Sulfur and sulfate concentrations in leaves of oilseed rape under field conditions

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ABSTRACT

In 1999–2001 sulfur and sulfate concentrations were studied in expanded young leaves of rapes of the line variety Lirajet and hybrid variety Pronto at the onset of stem elongation (DC 30), flowering (DC 64) and early maturity (DC 70) in different localities of the Czech Republic. Except the S-deficient site the concentration of total sulfur and sulfates in leaves considerably increased in higher growth stages. A less steep increase in S concentration in leaves was associated with rather humid growing season, especially with April precipitation. Great time variations in sulfur concentrations in leaves signal a possibility of diagnostic misinterpretation of plant analysis without exact definition of growth stage. The shape of trend of variations in S concentration in leaves indicates the S nutritive state of the site and the intensity of upward transport of sulfates with soil moisture in the crop nutrition with sulfur. Good yields of rapeseed were connected with minimum concentration of total sulfur 0.5%, and sulfate sulfur 0.2% in leaf dry matter at DC 30. The proportion of sulfates in total concentration of sulfur in rape leaves ranged from 30 to 60% at the onset of stem extension and it increased in higher phenophases. At flowering, sulfates accounted for 80% and more at sites where sulfate uptake from the soil environment was not problematic. Besides the S-soil test, the results of investigations indicate the importance of CEC value of soil for the preventive diagnosis of S-nutrient state of the site.

Keywords: winter rape; growth stages; expanded young leaves; sulfur; sulfates

Although sulfur is a major nutrient, it was not studied in the past as frequently as other nutrients. Research on sulfur was scarce because analytical methods of sulfur determination were complicated before the methods of inductively coupled plasma (ICP) and ion chromatography (IC) were introduced on a larger scale. Hardly any symptoms of sulfur deficiency were observed in farm crops in the Czech Republic until recently. Emissions from fossil fuel burning were a massive source of sulfur for the soil in the past. Sulfur fertilization was latent without considering sulfur applications. For example, important sources of sulfur were phosphorus fertilization when single superphosphates were used and nitrogen fertilization in form of ammonium sulfate applications.

Similarly like for other nutrients a rational fertilization system should be developed for sulfur to avoid unnecessary devaluation of a complex of other inputs into crop production through apparent or latent sulfur deficiency. The equivalence of sulfur nutrition of rape to the intensity of nitrogen nutrition can be an important prerequisite of effectiveness of farmers' inputs in N-fertilization including the national impact on the environment (Haneklaus et al. 1999). Sulfur metabolization in the plant to produce full-value proteins is closely associated with nitrogen metabolization (McGrath and Zhao 1996, Zhao et al. 1997).

Crop production rationalization requires operative information and tools while the diagnosis of nutritive state of soil and plants plays an important role. Analyses of plants for nutrient contents particularly at early growth stages can be an indicator of the need to adjust the nutritive state of the crop by fertilization. Research on sulfur concentrations in rape plants grown in natural field conditions is necessary for agronomic calibration of sulfur diagnosis (Blake-Kalff et al. 2000). Data on sulfur in plants from pot trials can be highly misleading from the aspect of agronomic interpretation. There is a consensus in rapes that the best information on sulfur nutrition is provided by a fully expanded young leaf in the upper part of the plant (McGrath and Zhao 1996, Schnug and Haneklaus 1998, Scherer 2001).

Sulfates are the main form of sulfur uptake by the plant; their interference with the solid phase of soil on the basis of physical and chemical principles is minimum in cultivated soils. The supply of readily available sulfur to plants is substantially influenced by the volume of soil solution and by capillary (soil solution) movement in the soil profile of the site. In dependence on the parent rock groundwater usually has higher concentrations of sulfates than current precipitation (Eriksen et al. 1998).

The objective of our research was to collect data on concentrations of total sulfur and sulfates in varieties of line and hybrid rapes in order to improve the diagnosis of the nutritive state of rapes grown in different localities of the Czech Republic.

