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Effects of sulphate level in the nutrient solution on plant growth and sulphur content in tomato plants

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ABSTRACT

The effect of various concentrations of sulphates in the nutrient solutions (I – 200, II – 400, and III – 600 mg SO_4^{2-} dm^{-3}) on sulphur content in plants as well as plant height and leaf area of tomato plants grown with nutrient film technique (NFT) were investigated. Total-S and S-SO_4 levels were determined in the leaf blades of the upper, medium and lower plant parts, during 3 phases of tomato growth and also in the roots. The increase of sulphate concentration in the nutrient solution resulted in the increase of total-S and S-SO_4 levels in all analysed plant parts, regardless of the growth phase. There were no significant effects of different SO_4^{2-} levels in the nutrient solution on tomato growth and leaf area.

INTRODUCTION

Sulphur is an important factor in plant feeding. It is one of the components of sulphur amino acids (cysteine and methionine) and many other compounds, e.g. glutathione or ferredoxin, which play important physiological functions. While demand for sulphur depends on plant species, the amount and rate of sulphur uptake from the nutrient solution depends on many factors, including pH, temperature, access to energy, sulphate concentration and the presence of other ions (Siuta and Rejman-Czajkowska 1980). With the increase in sulphate ions accumulation in the nutrient solution, their uptake by plants increases. Having reached a certain level, various for different plant species, further increase of concentration does not affect the uptake any longer. However, high sulphate concentrations may affect plant development and crop yield (Cerda et al. 1984).

In hydroponic cultivations surplus accumulation of certain ions, including sulphates, in the root zone is a frequent phenomenon (Zekki et al. 1996, Lopez et al. 1998). There is still little information available concerning the effect of increased sulphate concentration, resulting from its accumulation in the nutrient solution on plant development and yield.

The aim of the present study was to determine the effect of different sulphate concentrations in the nutrient solution on the growth and total-S and S-SO_4 levels in the plants of tomato cultivated in NFT system.

MATERIAL AND METHODS

Studies were conducted in 2001 and 2002 on greenhouse tomato plants 'Cunero F_1'. Plants were grown in 3 independent units of nutrient film technique (NFT), filled with rockwool slabs and supplied by nutrient solution with different primary sulphate concentrations (mg SO_4^{2-} dm^{-3}); i.e. unit I – 200, II – 400, and III – 600. During the cultivation, the concentration of other nutrients in all units was kept on the same level; depending on the phase of plant growth (Wysocka-Owczarek 2001) and the recommendations of De Ruiter Seeds Company for 'Cunero F_1' their concentration was adjusted. At the time of placement of the plants in the slabs the concentration of nutrients was (mg dm^{-3}): N 210, P 50, K 250-280, Ca 220, Mg 60-70, Fe 1.6, Cu 0.07-0.1, Mn 0.6-1.0, Zn 0.2, B 0.2-0.3, Mo 0.02-0.03. The first level of sulphate in the solution was achieved by a use of the multiple fertilizer (Superba Red). The remaining solutions were based on single fertilizers, salts and acids. Plant detopping was performed over the 8^{th} cluster.

The distribution of total-S and S-SO_4 in the tomato plants was assessed, with regard to the phase of its development and the location of the leaf blade sampled. Total-S and S-SO_4 concentrations were determined at three different growth stages, i.e. at the flowering of I-II cluster (F), at the ripening of the first fruits on first clusters (R) and at the stage of full fruiting (FF). At the stage of fruit formation, leaf blades sampled separately from the upper and lower part of the plant were analysed. For this purpose 3 plants grown as surplus ones in each unit of NFT were cut. They were then cut into half; by this way the upper and lower parts of plants were obtained. At the second and third stages of growth determinations were made in leaf blades sampled separately from three plant parts, i.e. the upper, medium and lower ones. At the end of cultivation, determinations were also made on samples collected of roots.

