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The effect of sulphate levels in the nutrient solution on mineral composition of leaves and sulphate accumulation in the root zone of tomato plants

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ABSTRACT

Tomato plants ('Cunero' F_1) were grown in 3 independent units of NFT, supplied by nutrient solutions with different primary sulphate levels (mg SO_4^{-2} dm^{-3}); unit: I - 200, II - 400, III - 600. Concentration of sulphates in the nutrient solutions increased during the entire growing season. At the stage of full harvest it reached the level of 850-1000 (I unit), 1000-1100 (II), 1250-1400 (III) and 800-850 (I unit), 900-1000 (II), 1250 (III) mg SO_4^{-2} dm^{-3}, respectively in the year 2000 and 2001. Sulphate accumulation significantly increased the level of S and S-SO_4 in the leaves as well as N content (in 2001) and decreased the level of P (in 2000) and Mg (in 2001). There were no effects of different sulphate levels in the nutrient solution on the concentration of assimilation pigments, carotenoids and sulphur amino acids.

INTRODUCTION

Accumulation of high levels of some ions in the root zone of plants may be a very serious problem in the cultivation in so-called open systems with the recirculation of the nutrient solution (Lopez et al. 1998, Papadopoulos et al. 1999, Pivot et al. 1999). It refers to chlorides, sulphates and bicarbonates (Zekki et al. 1996).

The amount and rate of sulphate accumulation depends on many factors including plant species, their stage of maturity, temperature and water quality. As a result ion antagonisms may occur together with the retardation of some nutrients. Such processes may affect nutrient uptake by the plants, and may hinder the exploitation of nutrient supply systems (blockage of the drippers).

The aim of the present study was to determine the effect of different sulphate concentrations in the nutrient solution on the rate their accumulation in the root zone, as well as on the mineral composition of plants and concentrations of assimilation pigments and sulphur amino acids in greenhouse tomato leaves.

MATERIAL AND METHODS

Tomato plants ('Cunero' F_1) were grown in the year 2000 and 2001 in the spring-summer cropping season, 3 independent units of NFT, supplied by nutrient solutions with different primary sulphate levels (mg SO_4^{-2} dm^{-3}), e.i.: unit I - 200, II - 400, III - 600. The first level was reached by the use of a typical multiple fertilizer (Superba Red). Other solutions were made on the basis of single fertilizers, technical salts and acids. In each solution, pH was fixed to 5.5-6.0 and it was then checked every day during the cultivation. Each unit of NFT consisted of 4 cultivation plastic troughs filled with the rockwool slabs (Grodan Master, Denmark) and 2 tanks for the nutrient solutions. During the cultivation, in every 7-14 day-periods, the chemical analysis of the solutions was performed and on the basis of the results, the concentration of nutrients was adjusted. Planting density was 3.4 plants per m^2 and detopping was performed over the 8^{th} cluster.

The rate of sulphate accumulation in the root zone was assessed every 7-14 days. To do so, a sample of nutrient solution was taken from the ¾ depth of the rockwool slabs, and the sulphates were determined. Mineral composition of plants was determined by the analysis of leaf petioles on the content of macro- (N, P, K, Ca, Mg, S, and S-SO_4) and microelements (Fe, Mn, Cu, Zn, Mo, and B). The leaves were sampled at the stage of fruit formation on the 4^{th} cluster, as well as at the stage of ripening of the first fruits. Mineral composition was determined in the 4^{th} top, fully matured leaf. At the same time, the content of assimilation pigments (chlorophyll a and b and carotenoids) was determined in the 5^{th} top leaf. The content of sulphur amino acids, cystine and methionine was determined in the leaf

petioles of the low part of the plants, sampled at ripening of the first fruits and in the leaf petioles of the middle part, sampled at full fruit stage, in the year 2001.

Mineral composition of nutrient solutions was determined according to Nowosielski (1988), whereas the content of sulphates was determined by the nephelometric method (Hermanowicz et al. 1976). The analyses of leaves regarding the contents of P, K, Ca, and Mg were performed in the extract made with the use of 2% acetic acid (Nowosielski 1988), and N by the Kjeldahl method. The concentration of microelements was determined after the dry mineralisation of the sample. The content of total S in the leaves was determined using Leco SC–132 apparatus, whereas the sulphates by the nephelometric method (Ostrowska et al. 1991), after the extraction with ammonium acetate. The content of assimilation pigments was determined by the spectrophotometric method (Wettstein 1957). Sulphur amino acids were determined on AA analyzer AAA 400, using the color reaction of amino acids with ninhydrin.