MATERIAL AND METHODS

Field trials with winter rape varieties were conducted on farms in 1998–2001. Rape varieties were sown in strips 18–24 m wide while the total area of a variety strip was

Table 1. Basic information on experimental parcels

Locality	Soil type (kg.ha^{-1})	Year	Parcel	pH_{KCl}	CEC [mmol(+).kg^{-1}]	S[1] (mg.kg^{-1})	Organic manuring[2] (t.ha^{-1})		Spring fertilization N dose	S dose[3]
Koloveč	Cambisols	1999	Lirajet	5.8	130	8.0	manure	35	172	0
			Pronto	5.7	125	8.1				
		2000	Lirajet	5.8	118	11.2	manure	40	160	0
			Pronto	5.9	139	11.7				
		2001	Lirajet	5.7	191	18.4	manure	35	210	32
			Pronto	6.4	130	21.1				
Žimutice	Albeluvisols	1999	Lirajet	6.0	100	9.1	manure	26	211	0
			Pronto	6.0	112	11.1				
		2000	Lirajet	5.5	120	18.0	manure	42	188	0
			Pronto	5.9	142	22.5				
		2001	Lirajet	6.7	121	17.1	manure	44	203	29
			Pronto	6.7	124	19.9				
Opařany	Vertic Cambisols	1999	Lirajet	5.7	152	10.4	manure	40	150	0
			Pronto	6.1	110	8.5				
		2000	Lirajet	5.3	141	20.1	manure	40	160	0
			Pronto	5.5	221	12.5				
		2001	Lirajet	5.2	162	12.5	manure	40	174	0
			Pronto	5.1	124	13.2				
Sychrov	Dystric Cambisols	1999	Lirajet	5.2	66	8.9	manure	40	177	0
			Pronto	5.9	79	11.0				
		2000	Lirajet	7.0	94	16.1	manure	40	150	16
			Pronto	5.6	92	21.2				
		2001	Lirajet	4.7	119	20.2	pig slurry	40	157	23
			Pronto	5.0	99	22.0				
Sobotka	Arenic Cambisols	1999	Lirajet	6.5	94	6.9	manure	30	150	0
			Pronto	6.4	99	6.9				
		2000	Lirajet	6.3	111	9.5	manure	30	150	0
			Pronto	6.1	117	10.8				
		2001	Lirajet	5.1	131	10.9	manure	30	150	0
			Pronto	5.7	117	13.0				
Červené Janovice	Albeluvisols	1999	Lirajet	6.7	133	13.4	0	171	0	
			Pronto	6.1	118	12.6				
		2000	Lirajet	6.5	128	12.4	manure	40	204	0
			Pronto	6.7	133	12.8				
		2001	Lirajet	6.1	139	14.6	0	205	0	
			Pronto	5.9	135	14.1				
Radouň	Arenic Cambisols	1999	Lirajet	6.8	163	9.9	0	169	0	
			Pronto	5.5	106	11.3				
		2000	Lirajet	6.7	112	10.7	manure	30	153	0
			Pronto	7.0	109	9.7				

[1] extraction KVK-UF (Matula 1999)
[2] before trial establishment
[3] fertilizer DASA, ammonium nitrate + amonium sulfate

0.8–1 ha. Strips with line variety Lirajet and hybrid variety Pronto were chosen for experimental observations. Three 5 m^2 control parcels (replications) were located in random within the variety strip; 15–20 fully expanded leaves of the upper storey were sampled on these parcels at the stage of stem extension (DC 30), flowering (DC 64) and after flowering terminated – at the beginning of maturity (DC 70). Leaf samples were washed with deionized water and transported in a portable cooling box (at 4–6°C) to a laboratory where they were dried at 65°C. Dry matter of homogenized leaves was mineralized in a MILESTONE microwave device in the medium of nitric acid and hydrogen peroxide. The content of total sulfur was determined on an ICP-OES Trace SCAN Thermo Jarrell Ash apparatus. A SAN Plus System SKALAR analyser was used to determine sulfates after extraction of leaf dry matter with water (0.5 g + 25 ml H_2O, 1 hour shaking in a rotary shaker).

Trials were conducted at seven localities in 1999–2000. In 2001, Radouň locality was not used. Table 1 shows the information on localities including some agrochemical characteristics of experimental parcels (strips), and intensity of nitrogen and sulfur fertilization.

