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CHANGES IN THE CHEMICAL COMPOSITION OF THE RHIZOSPHERE OF TOMATO GROWN ON INERT SUBSTRATES IN A PROLONGED CYCLE

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Abstract

The aim of this study, conducted in 2005-2007, was to determine changes in the chemical composition of extracts from the rhizosphere of tomatoes and of drainage water in tomato culture set up on rockwool, perlite and expanded clay and nourished with one of the two nutrient solutions containing different concentrations of macronutrients (EC I: 2.4 mS cm^{-1} and EC II: 3.6 mS cm^{-1}). Perlite and extended clay were placed in foil sleeves, whose shape and volume corresponded to the weight of rockwool. The tomatoes were grown with a dripping fertilization system and a closed nutrient solution circulation system, without recirculation, for watering. The solution supply frequency, controlled by a soltimer, depended on the intensity of solar radiation. The concentration and proportions of macronutrients in the nutrient solutions were adjusted to the requirements of particular developmental phases of the plants, in accordance with the current recommendations. The plants were grown in a prolonged cycle for 22 clusters (from the beginning of February to mid-October). Extracts from the rhizosphere and drainage water for analyses were sampled at a set time of the day, every four weeks, since the plants were placed on the mats. The analysis of the results revealed significantly more nitrate ions, phosphorus, potassium, calcium, magnesium, sulphates and sodium in extracts from the rhizosphere and in drainage waters sampled from treatments fertilized with the concentrated solution (EC II), compared to the basic solution. In the drainage water from treatments fertilized with a solution of the basic macronutrient composition (EC I), the increase of ion concentrations appeared in the following order: N-NH_4 > P-PO_4 > Ca > S-SO_4 > K > N-NO_3 > Mg, whereas in the drainage water flowing from the treatments fertilized with the solution containing 25% more macronutrients (EC II), the ion concentration range was as follows: N-NH_4 > P-PO_4 > Ca > N-NO_3 > S-SO_4 > K > Mg. In the present study, the sodium content in drainage water was depressed compared to the nutrient solution dosed under plants with either of the two liquid feeds.

Key words: rockwool, perlite, extended clay, EC of nutrient solution, rhisosphere, drainage waters.

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ZMIANY SK£ADU CHEMICZNEGO ŒRODOWISKA KORZENIOWEGO POMIDORA UPRAWIANEGO W POD£O¯ACH INERTNYCH W CYKLU WYD£U¯ONYM

Abstrakt

Celem badañ przeprowadzonych w latach 2005-2007 by³o okreœlenie zmian sk³adu chemicznego wyci¹gów ze œrodowiska korzeniowego oraz wód drenarskich w uprawie pomidora w we³nie mineralnej, perlicie i keramzycie z zastosowaniem dwu po¿ywek o zró¿nicowanej koncentracji makrosk³adników (EC I: 2.4 mS cm^{-1} oraz EC II: 3.6 mS cm^{-1}). Perlit i keramzyt umieszczono w rêkawach foliowych, formuj¹c kszta³t i ustalaj¹c objêtoœæ odpowiadaj¹c¹ macie we³ny mineralnej. W uprawie wykorzystano kroplowy system nawo¿enia i nawadniania z zamkniêtym obiegiem po¿ywki, bez recyrkulacji. Czêstotliwoœæ dostarczania po¿ywki, sterowana „soltimerem”, by³a uzale¿niona od natê¿enia promieniowania s³onecznego. Koncentracja oraz proporcje makrosk³adników w po¿ywce by³y zró¿nicowane wzglêdem wymagañ poszczególnych faz rozwojowych roœlin zgodnie z aktualnymi zaleceniami. Roœliny uprawiano w cyklu wyd³u¿onym na 22 grona (od pocz¹tku lutego do po³owy paŸdziernika). Wyci¹gi ze œrodowiska korzeniowego oraz wody drenarskie do analiz pobierano o ustalonej porze dnia co 4 tygodnie, pocz¹wszy od ustawienia roœlin na matach. Analiza wyników wykaza³a istotnie wiêcej jonów azotanowych, fosforu, potasu, wapnia, magnezu, siarczanów i sodu w wyci¹gach ze œrodowiska korzeniowego i w wodach drenarskich pobranych z obiektów nawo¿onych po¿ywk¹ zatê¿on¹ (EC II), w porównaniu z po¿ywk¹ podstawow¹. W wodach drenarskich z obiektów nawo¿onych po¿ywk¹ o podstawowym sk³adzie makroelementów (EC I) stwierdzono wzrost zatê¿enia jonów w kolejnoœci: N-NH_4 > P-PO_4 > Ca > S-SO_4 > K > N-NO_3 > Mg, natomiast w wodach drenarskich wyp³ywaj¹cych z obiektów nawo¿onych po¿ywk¹ zawieraj¹c¹ 25% wiêcej makroelementów (EC II) szereg zatê¿enia jonów by³ nastêpuj¹cy: N-NH_4 > P-PO_4 > Ca > N-NO_3 > S-SO_4 > K > Mg. W badaniach wykazano zmniejszenie zawartoœci sodu w wodach drenarskich w porównaniu z roztworem pokarmowym dozowanym pod roœliny z wykorzystaniem obu rodzajów po¿ywki.