The results were subjected to one-way analysis of variance and the Duncan's multiple-range test (SAS 1996).

RESULTS AND DISCUSSION

During the growth of tomato plants the accumulation of sulphates in the nutrient solution was observed (Figs 1 and 2). The sulphate levels were identical in the solutions sampled either from the slabs or capillars. At the stage of full harvest the concentration reached the levels 850-1000 (I unit), 1000-1100 (II), 1250-1400 (III) and 800-850 (I), 900-1000 (II), 1250 (III) mg dm^{-3}, respectively in the year 2000 and 2001. The concentration of sulphates in the nutrient solution increased during the entire growing season. Moreover, the apparent tendencies for increased accumulation of sulphates in May-June, in both years were observed. In this period, particularly in 2001, the highest variation in the concentration of sulphates was demonstrated. An increase in sulphate concentration in these months may have resulted from increased transpiration of plants, as well as from increased intake of nutrients by the plants being at the stage of fruit formation. Plants at this stage of growth require increased fertilization, including that with sulphate ions. Similar pattern of accumulation of sulphates during the entire growth season was observed by Pivot et al. (1999). It should be added that during the entire growth period the differences between units in sulphate concentration in the nutrient solution were relatively equal.

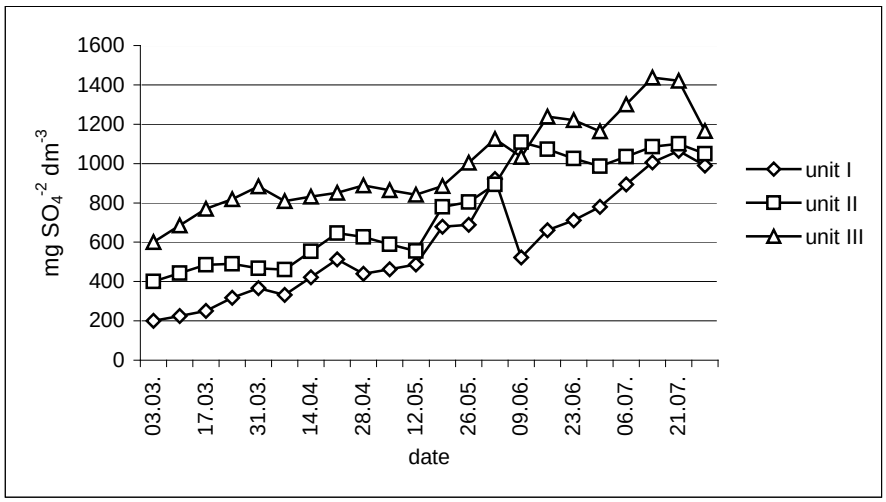

Figure 1. Sulphate accumulation in the nutrient solution at the root zone in the NFT units (unit I - 200, II - 400, III - 600 mg dm^{-3}) in 2000

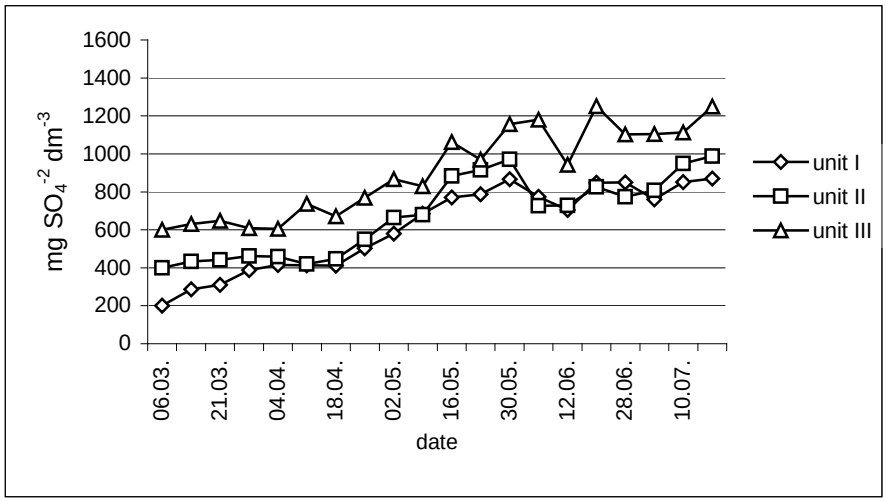

Figure 2. Sulphate accumulation in the nutrient solution at the root zone in the NFT units (unit I - 200, II - 400, III - 600 mg dm^{-3}) in 2001

The sulphate concentration affected mineral consumption of tomato leaves (Tables 1 and 2). However, irrespective of the cultivation year, this effect was more apparent in the leaves sampled at the stage of ripening of the first fruits (phase II) than at the fruit formation on the 4^{th} cluster (phase I).

