and one-hour soaking in distilled water) were planted onto the soil surface in vegetation pots and covered with 25 ml of coarse-grained quartz sand. After emergence ten barley plants were left in each pot. Moistening of vegetation pots was differentiated on the basis of an experimentally determined relationship between the field water capacity of soil and the value of its cation exchange capacity (CEC) (Matula et al. 2000). The moisture content was regularly renewed according to the weight loss of vegetation pot.

Cultivation took place in a climate chamber with the light and temperature regime: daylight 16 h, 20°C, dark 8 h, 15°C; photosynthetically active radiation 500 $\mu E/m^2/s$. Nitrogen dose of 6 mg N/pot was applied jointly with watering on days 4, 7, 9, 11 and 14 since the trial establishment. Harvested barley shoots were instantly dried at 65°C. A Milestone microwave device was used for mineralization of barley dry matter in the medium of nitric acid and hydrogen peroxide; the analysis was carried out on an ICP-OES Trace SCAN apparatus.

To process the experimental results statistical programme GraphPad PRISM, Ca., USA, version 3.0 and Microsoft Excel 2000 were used.

RESULTS AND DISCUSSION

Table 2 shows the basic yield results of dry matter of barley shoots from 18-day barley cultivation on the set of soils. Figures 1–6 illustrate the relative yield response (i.e. percentage of the difference in dry matter yield of barley shoots between variant A and B) related to the information on labile sulphur concentration in the set of tested soils. The large scatter of correlation field of the relationship,

Table 1. Basic information about the experimental set of soils

Soil No.	Analyses LECO CNS-2000			pH 0.2M KCl	Soil test KVK-UF (Matula and Pirkl 1988)					H_2O (1:5, w/v)	
	C (g/kg)	S (mg/kg)	N (g/kg)		CEC (mmol/kg)	K (mg/kg)	Mg (mg/kg)	P (mg/kg)	S (mg/kg)	S (ICP) (mg/kg)	S (SKALAR) (mg/kg)
1	8.3	85.8	0.87	6.1	100	95	211	13.7	6.4	4.5	3.7
2	16.6	196.1	1.74	5.8	246	458	208	11.3	6.6	9.4	9.3
3	12.5	63.9	0.93	6.9	119	244	35	3.7	8.3	7.2	5.2
4	14.0	150.3	1.44	6.5	195	767	224	5.0	8.7	13.6	13.3
5	9.5	100.4	1.10	6.3	110	171	51	18.2	10.0	7.2	5.9
6	18.0	197.2	1.93	6.2	249	249	217	2.9	10.0	10.3	7.7
7	11.4	129.9	1.14	5.9	106	174	100	23.4	12.3	10.6	9.9