RESULTS AND DISCUSSION

Figures 1–7 document high variability in concentrations of total sulfur and sulfates in young fully expanded rape leaves in relation to plant age. A steep increase in total sulfur and sulfate concentrations was recorded in most trials at higher growth stages of rapes. The exceptions were trials in Sychrov locality in 1999 (Figure 4) and in Radouň locality in 2000 (Figure 7). Both trials were conducted on light soils with low value of CEC (Table 1) and shallow soils on sandstones of the Bohemian Cretaceous platform. S-deficient locality Sychrov was identified by the KVK-UF soil test (Matula 1999) before the trial was established in 1998. In the course of pre-sowing preparation 40 t.ha^{-1} farmyard manure and 100 kg.ha^{-1} of ammonium sulfate (i.e. 24 kg S.ha^{-1}) were applied to the soil. Regardless of this fertilization measure, a low content of total sulfur and sulfates was determined in spring 1999 in young fully expanded leaves of rapes at the onset of stem exten-

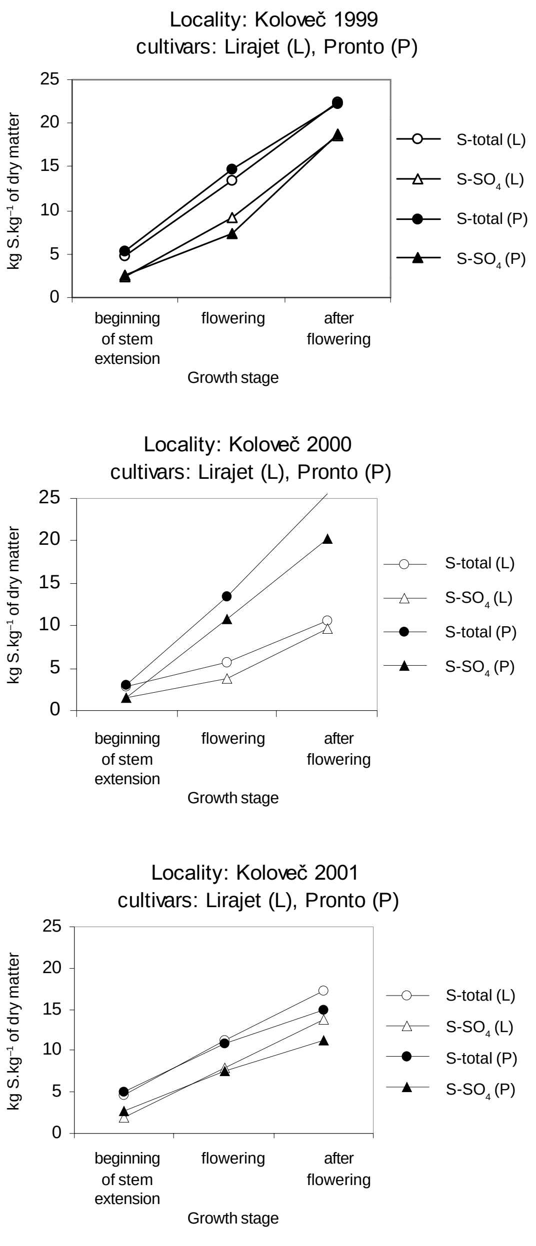

Figure 1. Concentrations of total sulfur and sulfates in fully expanded leaves in the upper part of plant at Koloveč locality

