ACTA Acta Sci. Pol., Hortorum Cultus 11(6) 2012, 131-143

POSSIBILITY OF REUSING EXPANDED CLAY IN GREENHOUSE TOMATO CULTIVATION. PART II. CHANGES IN THE COMPOSITION OF NUTRIENTS IN THE ROOT ENVIRONMENT AND LEAVES

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Abstract. The main cause of disturbances in proper nutrient uptake and distribution by plants grown in inert media is an increase of some nutrients in total ion concentration (EC) in the root environment. This phenomenon results from increased water uptake relative to nutrients and ballast ions. The aim of the present study, conducted in the period 2007–2008, was to determine changes in the nutrient contents of the root environment and leaves of tomato grown in expanded clay being post-production waste in soilless tomato culture under extended cycle conditions. The study used new expanded clay (I) as the control and expanded clay being post-production waste from year-round tomato cultivation with the following experimental design: chemically sterilized material (II); material washed in water with the remains of the old root system of plants removed and additionally chemically sterilized (III); and material without any modifying treatments (IV). Expanded clay was placed in 12 dm^3 poly sleeves and formed in the shape of growing slabs. Crops were grown using a drip irrigation and fertilization system with closed nutrient solution system, without recirculation. The nutrient solution was supplied to all plants in the same amount and with the same composition. The study did not find significant differences in the content of mineral nitrogen, phosphates, potassium, calcium, manganese, iron, and zinc in the root environment of plants grown in new and reused expanded clay. Changes in total ion concentration (EC) in the root environment of plants during growth did not differ significantly between the investigated treatments. The adverse phenomenon of alkalization of the root environment, characteristic for new expanded clay, was not found in expanded clay being post-production waste reused as a growing medium. The study did not find significant differences in plant nutrition which might prove that expanded clay under study cannot be reused as a growing medium in plant cultivation.

Key words: soilless culture, reused medium, rhizosphere, nutrients status, nutrients

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INTRODUCTION

When growing plants in inert media, an increase can be usually observed in the concentration of nutrients and ballast ions being an effect of increased water uptake and selective ion uptake by plants [Komosa 2002; Jarosz and Dzida 2011]. This causes an excessive concentration of some ions in the root environment, which disturbs the uptake and distribution of elements in the plant [Grava et al. 2001]. In the opinion of Dyśko and Kowalczyk [2005], changes in the chemical composition of the rhizosphere are also significantly affected by the developing root system and interactions between individual nutrients.

Some reports also indicate the possibility of the occurrence of ion exchange sorption and adsorption during plant cultivation in an expanded clay medium [Drizo et al. 1999; Johansson Westholm 2006]. In turn, Sonneveld and Voogt [2009] pointed out that it is important to know the full chemical composition of components from which a mineral medium is composed, since a part of these components may be released into the rhizosphere during cultivation. This seems to be confirmed by the study of Sonneveld and Wever [2005] who showed 10 times different iron and manganese concentrations during extraction of expanded clay granules using extractors with different chemical properties and a pH from 2.8 to 6.0. Dyśko et al. [2008] proved that phosphorus availability to plants grown in soilless culture was strictly dependent on rhizosphere pH; however, changes in pH and in availability of this nutrient occur quicker in an inert substrate than in an organic one. In turn, Sonneveld and Voogt [2009] emphasize that the optimal availability of micronutrients from the medium-grown plants is also dependent on the maintenance of rhizosphere pH within strictly defined limits. All these factors significantly affect the availability of nutrients and their uptake by plants.

The aim of the study was to evaluate changes in pH, total salt concentration (EC), and contents of some nutrients in the root environment as well as contents of some macro- and micronutrients in leaves of tomato grown in expanded clay being post-production waste from year-round tomato cultivation.