The chemical analyses were made following dry mineralization of the samples. The content of total S was determined using Leco SC-132 apparatus, whereas the sulphates by nephelometric method (Ostrowska et al. 1991), after the extraction with ammonium acetate. Sulphate concentration in the plants was expressed as % of sulphur ($S\text{-}SO_4$).

In the year 2001 the plant growth was determined by measuring the plant height and the leaf area. The leaves located under clusters were chosen for measurements. Leaf measurement was performed twice, i.e. at the growth and full development stages. Leaf area was calculated with the use of the formula $0.775 \times (a \times b)^{0.927}$, where „a" means the length and „b" the width of the leaf (Starzecki et al. 1989).

The results were subjected to one-way (leaf area and plant height) or two-way (total-S and $S\text{-}SO_4$ content) analysis of variance and Duncan's test at $p = 0.05$.

RESULTS AND DISCUSSION

During the whole growth period of tomato plants, the accumulation of sulphates in the nutrient solution was observed. At the stage of full fruiting the concentration reached the levels of 850-1000 (unit I), 1000-1100 (II), 1250-1400 (III) and 800-850 (I), 900-1000 (II), 1250 (III) mg dm^{-3}, respectively in the years 2000 and 2001. Detailed information concerning changes in sulphate content in particular units and at particular stages of growth phases were published in another publication (Kowalska 2004).

In both years of cultivation, an increase in sulphate concentration in the nutrient solution caused a significant increase in the contents of total-S and $S\text{-}SO_4$ in all analysed plant parts. The increase in total-S and $S\text{-}SO_4$ in the leaves and roots (Tables 1a and 1b) is a consequence of higher sulphate intake. According to Randle et al. (1999) plants grown in the condition of higher sulphate intake in relation to the needs, accumulate the surplus of uptaken sulphates in vacuoles as $S\text{-}SO_4$ or, in case of some species (e.g. cabbage), in the form of secondary organic metabolites (Randle et al. 1999).

Table 1a. The effects of the sulphate level in the nutrient solution and stage of plant development on mineral composition of leaves and roots (% of dry matter) of greenhouse tomato grown in NFT (in 2000)

Sulphate levels ($mg\ dm^{-3}$)	Stage of development[1]	S				$S\text{-}SO_4$			
		Leaves			Roots	Leaves			Roots
		upper	middle	lower		upper	middle	lower	
200	F	0.81		2.38		0.56		0.83	
	R	0.70	2.05	2.30	1.12	0.52	1.76	2.26	0.97
	FF	1.87	2.37	2.76	0.69	1.48	1.40	2.17	0.60
400	F	0.98		2.58		0.68		1.11	
	R	0.73	2.19	2.54	1.11	0.49	1.88	2.26	1.13
	FF	2.74	3.03	2.99	1.26	2.05	1.85	2.61	1.16
600	F	1.10		2.79		0.79		1.38	
	R	0.91	2.37	2.58	1.25	0.68	2.02	2.48	1.02
	FF	2.89	3.13	3.16	1.20	2.09	2.02	2.53	0.96
Mean for:									
Sulphate levels	200	1.13	2.21	2.48	0.90	0.85	1.61	1.75	0.78
	400	1.48	2.61	2.70	1.18	1.07	1.86	1.99	1.15
	600	1.63	2.75	2.84	1.22	1.18	2.02	2.13	0.99
Stage of development	F	0.96		2.58		0.67		1.11	
	R	0.77	2.20	2.47	1.16	0.56	1.89	2.33	1.04
	FF	2.50	2.84	2.97	1.05	1.87	1.77	2.44	0.90
$LSD_{0.05}$ for:									
Sulphate levels		0.113	0.205	0.167	0.093	0.127	0.189	0.140	0.124
Stage of development		0.113	0.164	0.104	0.076	0.127	n.s.	0.140	0.101
Interaction		0.196	0.290	n.s.	0.132	0.221	n.s.	n.s.	0.175

[1] F - flowering; R - ripening of first fruits; FF - full fruiting; n.s. - non-significant