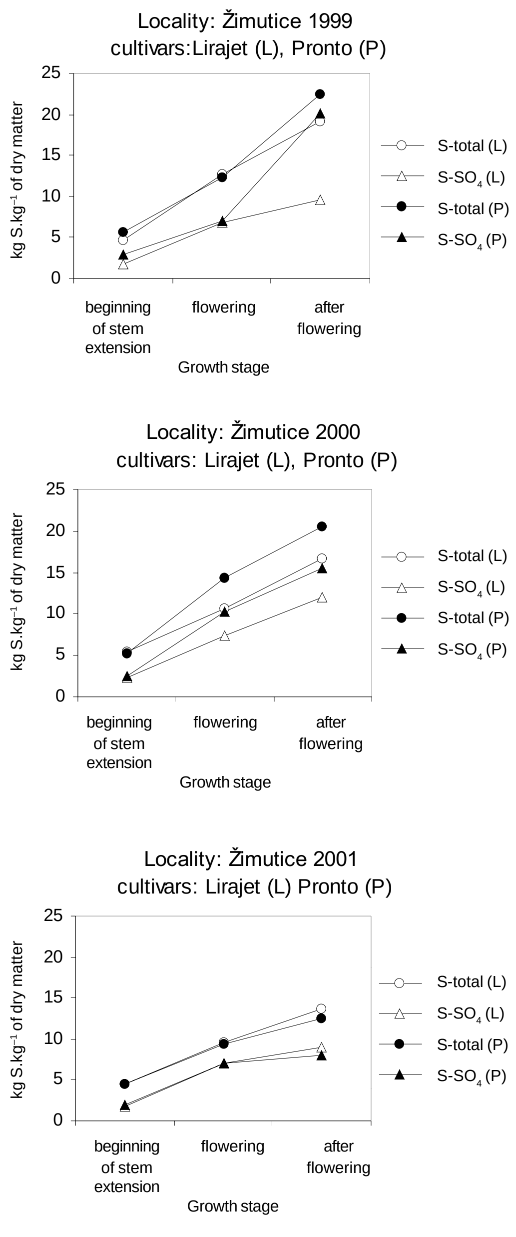

Figure 2. Concentrations of total sulfur and sulfates in fully expanded leaves in the upper part of plant at Žimutice locality

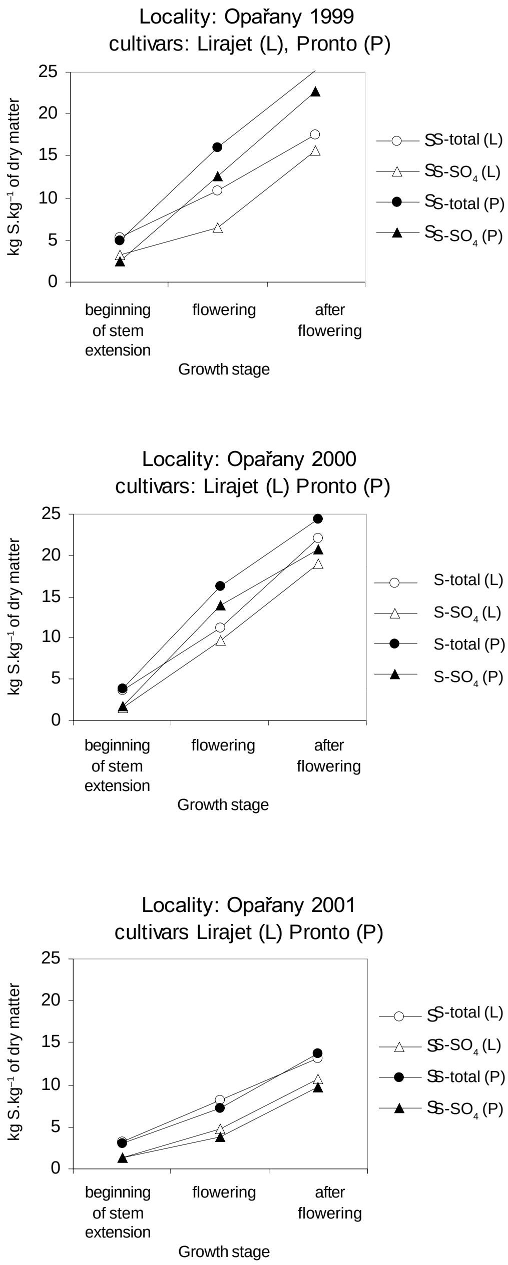

Figure 3. Concentrations of total sulfur and sulfates in fully expanded leaves in the upper part of plant at Opařany locality