MATERIALS AND METHODS

The present experiment on the tomato cultivar 'Cunero F_1', grown in a greenhouse in a medium of horticultural expanded clay with granulation of 8–16 mm (Optiroc--Gniew), was conducted in the period 2007–2008. The study used new expanded clay (I) as the control and expanded clay being post-production waste from year-round tomato cultivation with the following experimental design: chemically sterilized material (II); material washed in water with the remains of the old root system of the plants removed and additionally chemically sterilized (III); and material without any modifying treatments (IV). A 2% solution of the fungicide Previcur 607 SL was used for chemical sterilization. Expanded clay was placed in 12 dm^3 poly sleeves and formed in the shape of growing slabs. Two plants were grown in each slab. The experiment was set up as a completely randomized design with seven replications. A slab in which two plants were grown was one replication. Tomato plants were planted in their permanent place in the first decade of February (9 February 2007; 6 February 2008). Tomato was cultivated in extended cycle (22 clusters), at a density of 2.3 plant·m^{-2}, until the middle of October (12 October 2007 and 14 October 2008). Crops were grown using a drip irrigation and fertilization system with closed nutrient solution circulation, without recirculation. The study used a nutrient solution with the following average composition (mg·dm^{-3}): N-NH_4 – 12.2; 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 as well as pH – 5.95 and EC 2.3–2.9 mS·cm^{-1}. The nutrient solution was prepared with the following chemical composition of water (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 – 7.44; EC – 0.71 mS·cm^{-1}. The solution was supplied to all plants in the same amount and with the same composition. The composition and proportions of particular elements in the nutrient solution were changed during plant growth and adjusted to plant development stages in accordance with the latest recommendations [Sonneveld and Voogt 2009]. The amount of nutrient solution supplied was determined with an excess of about 25%. The frequency of nutrient solution supply, controlled by a solar timer, depended on solar radiation intensity. Flowers were pollinated by the large earth bumblebee (*Bombus terrestris*). Plant protection treatments were carried out using biological agents. All tending treatments were performed in accordance with the applicable recommendations [Adamicki et al. 2005].

The content of N-NH_4, N-NO_3, P-PO_4, K, Ca, Mg, Fe, Zn, Mn and Cu as well as the pH and electrical conductivity (EC) of the root environment were controlled every 4 weeks starting from the placement of plants in the media. Extracts from the growing slabs were taken with a syringe from designated placed located in the middle of the distance between plants. Ammonium and nitrate nitrogen were determined by the Bremner distillation method (modified by Starck), phosphorus was determined colourimetrically with ammonium-vanadium-molybdate (Nicolet Evolution 300 spectrophotometer), while potassium, calcium, magnesium, iron, zinc, manganese and copper by AAS (Perkin-Elmer AAnalyst 300).

Leaves for analyses (9^{th} leaf from the top) were collected at the beginning, in the middle and at the end of plant fruiting. After the material had been dried, (temp. 105°C) total nitrogen was determined in leaves with the use of Kjeldahl's method [Ostrowska et al. 1991]. After the material had been mineralized in the mixture of nitric and perchloric acids in the proportion of v:v 3:1 [Ostrowska et al. 1991] phosphorus was determined colorimetrically with ammonium vanadomolybdate (Thermo, Evolution 300), potassium, calcium, magnesium, iron, zinc, manganese and copper using AAS method (Perkin-Elmer, Analyst 300).

Statistical elaboration of results was conducted using the method of variance analysis on mean values, applying Tukey's test for assessing differences, at significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

In the opinion of Verdonck [2007], 16 million m^3 of substrates are used in Europe, including 3.5% of pre-shaped products (rockwool and different foam products) and 2.3% of mineral materials (sand, clay, perlite, expanded clay). Therefore, it is necessary to develop an easy and environment-friendly technology for post-production waste management. One of the solutions that significantly reduce the production and consumption of new materials is to reuse production waste in plant cultivation.

Yoon et al. [2007] showed that the density and water-holding capacity of the rhizosphere increase in reused organic media but, at the same time, the air-holding capacity decreases significantly (even by half). Many authors think that the maintenance of stable air and water conditions is the primary factor determining productivity of plants grown in inert substrates [Komosa 2002; Verhagen 2011]. Expanded clay is considered to be a stable substrate in terms of its form as well as air and water properties [Drizo et al. 1999]. Nevertheless, this material reused in plant production as a growing medium may differ significantly from a new one in terms of proportions of air to water due to the remains of the root system of plants.

The statistical analysis of the results obtained in the present study did not show significant differences in the content of nitrogen, phosphates, potassium, calcium, magnesium, iron, and zinc in the root environment of plants grown in the investigated types of expanded clay (Tab. 1). The lowest amount of manganese (average 1.89 mg·dm^{-3}) and copper (average 0.89 mg·dm^{-3}) was found in the nutrient solution collected from the root environment of tomato grown in new expanded clay, while the amounts of these micronutrients were significantly higher (respectively, 3.38 mg·dm^{-3} and 1.77 mg·dm^{-3}) in reused expanded clay without any modifying treatments (IV).