S³owa kluczowe: we³na mineralna, perlit, keramzyt, EC po¿ywki, œrodowisko korzeniowe, wody drenarskie.

INTRODUCTION

Growing plants on inert substrates with a precise fertilization and watering system is gaining in popularity as it ensures high and good quality fruit yield (Jarosz, Dzida 2005, Gajc-Wolska et al. 2008). According to many authors (Breœ, Ruprik 2006, Komosa, Kleiber 2007), systems allowing for recirculation of liquid solution dosed under plants are a necessity created by ecological and economical reasons. Implementation of nutrient solution recirculation, however, requires the knowledge of changes in nutrient concentrations in the plant rhizosphere and in drainage waters, compared to the solution dosed under plants (Kleiber, Komosa 2008). The rhizosphere as well as in drainage water typically contain high concentrations of nutrients, a result of an increased water uptake and selective ion uptake by plants. According to Dyœko and Kowalczyk (2005), changes in the rhizosphere's chemical composition are also significantly affected by a developing root system and interactions between particular nutrients. Modifications in the composition of the rhizosphere and drainage water, however, depend on the substratum, crop species and even on a cultivation system.

When growing tomatoes on inert substrates, the general ion concentration (EC) in a nutrient solution is frequently elevated, which improves the taste and certain biological value parameters of fruit (GRAVA et al. 2001, HAO, PAPADOPOULOS 2004). However, this solution may lead to excessive concentrations of certain ions in the rhizosphere, which disturbs the uptake and distribution of ions in plants (GRAVA et al. 2001).

The objective of this study has been to determine changes in the chemical composition of the rhizosphere and drainage water in a tomato cv. Cunero F_1 culture, depending on growing substrate (rockwool, perlite, extended clay) and two nutrient solutions with different concentrations of macronutrients.

MATERIAL AND METHODS

The study were conducted 2005-2007, in a greenhouse of the Department of Soil Cultivation and Fertilization of Horticultural Plants, University of Life Sciences in Lublin. Tomato plants of the cultivar Cunero F_1 were grown on rockwool (Grodan), perlite (Agroperlit) and extended clay (Optiroc-Gniew). Perlite and extended clay were placed in foil sleeves, with their shape and volume corresponding to the weight of rockwool. The tomato culture was conducted with a dripping fertilization and watering system with a closed solution circuit but no recirculation. Two types of nutrient solution were applied:

a) basic solution (I) with EC 2.4 mS cm^{-1}, containing on average (in mg dm^{-3}): N-NH_4 – 17.0; N-NO_3 – 188; P-PO_4 – 45; K – 280; Ca – 205; Mg – 75; S-SO_4 – 140; Na – 14.7; Cl – 12.3 ; Fe – 1.25; Mn – 0,55; B – 0.30 Cu – 0.05; Zn – 0,30; Mo – 0.03 and pH_{H_2O} – 5,60;
b) concentrated solution (II) by EC 3.6 mS cm^{-1} containing 25% more macronutrients, of the average composition (in mg dm^{-3}): N-NH_4 – 21.2; N-NO_3 – 235; P-PO_4 – 56.5; K – 350; Ca – 256; Mg – 94; S-SO_4 – 185; Na – 26; Cl – 18.5; Fe – 1.25; Mn – 0.55; B – 0.30; Cu – 0.05; Zn – 0.30; Mo – 0.03 and pH_{H_2O} – 5.65.

The concentration and proportions of macronutrients in the nutrient solutions were adjusted to the requirements of particular developmental phases of plants, in accordance with the current recommendations (ADAMICKI et al. 2005). The solutions were prepared taking the following chemical composition of water into account (in mg dm^{-3}): N-NH_4 – 0.02; N-NO_3 – 5.0; P-PO_4 – 4.0; K – 1.4; Ca – 121; Mg –13.8; S-SO_4 – 32.0; Cl – 9.5; Na – 2.7; Fe – 0.24; Mn – 0,026; Cu – 0.001; Zn – 0.038; pH_{H_2O} – 7.44, EC – 0.71 mS cm^{-1}. The daily outflow of the solution, depending on the developmental phase of plants ranged from 1.8 to 4.2 dm^3 $plant^{-1}$. The frequency of solution supply, controlled by a soltimer, depended on the intensity of solar radiation. A twofactorial experiment was established in a completely randomized design, with seven replications. Each replication was a culture slab, on which two plants grew. The plants were placed on the substrates in the first decade of February (04.02.2005; 07.02.2006; 09.02.2007). The cultivation was conducted in a prolonged cycle (22 clusters), at the plant density of 2.3 plants m^{-2}, until mid-October (20.10.2005; 17.10.2006; 12.10.2007). Plant protection and other treatments were performed in accordance with the recommendations (ADAMICKI et al. 2005).

Extracts from the rhizosphere and drainage water for analyses were sampled at a set time of the day, every four weeks, since the plants started to grow on the mats. Extracts from the cultivation mats were taken with a syringe, mid-way between the plants and from central part of the mat's height. Each time, the following determinations were completed in the collected samples: ammonium and nitrate nitrogen with Bremner's method (as modified by Starck), phosphorus by colorimetry with ammonium vanadomolybdate (Thermo, Evolution 300), potassium, calcium, magnesium and sodium with the ASA method (Perkin-Elmer, Analyst 300), sulphates by nephelometry with barium chloride, and electric conductivity (EC) by conductometry (NOWOSIELSKI 1988).

Statistical elaboration of the results was performed with the variance analysis method on mean values, applying Tukey's test for assessing differences at the significance level of α=0.05. The results are average values for all the dates of analyses from the three years of the experiment.

RESULTS AND DISCUSSION

A closed nutrient solution circuit system with recirculation saves significant amounts of water and mineral fertilizers (VAN OS 2001). It also limits the pollution of soil and groundwater with biogenic elements (KOMOSA, KLEIBER 2007). However, re-using a nutrient solution flowing out in the form of drainage water requires purification, disinfection and regulation of the concentrations of particular nutrients. Although there are many successful methods for disinfecting a nutrient solution before its reintroduction into cultivation, it is still necessary to know exactly the ranges of an increase or a decrease in the concentrations of particular elements in drainage water depending on a crop species, substrate and a cultivation technology (VAN OS 2001, KOMOSA, KLEIBER 2007, KLEIBER, KOMOSA 2008).