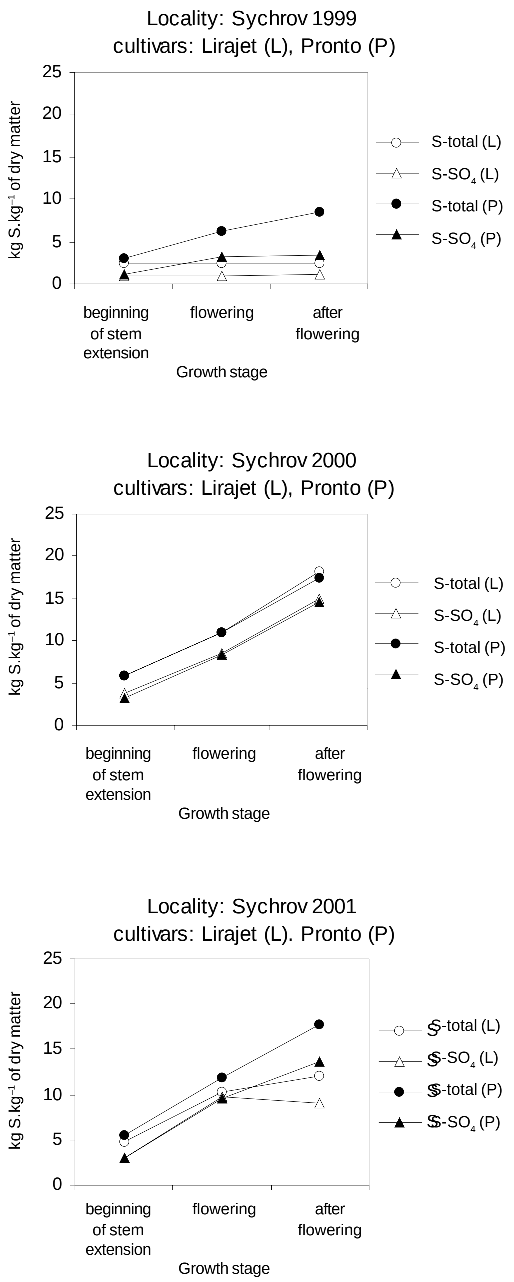

Figure 4. Concentrations of total sulfur and sulfates in fully expanded leaves in the upper part of plant at Sychrov locality

sion. The concentrations of 0.24% S_{tot} and 0.1% sulfur in form of sulfates were determined in dry matter of leaves in Lirajet variety; the respective values in Pronto variety were 0.3% S_{tot} and 0.12% sulfur in form of sulfates. These results are supported by conclusions of Pedersen et al. (1998) that organic fertilization does not prevent sulfur deficiency in crops. Although the intensity of nitrogen fertilization was high in the spring season (180 kg N.ha^{-1}), a substantial reduction in rapeseed yield was observed (Table 2). A slight increase in the concentration of total sulfur in leaves was recorded on Pronto parcel (Sychrov 1999) at higher growth stages of rape, contrary to stagnation on Lirajet parcel (Figure 4). It corresponds with the higher value of soil CEC and higher S-soil test of Pronto parcel.

In the next years DASA fertilizer (26% N, 13% S) was included in the system of the first spring fertilization in Sychrov locality: doses of 120 kg.ha^{-1} (2000) and 180 kg.ha^{-1} (2001) were applied. The application of sulfate sulfur at a dose of 16–23 kg S.ha^{-1} in the spring season after winter adjusted S deficiency of the site unlike the inefficiency of autumn application in 1998. Early spring sulfur fertilization was registered by the S-soil test (Table 1), it was reflected in sulfur concentration in rape leaves (Figure 4) and in rapeseed yield (Table 2).