In the present study, the ammonium nitrogen content in the nutrient solution supplied to plants throughout the whole growing season did not exceed 8% of the sum of $N\text{-}NH_4 + N\text{-}NO_3$, which is consistent with the current recommendations [Sonneveld and Voogt 2009]. In the opinion of Ho et al. [1999], an excess of ammonium cations in the root environment of plants reduce calcium uptake, which dangerously increases the risk of the occurrence of blossom-and-rot on tomato fruits. Interestingly, chemical analyses of nutrient solution taken from the root environment of plants carried out regularly during this study showed trace amounts of ammonium ions in the rhizosphere. The obtained results should be explained by both the uptake of ammonium nitrogen by plants and the process of oxidation of this form to nitrate ions.

Phosphate content in the nutrient solution collected from the investigated types of expanded clay seem interesting in relation to different times of analysis (Fig. 1a). During the initial two months of tomato culture, the nutrient solution taken from new expanded clay was shown to have by far fewer phosphorus ions available to plants compared to the other media under study. These results should be related to changes in the pH of the rhizosphere of plants grown in the investigated mediums during plant growth (Fig. 1c). Unlike the other substrates, during initial assays the pH of the extracts from new expanded clay showed pH values in the range of 6.7–7.2. As demonstrated by the study of Dyśko et al. [2008], the content of phosphorus available by plants is strictly correlated with the pH of the root environment. In the above cited study, rhizosphere pH