Table 1. The effects of sulphate levels in the nutrient solution on dry matter and mineral composition of leaves of tomato grown in NFT (in 2000)

Item		Sulphate level in nutrient solution (mg dm^{-3})			$LSD_{0.05}$
		200	400	600	
Stage I[1]					
Dry matter (%)		12.61	11.79	12.43	n.s.
Macroelements (% d.m.):					
	N	4.40	4.53	4.59	n.s.
	S	1.10	1.11	1.11	n.s.
	P	0.53	0.53	0.49	n.s.
	K	4.46	4.20	4.03	n.s.
	Ca	1.78	1.87	1.67	n.s.
	Mg	0.66	0.45	0.50	0.088
	$S\text{-}SO_4$	0.74	0.81	0.83	n.s.
Microelements (mg kg^{-1}d.m.):					
	Fe	116.63	111.25	124.89	n.s.
	Mn	52.30	83.83	53.88	13.699
	Cu	16.60	14.35	14.40	n.s.
	Zn	64.03	84.03	63.23	n.s.
	Mo	1.29	1.25	1.02	n.s.
	B	25.27	28.08	22.23	n.s.
Stage II[1]					
Dry matter (%)		9.67	10.46	10.72	n.s.
Macroelements (% d.m.):					
	N	4.00	3.88	4.35	n.s.
	S	2.05	2.19	2.37	0.251
	P	0.70	0.67	0.51	0.117
	K	5.80	6.14	6.09	n.s.
	Ca	3.60	3.85	3.66	n.s.
	Mg	0.68	1.15	0.72	0.157
	$S\text{-}SO_4$	1.76	1.88	2.09	0.293
Microelements (mg kg^{-1}d.m.):					
	Fe	220.50	204.30	213.67	n.s.
	Mn	55.47	31.97	93.53	13.840
	Cu	12.80	9.35	10.83	n.s.
	Zn	123.50	111.83	129.74	n.s.
	Mo	1.58	1.37	0.82	0.492
	B	50.87	58.74	24.35	10.377

[1] Stage I – fruit formation on the 4th cluster; stage II – ripening of the first fruits

Table 2. The effects of sulphate levels in the nutrient solution on dry matter and mineral composition of leaves of tomato grown in NFT (in 2001)

Item	Sulphate level in nutrient solution (mg dm^{-3})			$LSD_{0.05}$
	200	400	600	
Stage I				
Dry matter (%)	11.61	12.17	11.64	n.s.
Macroelements (% d.m.):				
N	4.93	5.23	5.12	n.s.
S	0.72	0.69	0.80	n.s.
P	0.56	0.63	0.65	n.s.
K	4.39	4.20	4.15	n.s.
Ca	2.54	2.77	2.61	n.s.
Mg	0.77	0.76	0.70	n.s.
$S\text{-}SO_4$	0.54	0.49	0.64	0.137
Microelements (mg kg^{-1} d.m.):				
Fe	96.64	89.72	85.59	n.s.
Mn	112.43	66.04	66.64	20.517
Cu	9.93	14.43	15.10	3.494
Zn	76.34	79.45	66.59	n.s.
Mo	1.17	1.29	0.79	0.428
B	27.15	28.18	23.02	3.643
Stage II				
Dry matter (%)	11.16	10.40	11.34	n.s.
Macroelements (% d.m.):				
N	4.15	4.68	4.37	0.321
S	1.71	1.72	2.01	0.236
P	0.55	0.54	0.51	n.s.
K	3.97	3.82	3.85	n.s.
Ca	5.42	5.79	5.49	n.s.
Mg	0.86	0.68	0.72	0.157
$S\text{-}SO_4$	1.22	1.34	1.46	0.051
Microelements (mg kg^{-1} d.m.):				
Fe	187.60	186.45	186.10	n.s.
Mn	142.92	109.65	196.84	32.620
Cu	5.77	7.09	7.06	0.510
Zn	162.14	142.21	147.49	n.s.
Mo	0.73	0.51	0.60	0.116
B	25.15	26.77	21.33	3.954

[1] Stage I – fruit formation on the 4^{th} cluster; stage II – ripening of the first fruits

It may have resulted from progressive accumulation of sulphates, which could have limited the availability of other nutrients at the later stage of growth. At the phase II, an increase in the sulphur concentration in the nutrient solution and increased accumulation of sulphates caused a significant increase in the contents of S, S-SO_4 and N (in 2001) in the leaves, as well as a decrease in the content of P (in 2000) and Mg (in 2001). Higher content of total S in the leaves seems to be a logical consequence of the increased intake of sulphates.