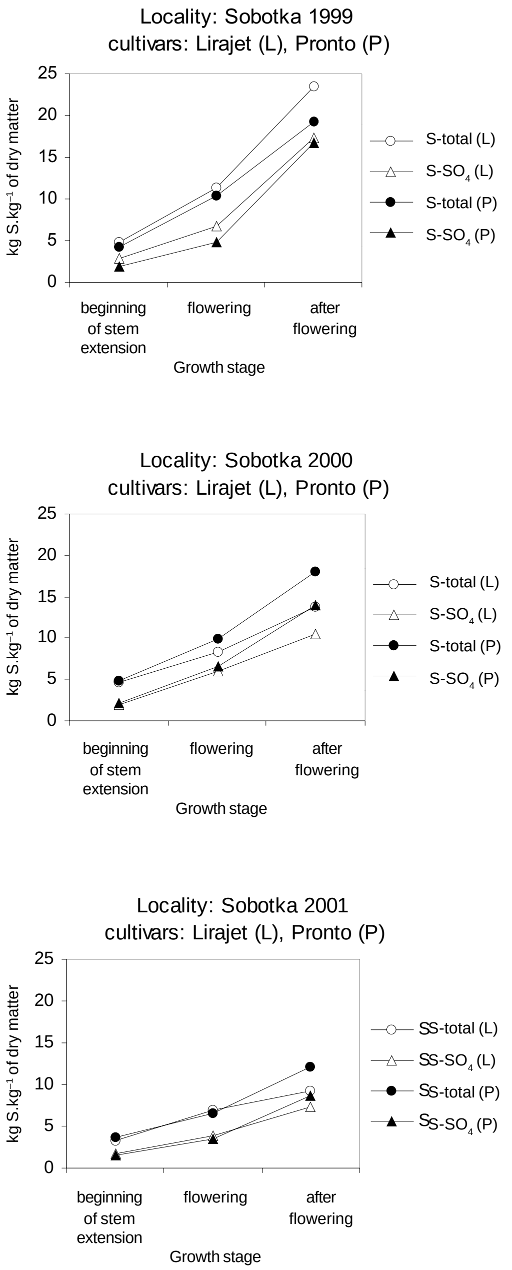

Figure 5. Concentrations of total sulfur and sulfates in fully expanded leaves in the upper part of plant at Sobotka locality

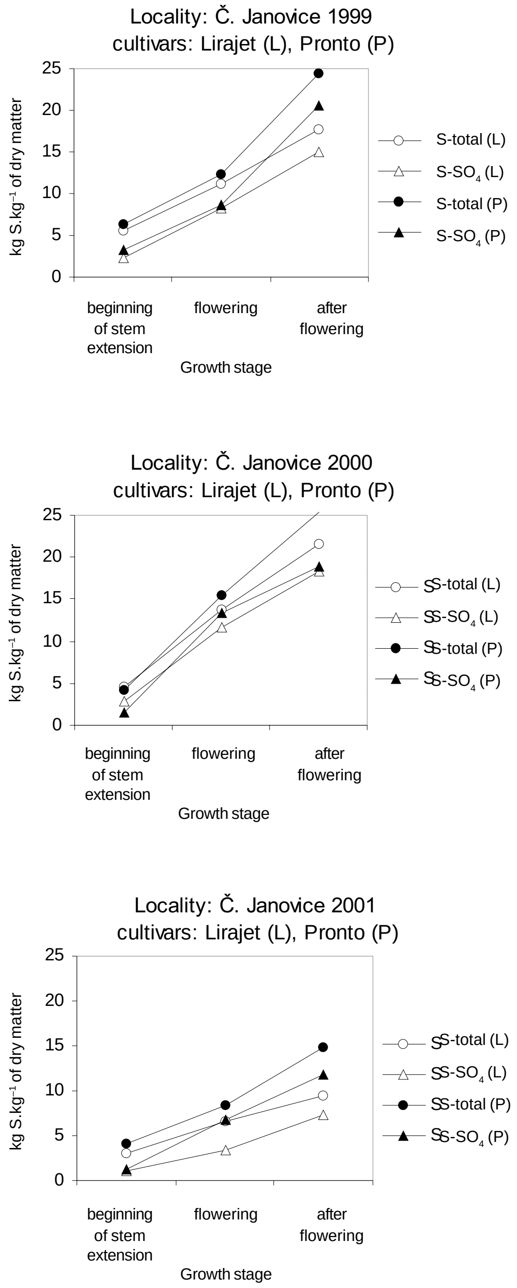

Figure 6. Concentrations of total sulfur and sulfates in fully expanded leaves in the upper part of plant at Červené Janovice locality

A possibility of great variations in sulfur concentration in rape leaves at higher growth stages of the crop signals a risk of misinterpretation of plant analyses for the diagnosis of crop nutritive state without adequate specification of growth stage. A trend of variations in dependence on time (progress of growth stages) would be a better criterion of the crop nutritive state at the site.

It can be deduced from the three-year results of study of relations in natural site conditions of rape crops that at the onset of stem extension a good yield of rapes requires minimally 5 g S_{tot}.kg^{-1} in dry matter of fully expanded young leaves of rapes, or 2 g S_{SO_4}.kg^{-1}.

Although the main supply of sulfur in the soil is a part of organic matter, our previous research indicated that it was not possible to rely on a higher supply of available sulfur to plants from mineralization of soil organic matter during the growing season (Matula et al. 1999, 2000), which is in accordance with research in Denmark (Eriksen et al. 1995, Eriksen 1997). The supply of available sulfur in the soil, i.e. particularly of sulfates, is derived from the volume of soil solution and sulfate concentration in the active soil profile of the plot because there is hardly any sorption interaction of sulfates with the solid phase of soil in cultivated soils.