The statistical analysis of our results revealed significant changes in the concentrations of elements in the rhizosphere and in drainage water, compared to those in the supplied nutrient solutions, depending on both of the examined factors (Table 1). The highest increase in the ion concentrations in drainage water flowing out of the mats was reported for ammonium cati-

Table 1

Nutrient content (mg dm^{-3}) and conductivity (mS cm^{-1}) in the rhizosphere and drainage water depending on the type of substrate and concentration of macronutrients in the nutrient solution (average of all analysis from 2005-2007)

Element/ /compound	Nutrient solution	Sampling source				Mean
		rockwool	perlite	expanded clay	drainage water	
$N-NH_4$	EC I	27.78*a*	24.94*a*	38.83*a*	33.38*a*	31.24*a*
	EC II	30.89*a*	31.06*a*	36.61*a*	47.67*a*	36.55*a*
	Mean	29.33*ab*	28.00*a*	37.72*ab*	40.53*b*	
$N-NO_3$	EC I	268.6*a*	268.8*a*	250.2*a*	261.6*a*	262.3*a*
	EC II	322.1*a*	308.2*a*	305.5*a*	295.8*a*	307.9*b*
	Mean	295.4*a*	288.5*a*	277.9*a*	278.7*a*	
$P-PO_4$	EC I	79.72*a*	82.89*a*	70.94*a*	79.78*a*	78.33*a*
	EC II	96.33*a*	94.28*a*	81.83*a*	86.67*a*	89.78*b*
	Mean	88.03*b*	88.58*b*	76.39*a*	83.22*ab*	
K	EC I	381.6*a*	380.6*a*	381.7*a*	390.5*a*	383.5*a*
	EC II	477.3*a*	473.6*a*	459.0*a*	431.8*a*	460.4*b*
	Mean	429.5*a*	427.1*a*	420.2*a*	411.2*a*	
Ca	EC I	318.9*a*	316.9*a*	313.7*a*	296.2*a*	311.4*a*
	EC II	385.9*a*	379.2*a*	409.5*a*	354.8*a*	382.3*b*
	Mean	352.4*a*	348.1*a*	361.6*a*	325.5*a*	
Mg	EC I	92.41*a*	91.12*a*	91.00*a*	92.82*a*	91.84*a*
	EC II	106.1*a*	107.5*a*	116.0*a*	105.8a	108.8*b*
	Mean	99.23*a*	99.29*a*	103.5*a*	99.32*a*	
$S-SO_4$	EC I	185.9*a*	195.4*a*	191.4*a*	199.5*a*	193.1*a*
	EC II	233.2*a*	238.6*a*	230.3*a*	232.8*a*	233.7*b*
	Mean	209.6*a*	217.3*a*	210.9*a*	216.2*a*	
Na	EC I	18.67*a*	18.60*a*	17.58*a*	13.50*a*	17.10*a*
	EC II	25.33*a*	25.75*a*	20.00*a*	18.41*a*	22.37*b*
	Mean	22.00*b*	22.21*b*	18.79*ab*	15.95*a*	
Conductivity	EC I	3.179*a*	3.312*a*	3.330*a*	3.131*a*	3.239*a*
	EC II	3.713*a*	3.789*a*	3.707*a*	3.617*a*	3.706*b*
	Mean	3.446*a*	3.550*a*	3.520*a*	3.374*a*	

Values marked with the same letter are not differ significantly at α=0.05, according to Tukey's test.

ons (Table 2). This increase, compared to the nutrient solution supplied to plants, was on average + 96.41% for the basic solution (EC I) and +124.9% for the solution with an increased content of macronutrients (EC II). Contrary results were obtained by KOMOSA et al. (2010), who demonstrated a decrease in ammonium nitrogen from 11.7 to 26.6% in the rhizosphere of tomato grown on rockwool and fiber wood. Irrespective of the type of the applied solution, the content of $N\text{-}NH_4$ in drainage water (40.53 mg dm^{-3}) was significantly higher than the concentration of these ions in the rhizosphere of tomato grown on perlite (28.00 mg dm^{-3}). Many articles emphasize that the concentration of ammonium cations in tomato rhizosphere should not exceed 10% of the total amount of mineral nitrogen, as an excess of NH_4^+ may inhibit the uptake of calcium and magnesium (HO et al.