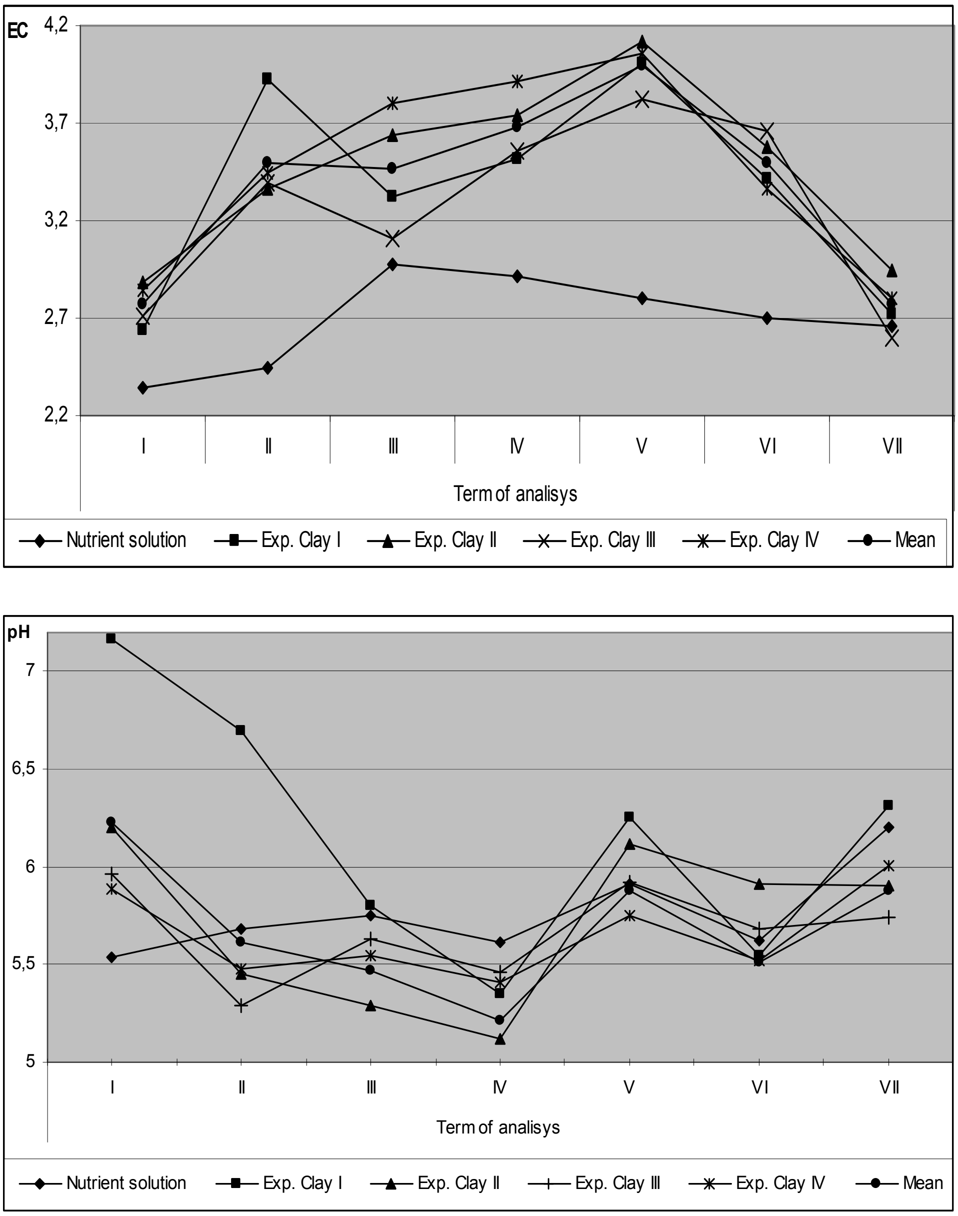

Fig. 1. The electrical conductivity ($mS \cdot cm^{-1}$) and pH in the root zone of tomato grown in tested medium (means for 2007–2008 years)

Rys. 1. Przewodność elektryczna ($mS \cdot cm^{-1}$) oraz pH w środowisku korzeniowym pomidora uprawianego w badanym podłożu (średnio z lat 2007–2008)

Table 1. The contents of selected macronutrients ($mg \cdot dm^{-3}$) in the root zone of tomato, depending on the preparing of expanded clay

Tabela 1. Zawartość wybranych makroskładników ($mg \cdot dm^{-3}$) w środowisku korzeniowym pomidora w zależności od sposobu przygotowania keramzytu

Treatment Kombinacja	$N\text{-}NH_4$+$N\text{-}NO_3$			$P\text{-}PO_4$			K			Ca			Mg		
	2007	2008	$\bar{x}$	2007	2008	$\bar{x}$	2007	2008	$\bar{x}$	2007	2008	$\bar{x}$	2007	2008	$\bar{x}$
Exp. Clay I	297	320	308	58	72	65	355	379	367	290	364	327	80	95	89
Exp. Clay II	346	298	322	63	75	69	422	395	409	345	348	347	92	108	100
Exp. Clay III	306	257	281	66	78	72	421	359	390	277	316	296	93	91	92
Exp. Clay IV	328	327	327	70	74	72	437	392	415	279	347	312	105	114	110
$\bar{x}$	319	301		64	75		409	382		297	343		92	102	
$LSD_{0.05}$ – $NIR_{0,05}$															
Treatment – Kombinacja	n.s. – r.n.			n.s. – r.n.			n.s. – r.n.			n.s. – r.n.			n.s. – r.n.		
Year – Rok	n.s. – r.n.			n.s. – r.n.			n.s. – r.n.			n.s. – r.n.			n.s. – r.n.		
Treatment × year	n.s. – r.n.			n.s. – r.n.			n.s. – r.n.			n.s. – r.n.			n.s. – r.n.		

Note: n.s. – no significant differences, r.n. – różnice nieistotne statystycznie

Table 2. The contents of selected micronutrients ($mg \cdot dm^{-3}$) in the root zone of tomato, depending on the preparing of expanded clay
Tabela 2. Zawartość wybranych mikroskładników ($mg \cdot dm^{-3}$) w środowisku korzeniowym pomidora w zależności od sposobu przygotowania keramzytu

Treatment Kombinacja	Fe			Mn			Zn			Cu		
	2007	2008	$\bar{x}$	2007	2008	$\bar{x}$	2007	2008	$\bar{x}$	2007	2008	$\bar{x}$
Exp. clay I	2.69	2.47	2.58	1.96	1.83	1.89	1.49	1.26	1.37	0.82	0.96	0.89
Exp. clay II	3.48	3.24	3.36	3.57	2.63	3.10	1.77	1.79	1.78	0.86	1.26	1.06
Exp. clay III	2.64	2.73	2.69	2.36	1.69	2.02	1.33	1.54	1.43	1.20	0.80	1.01
Exp. clay IV	3.08	3.59	3.33	3.65	3.11	3.38	2.32	2.25	2.29	1.57	1.98	1.77
$\bar{x}$	2.97	3.01		2.88	2.31		1.73	1.70		1.11	1.25	
$LSD_{0.05}$ – $NIR_{0,05}$												
Treatment – Kombinacja		n.s. – r.n.			1.40			n.s. – r.n.			0.80	
Year – Rok		n.s. – r.n.			n.s. – r.n.			n.s. – r.n.			n.s. – r.n.	
Treatment × year		n.s. – r.n.			n.s. – r.n.			n.s. – r.n.			n.s. – r.n.	