8	13.4	130.7	1.31	5.5	176	237	111	6.0	12.4	8.4	8.1
9	10.4	113.2	1.25	5.3	117	289	167	39.1	14.1	9.9	8.2
10	14.5	166.5	1.57	6.3	181	187	142	7.5	14.2	8.4	6.8
11	10.2	118.1	1.11	5.5	122	187	170	30.9	16.2	12.8	10.4
12	12.1	130.8	1.33	6.0	125	230	124	25.0	17.5	21.9	18.2
13	10.6	130.0	1.14	5.6	107	103	106	19.6	6.7	5.2	4.4
14	13.2	149.6	1.47	5.7	145	215	82	17.5	6.8	5.8	4.7
15	9.2	101.1	1.01	5.1	118	153	64	10.2	8.7	7.6	7.4
16	13.6	141.4	1.42	5.7	184	174	175	7.2	8.6	9.8	7.0
17	16.3	136.2	1.48	6.7	208	403	196	9.2	10.9	11.3	9.7
18	15.3	157.3	1.61	6.6	195	353	151	10.4	10.8	10.2	7.2
19	11.9	124.2	1.13	5.3	113	140	98	11.9	12.6	10.7	9.4
20	14.1	164.3	1.52	5.1	159	143	168	9.6	12.7	8.4	6.9
21	14.8	217.0	1.52	6.3	123	177	77	15.1	14.1	12.0	9.1
22	10.9	129.2	1.15	5.8	118	216	153	24.2	14.6	11.8	10.1
23	9.6	110.3	1.07	4.7	125	159	63	8.7	17.0	9.6	8.5
24	10.1	117.1	1.12	5.0	126	210	99	11.1	18.8	16.3	14.7
25	10.3	112.2	1.10	5.8	147	155	63	5.5	6.7	6.5	6.7
26	8.6	85.6	0.89	6.3	95	163	163	22.8	6.8	4.9	3.7
27	9.6	100.4	0.97	5.9	84	145	113	22.6	9.0	5.9	6.0
28	9.7	111.6	1.11	5.6	132	163	123	8.8	9.1	9.0	8.3
29	12.1	121.5	1.28	6.7	145	321	96	7.1	11.0	10.7	8.6
30	9.1	105.1	1.01	5.5	122	174	156	12.4	11.0	10.4	9.2
31	13.6	153.6	1.36	6.0	169	177	245	5.2	12.8	12.3	12.5
32	8.4	102.3	0.92	5.4	120	209	153	17.5	13.0	10.3	10.1
33	11.7	131.1	1.26	5.0	142	233	113	8.5	15.2	8.8	9.1
34	10.9	122.7	1.13	5.9	114	197	153	25.1	15.3	11.0	9.3
35	10.1	121.6	1.16	5.6	133	157	125	13.3	26.0	26.7	21.8
36	10.0	132.7	1.09	4.9	119	160	170	19.1	27.3	30.2	22.3
37	13.0	151.0	1.43	5.2	103	250	64	36.8	7.5	8.7	7.7
38	17.1	138.3	1.51	6.8	197	354	124	6.1	7.8	8.1	6.1
39	10.0	105.8	1.08	6.6	109	302	61	31.4	9.7	7.1	6.7
40	22.3	223.6	2.34	6.5	291	269	221	1.3	9.7	12.0	7.4
41	12.8	111.0	1.29	6.9	145	379	66	12.0	11.2	9.7	7.0
42	11.3	132.5	1.12	5.2	112	212	119	13.2	11.5	9.9	9.8
43	13.1	139.6	1.40	6.4	135	211	236	9.8	13.3	11.2	9.5
44	10.2	136.9	1.18	4.5	112	222	52	40.9	13.8	18.5	13.3
45	10.8	126.1	1.07	6.1	111	125	139	23.0	15.5	11.8	9.5
46	14.5	161.3	1.49	5.3	129	173	194	16.9	15.7	11.4	11.1
47	9.6	116.6	1.03	6.0	125	327	175	13.7	28.2	33.4	27.2
48	46.5	302.7	2.43	6.8	207	1331	471	117.5	29.0	23.1	19.7
Mean	12.8	135.6	1.30	5.9	143	253	141	17.3	12.8	11.6	9.8
v%	45	30	25	11	31	77	52	101	43	53	50