After being uptaken by the plant, the sulphates are transported by xylem to chloroplasts of leaf cells, where they are activated. Due to the process of activation, the further reduction of sulphates is possible, which then enables the synthesis of sulphur amino acids (Giovanelly 1990, Randle et al. 1999). According to Cerda et al. (1984) tomato is characterized by relatively high requirements for S and may accumulate high levels of sulphates in the vascular tissues or vacuoles, without a negative effect on yield. In none of the experimental units symptoms of S toxicity were observed. The surplus of S uptaken by the roots may stimulate glutathione synthesis in the leaves (Herschbach and Ronnenberg 1994). After transportation of glutathione to the roots, it may decrease the sulphate intake by the plant.

A possible negative effect of sulphate accumulation in the solution on the mineral composition of leaves may not concern the sulphur itself, but rather a negative effect of sulphates on the intake of other nutrients, being a result of ion antagonisms and chemical sorption, as well as a result of slower rate of solution flow caused by the capillar blockage.

A lack of effect of accumulated sulphates on the content of Ca in the leaves in this experiment is contrary to the results of other authors (Martinez et al. 1984, Lopez et al. 1996 and 1998), who observed a negative effect of higher levels of sulphates in the nutrient solution on Ca concentration in the leaves, which may suggest the negative effect of sulphates on Ca uptake by plants. Such an effect was more apparent in older plants (16-week-old) than in 2-8-week-old ones (Lopez et al. 1996). However, the concentration of sulphates in the nutrient solution in the experiment of Lopez et al. (1998) reached much higher levels compared to the present results (41 *vs.* 14 mmol dm^{-3}, respectively). On the other hand, as a result of the high concentration of Ca in water used in this experiment (65-90 mg dm^{-3}), the accumulation of Ca^{+2} ions in the nutrient solution also occurred (results are not presented here). At the stage of full harvest, the concentration of Ca in the nutrient solutions reached the level of about 300 mg dm^{-3}. Such a high concentration of Ca might fully cover the plant requirements for Ca, even though the high concentration of sulphates in the nutrient solutions might have disturbed an uptake of Ca by plants. The lack of BER symptoms confirms a good nutritional status of tomatoes.

The changes in microelement concentration in the leaves, observed in both years at the stage II and in 2001 at the stage I were not regular. The effect of

sulphates on the decreasing contents of Mo and B should be, however, noted which in a case of B is contrary to the results observed by Terabayashi et al. (1995). In their experiment, increasing the concentration of sulphates from 2 to 20 meq dm^{-3} resulted in an increase of the content B in the tomato shoots. The authors presented only the sulphate concentration at the start of experiment, and there are no data regarding their accumulation.

Irrespective of the relationships presented above, it should be stated here that according to the mineral composition of the leaves, the plants were in the optimal nutritional status, as described by Papadopoulos (1991).

The content of chlorophyll a, b and carotenoids was not affected by the treatments (Table 3).

Table 3. The effects of sulphate levels in the nutrient solution on the content of assimilation pigments in the leaves of tomato grown in NFT (mg g^{-1} fresh matter)

Item	Sulphate level in nutrient solution (mg dm^{-3})			$LSD_{0.05}$
	200	400	600	
Year 2000				
Stage I[1]				
Chlorophyll a	1.67	1.47	1.52	n.s.
Chlorophyll b	0.75	0.72	0.69	n.s.
Carotenoids	0.85	0.83	0.80	n.s.
Stage II[1]				
Chlorophyll a	1.70	1.73	1.93	n.s.
Chlorophyll b	0.68	0.70	0.81	n.s.
Carotenoids	0.85	0.85	0.91	n.s.
Year 2001				
Stage I[1]				
Chlorophyll a	2.14	1.87	1.86	n.s.
Chlorophyll b	0.85	0.77	0.75	n.s.
Carotenoids	0.89	0.81	0.78	n.s.
Stage II[1]				
Chlorophyll a	1.63	1.73	1.81	n.s.
Chlorophyll b	0.72	0.67	0.72	n.s.
Carotenoids	0.83	0.74	0.81	n.s.