Table 2

Percentage change (increase or decrease) in the composition of the extract from the rhizosphere and drainage water compared to a nutrient solution from a dripper (average of all analysis from 2005-2007)

Element/ /compound	Nutrient solution	Sampling source			
		rockwool	perlite	expanded clay	drainage water
$N\text{-}NH_4$	EC I	+63.41	+46.70	+128.4	+96.41
	EC II	+45.71	+46.51	+72.69	+124.9
$N\text{-}NO_3$	EC I	+42.87	+42.98	+33.08	+39.15
	EC II	+37.06	+31.15	+30.00	+25.87
$P\text{-}PO_4$	EC I	+77.15	+84.2	+57.64	+77.29
	EC II	+70.49	+66.87	+44.83	+53.40
K	EC I	+36.28	+35.93	+36.25	+39.46
	EC II	+36.37	+35.31	+31.14	+23.37
Ca	EC I	+55.56	+54.58	+53.02	+43.02
	EC II	+50.74	+48.12	+59.96	+38.28
Mg	EC I	+23.21	+21.49	+21.33	+23.76
	EC II	+12.87	+14.36	+23.40	+12.55
$S\text{-}SO_4$	EC I	+32.78	+39.57	+36.71	+42.50
	EC II	+26.05	+28.97	+24.49	+25.83
Na	EC I	+27.01	+26.53	+19.59	- 8.160
	EC II	-3.321	-1.72	-23.66	-29.69
EC	EC I	+24.50	+37.96	+38.92	+30.46
	EC II	+3.139	+5.250	+2.972	+0.472

Values marked with the same letter are not differ significantly at α=0.05, according to Tukey's test.

1999). While analyzing the composition of extracts from the rhizosphere in the examined treatments, it was noticed that proper ratios between these ammonium cations and mineral nitrogen became unbalanced when growing tomato on extended clay.

In the present experiment, no significant differences were found in the concentration of nitrate ions in the rhizosphere of tomato growing on the examined substrates and in drainage water flowing out of the mats. Irrespective of a sampling site, significantly more N-NO_3 (307.9 mg dm^{-3}) was reported in treatments fertilized with solution containing 25% more macroelements (EC II). The increased concentration of nitrates in drainage water compared to the nutrient solution dosed under plants ranged from 25.87 to 39.15% (Table 2). An event of nitrate ion concentration rise in plant rhizosphere and drainage water compared to a nutrient solution has been reported in other studies (DYŒKO and KOWALCZYK 2005, KOMOSA et al. 2009)

The analysis of extracts from the rhizosphere of tomato growing on extended clay revealed significantly less phosphorus (76.39 mg dm^{-3}) compared to the remaining substrates (Table 1). DYŒKO at al. (2008) demonstrated that the content of phosphorus available to plants is closely related to the reaction of the rhizosphere. In their study, an increase in the pH in the dosed nutritional solution was followed by a higher reaction in the rhizosphere reaction, which in turn was accompanied by a significant decrease in the content of plant-available phosphorus. As it is well known, extended clay granules are characterized by high primary reaction, which causes alkalization of the rhizosphere of plants growing on this substrate in the initial weeks of cultivation. This phenomenon, also observed in the authors' own research, might have affected the results. Besides, MEINKEN (1997) points to possible temporary accumulation of certain nutrients, including phosphate ions, inside extended clay granules, which an considerably modify the composition of the rhizosphere.