Table 2. Yield of barley shoots and sulphur concentration in dry matter of barley shoots

Soil No.	Variant A (control)			Variant B (S-treated response)		
	yield (g DM/pot)	*SD*	S-concentration (g/kg)	yield (g DM/pot)	*SD*	S-concentration (g/kg)
1	0.328	0.042	1.08	0.436	0.020	3.36
2	0.688	0.030	0.84	0.838	0.079	2.26
3	0.446	0.032	1.42	0.501	0.073	2.40
4	0.635	0.039	1.11	0.674	0.023	2.99
5	0.416	0.021	1.21	0.444	0.071	3.08
6	0.652	0.047	1.27	0.758	0.046	2.15
7	0.540	0.059	1.21	0.604	0.032	2.53
8	0.468	0.064	0.90	0.595	0.069	2.78
9	0.438	0.031	1.40	0.529	0.023	2.91
10	0.469	0.038	1.31	0.550	0.026	3.01
11	0.565	0.060	1.23	0.564	0.036	2.51
12	0.593	0.037	1.65	0.640	0.047	2.87
13	0.379	0.036	0.98	0.459	0.026	3.55
14	0.475	0.034	1.05	0.572	0.017	3.12
15	0.401	0.003	0.85	0.539	0.051	2.85
16	0.559	0.015	1.02	0.568	0.040	2.89
17	0.602	0.035	0.97	0.614	0.006	3.01
18	0.671	0.020	1.03	0.635	0.031	2.85
19	0.445	0.030	1.16	0.433	0.042	3.66
20	0.502	0.008	1.01	0.482	0.021	2.99
21	0.503	0.021	1.20	0.462	0.022	3.66
22	0.572	0.034	1.05	0.524	0.030	3.40
23	0.426	0.022	1.12	0.393	0.021	3.43
24	0.493	0.037	1.88	0.466	0.018	3.91
25	0.427	0.043	0.83	0.543	0.011	2.52
26	0.397	0.047	0.86	0.547	0.021	2.59
27	0.330	0.011	1.06	0.489	0.044	2.86
28	0.438	0.007	0.86	0.560	0.006	2.35
29	0.556	0.036	1.07	0.600	0.012	3.36
30	0.472	0.029	1.50	0.542	0.020	3.01
31	0.517	0.034	1.40	0.570	0.028	2.74
32	0.455	0.012	1.06	0.503	0.026	2.91
33	0.469	0.010	1.03	0.516	0.023	2.88
34	0.522	0.023	1.09	0.554	0.009	2.83
35	0.513	0.029	2.39	0.539	0.018	3.14
36	0.560	0.032	2.62	0.536	0.042	4.18
37	0.508	0.024	1.00	0.564	0.036	2.95
38	0.554	0.022	0.81	0.602	0.031	2.77
39	0.513	0.017	0.90	0.642	0.029	2.48
40	0.698	0.049	1.12	0.717	0.039	2.61
41	0.572	0.025	0.99	0.687	0.038	2.34
42	0.502	0.015	1.06	0.517	0.019	3.60
43	0.518	0.038	1.10	0.555	0.035	2.85
44	0.549	0.022	1.08	0.513	0.007	3.36
45	0.547	0.025	0.84	0.581	0.059	2.26
46	0.508	0.022	1.42	0.522	0.022	2.40
47	0.584	0.026	1.11	0.623	0.037	2.99
48	0.771	0.037	1.21	0.786	0.027	3.08
Mean	0.5155			0.5643	paired *t*-test:	
SD	0.0923			0.0905	means are significant different	
Lower 95% *CI*	0.4887			0.5380	mean of differences = 0.0482 95% *CI* = –0.06528 to –0.03237	
Upper 95% *CI*	0.5423			0.5906	*R* squared = 0.4317	
v%	17.90%			16.04%	*r* = 0.7912	

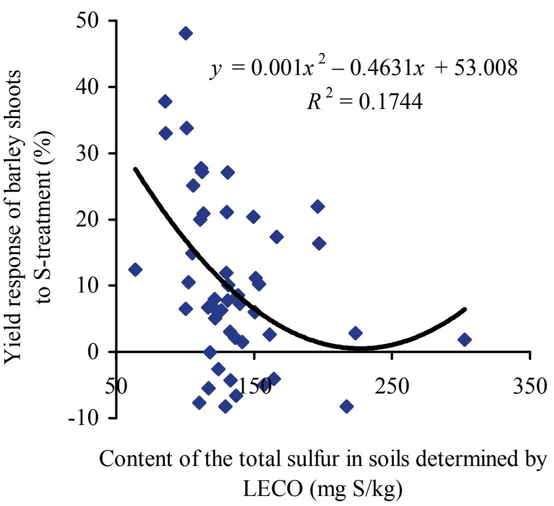

Figure 1. Relationship between the total content of sulphur in soil and the response of barley shoot biomass

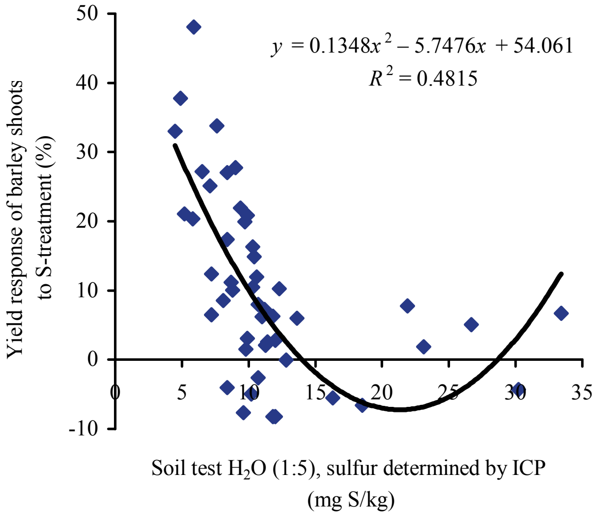

Figure 2. Relationship between the H_2O (1:5) S-soil test (sulphur determined by ICP technique) and the response of barley shoot biomass