[1] Stage I – fruit formation on the 4th cluster; stage II – ripening of the first fruits

In the literature the effect of lack of sulphates on the level of assimilation pigments has been often presented (Lopez et al. 1996, Xu et al. 1996). Xu et al.

(1996) observed a decrease in the concentration of chlorophyll (chlorosis) in tomatoes fertigated by a very low sulphate solution (0.1 mmol dm^{-3}). Decreasing the chlorophyll content, as a result of sulphur deficit, lowers the rate of photosynthesis. Considering it, the sulphates in the nutrient solutions seem to stimulate the photosynthesis in the tomato plants (Lopez et al. 1996).

There was no significant effect of sulphates in the nutrient solution on the content of sulphur amino acids (Table 4), which confirms the results obtained by Lopez et al. (1998). On the other hand, since sulphur in amino acids composes about 90% of total S in plants (Lopez et al. 1998) and the effect of sulphates in the solution on the content of S in the leaves was clearly confirmed (Tables 1 and 2), the effect of sulphates in the solution on the level of sulphur amino acids in the leaves was expected. Considering the fact that a difference between the level of total-S and S-SO_4, representing the level of organic-S (Cerda et al. 1984), was relatively constant (about 0.3-0.5% of dry matter) in the present experiment, it may be judged that the effect of solution sulphates on total-S in the leaves resulted mainly from the content of S-SO_4 (inorganic-S). It may be possible that in each unit (differing in the content of sulphates in the solution) the capacities for amino acid synthesis were fully filled. The plants store the rest of sulphur in vacuoles and chloroplasts (Giovanelly 1990), in an inorganic form.

Table 4. The effects of sulphate levels in the nutrient solution on sulphur amino acids content (mg g^{-1} dry matter) in the leaves of tomato grown in NFT (in 2001)

Item	Sulphate level in nutrient solution (mg dm^{-3})			$LSD_{0.05}$
	200	400	600	
Stage I[1]				
Methionine	1.35	1.41	1.50	n.s.
Cysteine	0.99	1.02	1.15	n.s.
Stage II[1]				
Methionine	1.59	1.59	1.44	n.s.
Cysteine	1.32	1.46	1.18	n.s.

[1] Stage I – leaves of the bottom part of the plant sampled at fruit ripening on the first clusters; stage II – leaves of the middle part of the plant sampled at full harvest

CONCLUSION

In the NFT cultivation of tomato the accumulation of considerable amounts of sulphate ions in the root zone occurred. Compared to the initial sulphate levels there was about 2-3 times increase at the stage of full harvest. Irrespective of the plant maturity, tomato plant may tolerate a high level of sulphates in the root zone. There were no effects of different sulphate levels in the nutrient solution on the concentration of assimilation pigments, carotenoids and sulphur amino acids.

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WPŁYW POZIOMÓW SIARCZANÓW W POŻYWCE NA STAN ODŻYWIENIA I GROMADZENIE SIARCZANÓW W ŚRODOWISKU KORZENIOWYM POMIDORA

Streszczenie: Pomidor ‘Cunero’ F_1 uprawiano w 3 niezależnych zestawach systemu cienkowarstwowych kultur przepływowych (NFT), zasilanych pożywkami o zróżnicowanym poziomie wyjściowym siarczanów (mg SO_4^{-2} dm^{-3}), tj. zestaw I - 200, II - 400, III - 600. Koncentracja siarczanów w roztworze pokarmowym wzrastała w czasie całego sezonu uprawy. W fazie pełnego zbioru owoców osiągnęła poziom 850-1000 (I zestaw), 1000-1100 (II zestaw), 1250-1400 (III zestaw) i 800-850 (I zestaw), 900-1000 (II zestaw), 1250 (III zestaw) mg SO_4^{-2} dm^{-3}, odpowiednio w 2000 i 2001 roku. Wzrost stężenia siarczanów w pożywce

powodował istotne zwiększenie zawartości w liściach S, S-SO_4 oraz N (2001) oraz zmniejszenie zawartości P (2000) i Mg (2001). Nie wykazano wpływu zróżnicowanych zawartości siarczanów w pożywkach na zawartość barwników asymilacyjnych, karotenoidów oraz aminokwasów siarkowych.

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