Table 1b. The effects of the sulphate level in the nutrient solution and stage of plant development on mineral composition of leaves and roots (% of dry matter) of greenhouse tomato grown in NFT (in 2001)

Sulphate levels (mg dm^{-3})	Stage of development [1]	S				$S-SO_4$			
		Leaves			Roots	Leaves			Roots
		upper	middle	lower		upper	middle	lower	
200	F	0.73		1.23		0.33		0.96	
	R	0.58	1.72	2.23	0.74	0.23	1.21	1.90	0.58
	FF	1.21	1.48	2.12	0.87	1.07	1.32	1.85	0.71
400	F	0.78		1.22		0.42		1.08	
	R	0.61	1.72	2.21	0.90	0.31	1.29	2.11	0.70
	FF	1.43	2.33	2.24	1.17	1.14	1.69	2.16	0.92
600	F	0.84		1.33		0.64		1.26	
	R	0.72	2.01	2.67	0.83	0.34	1.45	2.57	0.66
	FF	1.81	2.60	2.92	1.09	1.46	2.21	2.69	1.12
Mean for:									
Sulphate levels	200	0.84	1.61	1.86	0.80	0.54	1.27	1.57	0.65
	400	0.94	2.03	1.89	1.04	0.63	1.49	1.78	0.81
	600	1.12	2.31	2.30	0.96	0.81	1.83	2.17	0.89
Stage of	F	0.78		1.26		0.46		1.10	
development	R	0.63	1.82	2.37	0.82	0.29	1.32	2.19	0.64
	FF	1.48	2.14	2.42	1.04	1.22	1.74	2.23	0.92
$LSD_{0.05}$ for:									
Sulphate levels		0.155	0.262	0.122	0.154	0.116	0.333	0.193	n.s.
Stage of development		0.155	0.214	0.122	0.126	0.116	0.279	0.193	0.178
Interaction		n.s.	0.370	0.211	n.s.	n.s.	n.s.	n.s.	n.s.

[1] Note: see Table 1a

The differences between total-S and $S\text{-}SO_4$ content in the middle and lower leaves (Tables 1a and 1b), regardless of sulphate concentration in the nutrient solution, had no effect on the concentration of synthesised organic sulphur, and the surplus of uptaken sulphur was stored in the form of sulphates.

High content of total-S and $S\text{-}SO_4$ in tomato plants indicates surplus intake of sulphates. However, simultaneous accumulation of sulphates in the root zone of the plants in all units indicates the activity of mechanisms blocking sulphate intake in the amounts being toxic for plants. External symptoms of toxicity related to surplus sulphate content in the nutrient solution were not observed. The effect of different sulphate contents on crop yield and quality was not proved either, which was documented by others (Kowalska and Sady 2003). According to Herschbach and Ronnenberg (1994), when sulphate concentration in the root zone is excessive, their excessive uptake by roots increases the synthesis of glutathione in the leaves and certain amount of it is transported to the roots, which signals the necessity to decrease sulphate intake.

In the upper leaves, together with the increase in sulphate content in the nutrient solution, the increase of organic sulphur content was observed (differences between total-S and $S\text{-}SO_4$ increase, Tables 1a and 1b). The upper leaves, which were subjected to determinations, were often the youngest, often still growing ones. Reactions of assimilative sulphate reduction to organic compounds are most intense at the stage of maximal leaf growth (Starck 2002). Most probably these reactions led to the increase in organic sulphur content in these leaves.

The concentration of the analysed components also depended on the stage of the plant growth. With plant aging, total-S and $S\text{-}SO_4$ concentration in the leaves increased. The difference between total-S and $S\text{-}SO_4$ at particular stages of growth in 2001 decreased (Table 1b). Such tendency was not observed in the year 2000. According to Nowotny-Mieczyńska (1976), with plant aging content of sulphur-including organic compounds decreases, with the simultaneous increase in non-organic compounds. This phenomenon is the direct result of weakening of sulphate reduction processes and translocation to the generative organs of only the indispensable amount of sulphur necessary to incorporate into generative spare organs.