hence the low coefficient of determination (R^2) of the trend of the relationship to the concentration of the total sulphur in the soil determined on a LECO CNS 2000 analyser, is in agreement with our previous results (Matula 1999a, b) documenting that the total content of sulphur in the soil has a low informative value for the purposes of preventive diagnostics of the nutrient status of soil in the field. The coefficient of determination (R^2) of the relationship of yield response to the information on the soil reserve of sulphur was considerably better for the used extraction soil tests (H_2O and KVK-UF) (Figures 2–4) but the scatter of correlation field was still large to enable more exact specification of the appropriate soil reserve of sulphur.

In a variegated set of soils with different statuses of nutrients (also others besides sulphur) (Table 1) a simple relationship between the soil reserve of labile sulphur and the production of barley shoot biomass can hardly be assumed because the plant growth integrates the participation of all vegetation factors although the influence of basic factors (light, warmth, water) should be standardised by plant cultivation in a plant growth chamber. A comparison of Figures 2 and 3 should indicate that the final analytical technique of sulphur deter-

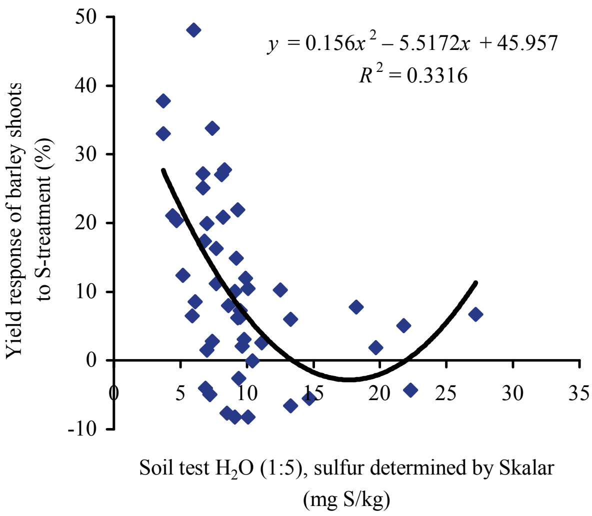

Figure 3. Relationship between the H_2O (1:5) S-soil test (sulphur determined by SKALAR technique) and the response of barley shoot biomass

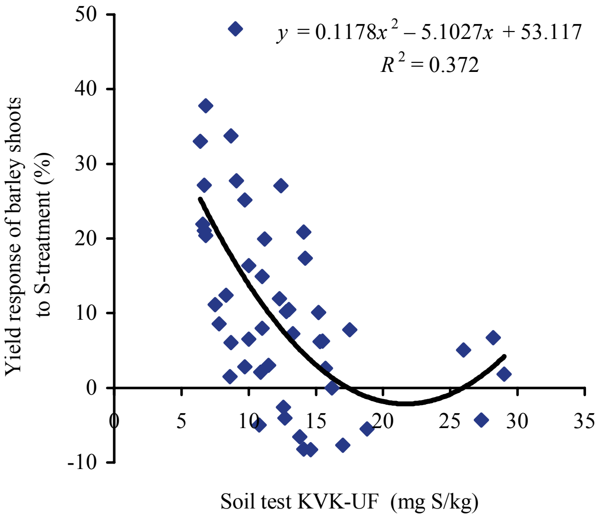

Figure 4. Relationship between the KVK-UF soil test (sulphur determined by ICP technique) and the response of barley shoot biomass

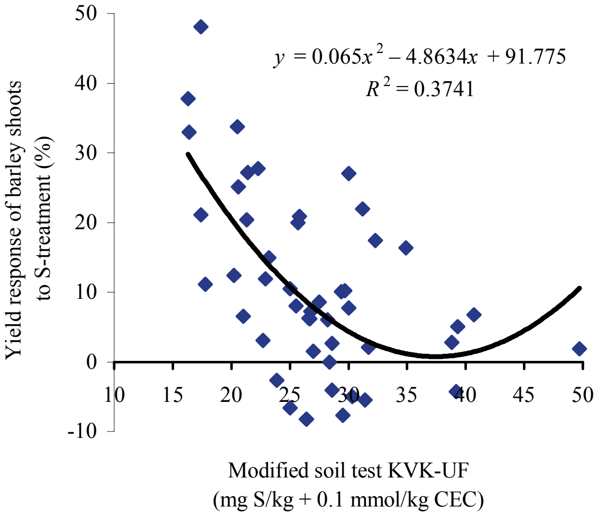

Figure 5. Relationship between the modified KVK-UF soil test (sulphur determined by ICP technique) and the response of barley shoot biomass