In this experiment, significantly more phosphorus was found in extracts and drainage water from treatments fertilized with the solution containing a higher concentration of macroelements. Compared to the liquid fed through a dripper, an increase in the phosphate ion concentration in drainage water was 77.29% for the basic solution (EC I) and 53.40% for the concentrated solution (EC II). BREŒ and RUPRIK (2006), as well as KOMOSA et al. (2010) reported a decrease in the phosphate content in the rhizosphere and drainage water compared to the solution dosed under plants.

In the present tests, no significant differences were found in the concentrations of potassium, calcium and magnesium in the rhizosphere and drainage water of the tomato grown on the examined substrates. Significantly more of these elements (460.4 mg K dm^{-3}, 382.3 mg Ca dm^{-3} and 108.8 mg Mg dm^{-3}) were found after the application of the concentrated solution (EC II) compared to the basic one (EC I). The analysis of the results demonstrated distinctly higher concentrations of potassium, calcium and magnesium in drainage water flowing out of the cultivation mats compared to the liquid feed dosed through a dripper. Depending on the applied solution, the increase of potassium concentration ranged from 23.37% to 39.46%, calcium 38.28%-43.02% and magnesium 12.55%-23.76%. Similar results are presented by KOMOSA et al. (2009). A much higher concentration of these elements was reported by BREŒ, RUPRIK (2006). In another study completed by KOMOSA et al. (2010), a decrease in magnesium was reported in the rhizosphere of tomato grown on rockwool and wood fiber, compared to the solution dosed through a dripper.

Interesting results showing changes in sodium concentration in the examined treatments are noteworthy. Most of the references claim that it is a ballast element, reaching the highest concentration in drainage water, which therefore should be diluted before eing re-introduced under plants (DYŒKO, KOWALCZYK 2005, KOMOSA, KLEIBER 2007, KOMOSA et al. 2009, 2010). In the present study, a decrease in thesodium ion content was observed (from -8.160 to -29.69%) compared to the amount of this element supplied under plants in the form of a nutrient solution.

The analysis of the results obtained from the present experiment has demonstrated differences in the composition of drainage water depending on the applied nutrient solution. In the drainage water from the treatments fertilized with the solution of basic macronutrient composition (EC I), the following ion concentration range was found: $N\text{-}NH_4 > P\text{-}PO_4 > Ca > S\text{-}SO_4 > K > N\text{-}NO_3 > Mg$. In the drainage water flowing out of the treatments fertilized with the solution containing 25% more macronutrients (EC II), the ion concentration range was the following: $N\text{-}NH_4 > P\text{-}PO_4 > Ca > N\text{-}NO_3 > S\text{-}SO_4 > K > Mg$. The ranges of ion concentrations in drainage water produced while growing tomato on inert substrates, quoted in the literature, are different (KOMOSA et al. 2009, 2010). Thus, the composition of drainage water depends on the concentration of nutrients in the initial solution, as well as on the quantity of ions selectively taken up by particular cultivars. These results prove that it is necessary to monitor the chemical composition of drainage water before its reintroduction under plants through a fertigation system which allows solution recirculation.

CONCLUSIONS

1. Significantly more ions of nitrates, phosphorus, potassium, calcium, magnesium, sulphates and sodium were found in extracts from the rhizosphere and in drainage water collected from the treatments fertilized with the concentrated solution (EC II).

2. In the drainage water from the treatments fertilized with the basic solution (EC I), the increase in ion concentrations appeared in the following order: N-NH_4 > P-PO_4 > Ca > S-SO_4 > K > N-NO_3 > Mg, whereas when the concentrated solution (EC II) was applied, it turned to be: N-NH_4 > P-PO_4 > Ca > N-NO_3 > S-SO_4 > K > Mg.

3. A decrease in the sodium concentration in drainage water was demonstrated compared to the nutrient solution dosed under plants with either of the two liquid feeds.

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