In both years of the cultivation, a significant interaction between the level of sulphates in the nutrient solution and the stage of plant growth in respect to total-S content in plants (with exception of upper leaves in the year 2001; Tables 1a and 1b) and $S\text{-}SO_4$ content in the upper leaves and roots (in the year 2000; Table 1a) was observed. In younger plants, total-S content in leaves increased with the increase of sulphate level in the nutrient solution, whereas in older plants no effect of highest sulphate doses on total-S content in the leaves was found. Similar tendencies were also observed by Lopez et al. (1996).

SO_4^{2-} level in the nutrient solution had no effect on the height of tomato plants (Table 2) and the leaf area at the stages of growth and full development (Table 3). Only the leaf area under the fifth cluster measured at the stage of growth in unit III, i.e. with the highest initial sulphate content, was significantly lower than in a case of plant leaves grown in units I and II (200 and 400 mg SO_4^{2-} dm^{-3}, respectively). These differences were not found in the next leaf measurement made at the stage of full development. Similarly, Bellert et al. (1998) did not prove the effect of sulphate level in nutrient solution in NFT cultivation on the growth and area of the leaves. In studies conducted by Cerda et al. (1984), sulphate content exceeding 45 me dm^{-3} decreased leaf area. The results obtained in the present experiment indicate that sulphates do not have significant effect on the vegetative development of tomato plants, which is probably a consequence of adequate plant nutrition.

Table 2. Effects of the sulphate level in the nutrient solution on height (cm) of tomato plants (in 2001)

Sulphate levels (mg dm^{-3})	The date of measurement				
	3rd 10 days of March	1st 10 days of April	2nd 10 days of April	3rd 10 days of April	3rd 10 days of May
200	86.3	111.8	122.3	141.7	197.0
400	83.8	109.0	118.3	136.1	196.4
600	82.1	107.3	116.8	135.7	194.1
$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.	n.s.

Table 3. Effects of the sulphate level in the nutrient solution on leaf area (cm^2) of tomato plants (in 2001)

Sulphate (mg dm^{-3})	Under 2nd cluster		Under 3rd cluster		Under 5th cluster	
	The date of measurement					
	3rd 10 days of March	1st 10 days of April	1st 10 days of April	2nd 10 days of April	2nd 10 days of April	3rd 10 days of April
200	528.5	741.5	588.6	862.2	186.2	586.8
400	509.4	802.6	578.4	777.2	191.1	488.7
600	479.8	777.4	470.1	730.4	127.8	396.8
$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.	53.50	n.s

CONCLUSIONS

– With an increase in sulphate level in the nutrient solution, sulphate content in the leaves increased.
– High concentration of total-S and $S\text{-}SO_4$ was not accompanied by external toxicity symptoms.
– Differences in sulphate levels in plants did not have effect on the leaf blade area and plant height.

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WPŁYW ZAWARTOŚCI SIARCZANÓW W POŻYWCE NA ROZWÓJ I ZAWARTOŚĆ SIARKI W ROŚLINACH POMIDORA

Streszczenie: Badano wpływ zróżnicowanych koncentracji siarczanów w pożywce (I – 200, II – 400 i III – 600 mg SO_4^{2-} dm^{-3}) na zawartość siarki w roślinie oraz wysokość i powierzchnię liści pomidora uprawianego metodą NFT. Oznaczenia S ogólnej i siarczanowej przeprowadzono w blaszkach liściowych z części górnej, środkowej i dolnej roślin, pobranych w 3 fazach wzrostu pomidora, a także w masie korzeniowej. Zwiększenie koncentracji siarczanów w pożywce powodowało wzrost zawartość siarki ogólnej i siarczanowej we wszystkich analizowanych częściach rośliny, bez względu na fazę rozwojową. Nie wykazano istotnego wpływu poziomu SO_4^{2-} w pożywce na wzrost pomidora i powierzchnię liści.

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