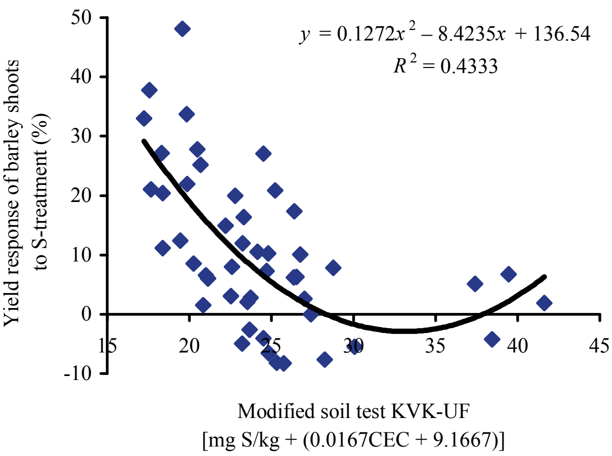

Figure 6. Relationship between the modified KVK-UF soil test (sulphur determined by ICP technique) and the response of barley shoot biomass

mination is important for water extraction of soil. Higher closeness of the trend of the relationship between soil reserve of sulphur and yield response of barley was found out in the ICP technique that indicates all extracted forms of sulphur including the organic form unlike the analytical technique SKALAR when only the sulphate form of sulphur was determined. Matula and Pechová (2002), who evaluated the soil reserve of sulphur by KVK-UF test, reported some indications of the relationship between the sulphur status of soil and CEC value of soil. Therefore the determined sulphur concentration in the soil was adjusted in Figures 5 and 6 by a portion of the CEC value. In Figure 5 a tenth of the CEC value was added up to the sulphur value determined by KVK-UF test. In Figure 6 a variable portion of CEC was used for adjustment in relation to its absolute magnitude (0.0167CEC + 9.1667) that increased the closeness of the relationship between soil sulphur and yield response of barley.

An appropriate level of the soil reserve of available sulphur should correspond to plant requirements while the nutrient is utilised for plant production

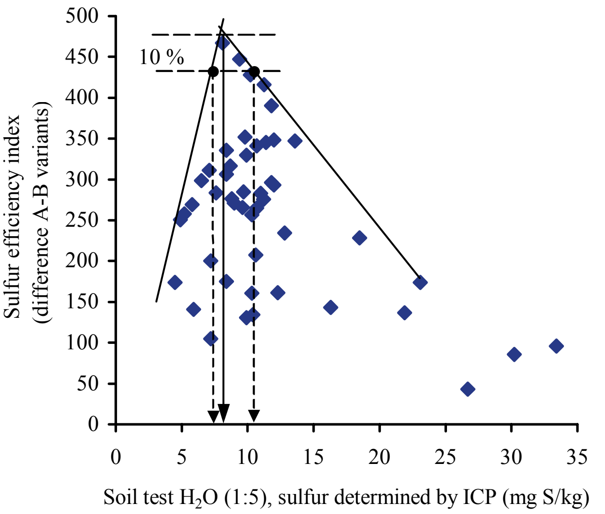

Figure 7. Use of sulphur efficiency index and boundary line approach for the approximation of appropriate levels of sulphur labile forms in soil determined by the H_2O (1:5) S-soil test (sulphur determined by ICP technique)