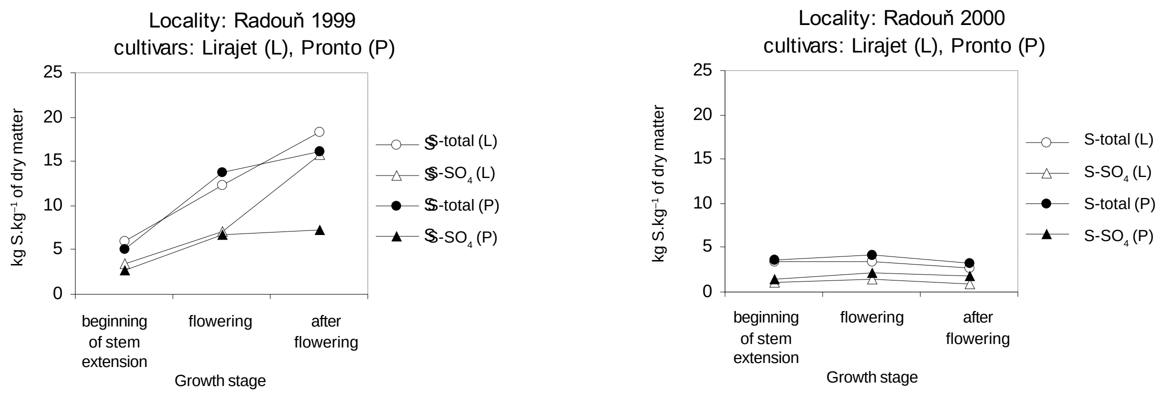

Figure 7. Concentrations of total sulfur and sulfates in fully expanded leaves in the upper part of plant at Radouň locality

After the emissions of sulfur oxides from coal burning in power plants in the CR radically decreased, precipitation ceased to be a source of sulfur input into the soil. Precipitation dilutes sulfur concentration in the surface layer of soil while sulfate concentration in the lower layer of available water is regularly 10–100 higher (Eriksen et al. 1998).

Therefore, the crop nutrition with sulfur at a site will be significantly influenced by the volume of soil solution and direction of soil moisture movement in the active profile of soil during vegetation. This phenomenon could explain an increase in sulfur concentration in plants at higher growth stages in most experimental localities. In the course of vegetation, the capillary flow of soil moisture usually rises because of the increasing transpiration consumption of water by the crop. The intensity and capillary movement of water in the soil profile are influenced in the conditions of this country by April precipitation. Average sums of April precipitation in the Czech part of the Czech Republic were in the experimental years as follows: 1999 – 34 mm, 2000 – 19 mm and 2001 – 65 mm. A considerably less steep increase in sulfur concentration in rape leaves at higher growth stages than in preceding drier years is correlated with relatively humid year 2001 (Figures 1–7) while the parameters of S-soil test of topsoil and CEC values were similar.

Table 2. Rapeseed yields

Locality	1999		2000		2001	
	Lirajet	Pronto	Lirajet	Lirajet	Pronto	Lirajet
Koloveč	4.3	3.6	3.8	4.4	4.4	5.1
Žimutice	4.2	4.7	5.2	5.3	4.2	4.8
Opařany	3.9	3.6	3.6	3.2	3.5	3.8
Sychrov	2.7	3.4	4.3	4.8	4.1	4.3
Sobotka	3.4	4.9	4.0	4.7	3.1	4.4
Č. Janovice	4.0	3.8	3.8	4.2	3.8	4.3
Radouň	4.1	4.0	2.5	3.4	–	–

The results of the study of sulfur concentration in leaves of selected rape varieties (Lirajet and Pronto) in the experimental years 1999–2001 do not allow to explain the established differences (Figures 1–7) by variety heterogeneity. Different concentrations of sulfur in leaves of rape varieties were always associated with differences in soil characteristics, CEC value and S-soil test (Figures 1–7 and Table 1). For instance Figure 1: in the first experimental year (1998–1999), the varietal trial was established on a flat plot with very balanced soil parameters of experimental parcels (CEC value 125–130, S-soil test 8.0–8.1). Sulfur concentrations and responses of Lirajet (L) and Pronto (P) varieties were very similar. The trial was located on a slope in the next year. Lirajet parcel was located at a higher part of the slope with CEC value 118 mmol(+).kg^{-1} while Pronto parcel was in the lower (inundation) part of the plot. The higher CEC value 139 mmol(+).kg^{-1} indicated the translocation of soil colloid particles. Differences in the value of S-soil test were small (11.2–11.7 mg S.kg^{-1}). Higher level of sulfur concentration in leaves of Pronto corresponded with higher CEC value of the parcel. In 2000–2001 differences in CEC value between Lirajet and Pronto parcels were still larger [L 191 mmol(+).kg^{-1}, P 130 mmol(+).kg^{-1}] and differences in the values of soil S-test were of opposite trend (L 18.4 mg S.kg^{-1}, P 21.1 mg S.kg^{-1}). The course of sulfur concentration in plants of rape varieties was discoupled on the last date of leaf sampling, lower concentration of sulfur in leaves of Pronto was associated with lower CEC value.