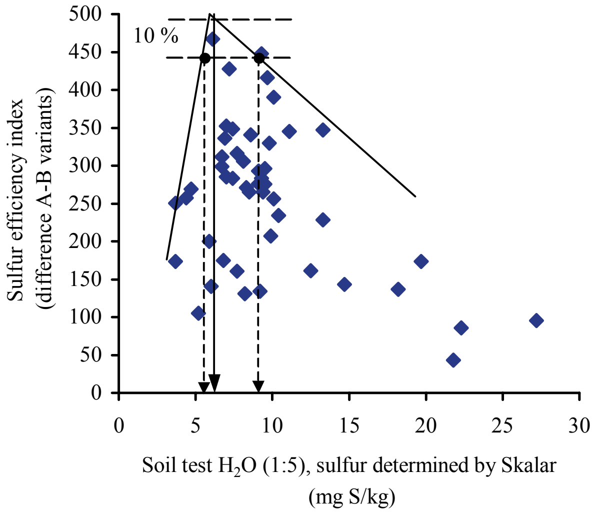

Figure 8. Use of sulphur efficiency index and boundary line approach for the approximation of appropriate levels of sulphur labile forms in soil determined by the H_2O (1:5) S-soil test (sulphur determined by SKALAR technique)

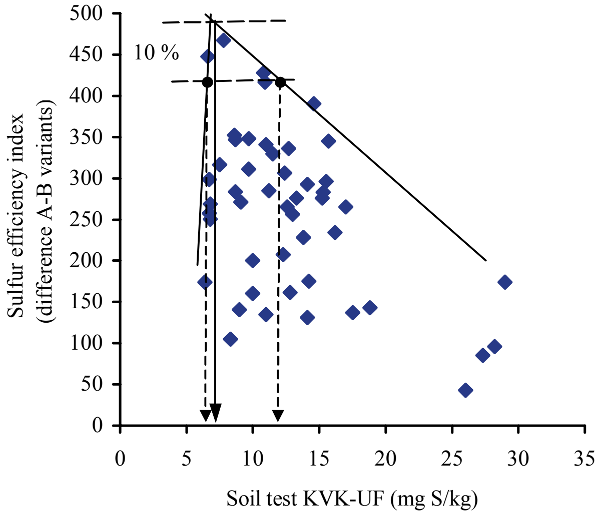

Figure 9. Use of sulphur efficiency index and boundary line approach for the approximation of appropriate levels of sulphur labile forms in soil determined by the KVK-UF soil test (sulphur determined by ICP technique)

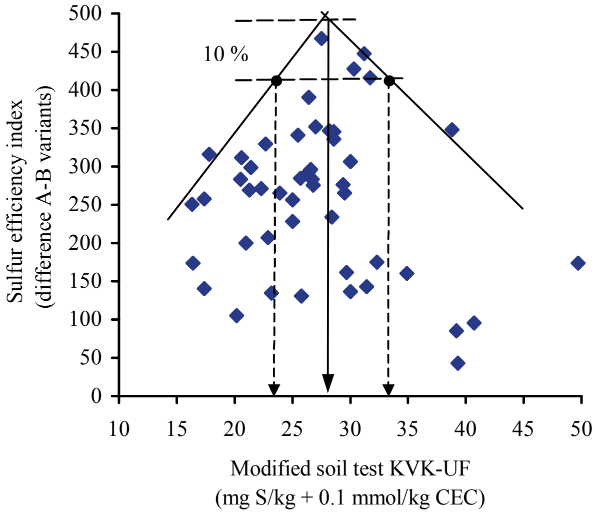

Figure 10. Use of sulphur efficiency index and boundary line approach for the approximation of appropriate levels of sulphur labile forms in soil determined by the modified KVK-UF soil test (mg S/kg + 0.1 mmol/kg CEC)

as best as possible. To evaluate the efficiency of nutrient utilisation, index of nutrient efficiency (IE) is used that is defined as a ratio of nutrient concentration in the crop (N) and total crop yield (Y), IE = Y/N (Matula et al. 1982, Matula 1986).

A boundary line approach can be employed to evaluate the appropriate soil reserve of a specific nutrient in relation to crop yield (Webb 1972, Evanylo and Summer 1987, Black 1993). This approach is based on the fact that crop yield is a resultant of the combination of all vegetation factors. If the vegetation factors approach the equipoise, yield increases and the scatter of correlation field is reduced. The apex of the intersection of boundary lines should indicate the appropriateness of soil reserve of a specific nutrient.

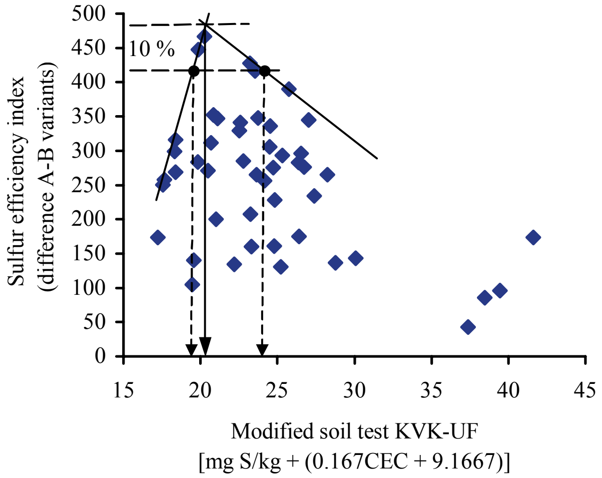

Figure 11. Use of sulphur efficiency index and boundary line approach for the approximation of appropriate levels of sulphur labile forms in soil determined by the modified KVK-UF soil test [mg S/kg + (0.0167CEC + 9.1667)]

The approaches of the index of nutrient efficiency and boundary lines were combined in Figures 7–11 to estimate the efficient soil reserve of sulphur defined by soil tests of water extraction and KVK-UF. In the soil test of water extraction with sulphur determination by the ICP technique (Figure 7) the most efficient reserve was about 8 mg S/kg, up to 11 mg S/kg. When only sulphates were determined on a SKALAR analyser, the maximum efficiency of sulphur utilisation was about 6 mg S/kg, up to 10 mg S/kg. The range of 7–12 mg S/kg indicated the efficient utilisation of sulphur from the soil reserve in the KVK-UF soil test. After the soil reserve of sulphur was adjusted by adding up 1/10 of the CEC value to the value of S-soil test, the appropriate range was between 24 and 34. Following the adjustment of KVK-UF S-soil test by adding up a variable portion of the CEC value (0.0167CEC + 9.1667), the range of the efficient utilisation of soil sulphur was indicated by the value of S-index 19–23. The condensation of the point field (Figure 11) suggested that this mode of adjustment to the index of soil reserve of sulphur was more correct, also from the aspect of the asymmetric shape of boundary line. The asymmetric shape of the function corresponds better to the biological principle of the relationship. The kurtosis of the left part of the function illustrates a biological response to the stimulus that ends in a maximum response followed by the abatement phase of the response – a slow decrease.

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ABSTRAKT

Reakce ječmene na zásobu síry v půdě a síran amonný v krátkodobých experimentech za kontrolovaných podmínek kultivace

Cílem pokusu bylo indikovat vhodnou koncentraci dostupné síry v půdě pro počáteční růst rostlin. K informaci o zásobě síry na základě předchozího výzkumu byly použity dva postupy extrakce půdy: vodou (H_2O 1 : 5, w/v) a 0,5M octanem amonným s přídavkem NH_4F (půdní test KVK-UF). Testovací plodinou zásobenosti půdy sírou a odezvy na přídavek síry do půdy byl jarní ječmen. K tomuto účelu byla vytvořena kolekce 48 vzorků půd ornice ze zemědělsky významných lokalit ČR s výraznými parametry rozdílů výživného stavu půd. Se souborem půd byly zakládány krátkodobé vegetační experimenty v klimaboxu podle schématu: A) kontrola – bez přídavku síry a B) odezvová varianta s přídavkem 30 mg S/kg půdy ve formě $(NH)_4SO_4$; ve variantě A byl dusík vyrovnán NH_4Cl. K posouzení efektivnosti výživy ječmene sírou byl použit koncept indexu účinnosti živiny (IE = Y/N, kde Y = výnos a N = koncentrace živiny v rostlině) a hraničních linií bodového pole. Pro půdní test H_2O (1 : 5) byla indikována efektivní zásoba síry v půdě v rozmezí 8–11 mg S/kg při analytické koncovce ICP a 6–10 mg S/kg při detekci síranů na analyzátoru SKALAR. Pro půdní test KVK-UF bylo efektivní využití síry ječmenem z půdy v oblasti 7–12 mg S/kg. Převod S-testu KVK-UF na index zásoby síry v půdě přídavkem proměnlivého podílu z hodnoty CEC k hodnotě stanovené síry půdním testem (0,0167CEC + 9,1667) zlepšil těsnost vztahu závislosti mezi půdou a rostlinou.

Klíčová slova: síra; testování půd; ječmen

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