The results of observations at all localities in experimental years indicate a relationship between the CEC value of soil and plant nutrition with sulfur at the site. CEC value is an important parameter complementing the S-soil test because it is in close correlation with water capacity of soil. Eriksen et al. (1998) reported that the capacity of S supply in the soil is a function of the capacity of water storage available to plants, depending on the texture, soil depth and volume of soil available to roots.

At a glance, the 1999 results from Opařany locality could be in contradiction with the above-mentioned deduction about the important role of CEC value for plant nutrition with sulfur at the site (Figure 3). The density of Pronto plants was extremely low in this locality (7–10 plants.m^{-2}) while the Lirajet crop was of standard density (45–50 plants.m^{-2}). Therefore, Pronto plants had a larger nutritive space per plant and it could explain the apparently contradictory experimental results.

The proportion of sulfates in the total concentration of sulfur in rape leaves ranged from 30 to 60% at the onset of stem extension and it increased at higher phenophases. At the flowering stage sulfates accounted for about 80% and more at the sites where the uptake of sulfates from the soil was not problematic.

Sulfate determination has a laboratory advantage because only sample extraction (with water) is made. It is not necessary to carry out complicated mineralization of plant sample before the analytical determination of total sulfur that is also a more costly method than sulfate determination. The anticipated advantage of sulfate determination for the diagnosis of plant nutrition with sulfur was based on an assumption that sulfates, as an unmetabolized component of sulfur would respond more sensitively to the level of sulfur nutrition than the content of total sulfur, analogically to the behaviour of nitrates with respect to plant nutrition with nitrogen. The sensitivity of indication of the plant nutritive state through sulfates can be complicated by a high content of sulfates in the plant that need not be compatible with emergency supply of sulfur for metabolization. A large part of sulfates can be inactivated in vacuoles (Blake-Kalff et al. 2000, 2001), which is incompatible with easily available supply of sulfur for metabolization to basic products (proteins).

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ABSTRAKT

Koncentrace síry a síranů v listech řepky pěstované v polních podmínkách

V letech 1999 až 2001 byly sledovány změny koncentrace síry a síranů v rozvinutých mladých listech řepky liniové odrůdy Lirajet a hybridní odrůdy Pronto ve fázi počátku dlouživého růstu (DC 30), kvetení (DC 64) a na počátku zrání (DC 70) v rozdílných lokalitách ČR. Mimo stanoviště vyloženě na síru deficitního vzrůstala výrazně koncentrace celkové síry a síranů v listech s postupem růstových fází. Nižší strmost růstu koncentrace síry v listech byla spojena s výrazně vlhčím vegetačním rokem, zvláště s dubnovými srážkami. Výrazné změny koncentrace síry v listech s časem signalizují možnost chybné diagnostické interpretace analýz rostlin bez přesného definování růstové fáze. Strmost trendu změny koncentrace síry v listech indikuje výživný stav síry stanoviště a intenzitu účasti vzestupného transportu síranů s půdní vláhou na výživě porostu sírou. Dobré výnosy semene řepky byly spojeny s minimální koncentrací 0,5 % celkové síry a 0,2 % síranové síry v sušině listů v DC 30. Podíl síranů na celkové koncentraci síry v listech řepky se pohyboval mezi 30 až 60 % ve fázi počátku dlouživého růstu a s postupem fenofází dále vzrůstal. V době kvetení sírany představovaly již kolem 80 % a více na stanovištích bezproblémového příjmu síranů z půdního prostředí. Výsledky naznačují významnost hodnoty CEC půdy vedle půdního testu síry pro preventivní diagnostiku výživného stavu stanoviště sírou.

Klíčová slova: ozimá řepka; růstové fáze; rozvinuté mladé listy; síra; sírany

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