Note: See table 1 – Patrz tab. 1

Table 3. Effect of the preparing method of expanded clay on the some macronutrients content (% d.w.) in leaves of tomato
Tabela 3. Wpływ sposobu przygotowania keramzytu na zawartość makroskładników pokarmowych (% s.m.) w liściach pomidora

Treatment Kombinacja	N Total , N ogółem			P			K			Ca			Mg		
	2007	2008	$\bar{x}$	2007	2008	$\bar{x}$	2007	2008	$\bar{x}$	2007	2008	$\bar{x}$	2007	2008	$\bar{x}$
Exp. Clay I	4.24	3.96	4.10	0.23	0.35	0.29	5.63	5.42	5.52	2.05	3.17	2.61	0.31	0.32	0.31
Exp. Clay II	4.38	4.12	4.25	0.38	0.42	0.40	5.35	5.14	5.24	2.11	3.40	2.76	0.30	0.36	0.33
Exp. Clay III	3.99	4.02	4.01	0.29	0.37	0.33a	5.02	5.54	5.28	2.12	3.82	2.97	0.36	0.40	0.38
Exp. Clay IV	4.06	3.67	3.86	0.44	0.46	0.45	5.55	5.33	5.44	2.37	3.26	2.81	0.37	0.41	0.39
$\bar{x}$	4.17	3.94		0.34	0.40		5.39	5.35		2.16	3.41		0.35	0.37	
$LSD_{0.05}$ – $NIR_{0,05}$															
Treatment – Kombinacja		0.23			0.11			n.s. – r.n.			n.s. – r.n.			0.07	
Year – Rok		0.12			0.05			n.s. – r.n.			0.27			0.02	
Treatment × year		n.s. – r.n.			n.s. – r.n.			n.s. – r.n.			n.s. – r.n.			n.s. – r.n.	

Note: See table 1 – Patrz tab. 1

Table 4. Effect of the preparing method of expanded clay on the some micronutrients content ($mg \cdot kg^{-1}$ d.w) in leaves of tomato
Tabela 4. Wpływ sposobu przygotowania keramzytu na zawartość mikroskładników pokarmowych ($mg \cdot kg^{-1}$ s.m.) w liściach pomidora

Treatment Kombinacja	Fe			Mn			Zn			Cu		
	2007	2008	$\bar{x}$	2007	2008	$\bar{x}$	2007	2008	$\bar{x}$	2007	2008	$\bar{x}$
Exp. clay I	135.6	127.8	131.7	189.4	116.1	152.7	41.9	45.4	43.6	12.3	10.2	11.3
Exp. clay II	150.5	136.9	143.7	172.6	104.6	138.6	45.2	44.9	45.1	11.4	10.5	10.9
Exp. clay III	133.5	111.4	122.4	142.2	103.7	122.9	31.0	37.9	34.7	9.8	10.7	10.3
Exp. clay IV	160.4	127.5	144.0	136.3	97.6	116.9	46.8	50.7	48.8	11.1	11.3	11.2
$\bar{x}$	145.0	125.9		160.1	105.5		41.2	44.8		11.2	10.7	
$LSD_{0.05}$ – $NIR_{0,05}$												
Treatment – Kombinacja		n.s. – r.n.			n.s. – r.n.			10.82			n.s. – r.n.	
Year – Rok		14.3			24.57			n.s. – r.n.			n.s. – r.n.	
Treatment × year		n.s. – r.n.			n.s. – r.n.			n.s. – r.n.			n.s. – r.n.	

Note: See table 1 – Patrz tab. 1

was found to increase with an increase in the pH of the nutrient solution applied, and this was accompanied by a significant decrease in the content of phosphorus available to plants. In the present study, the composition and pH of the nutrient solution supplied to plants were the same for all treatments and consistent with the current recommendations [Sonneveld and Voogt, 2009]. The causes of excessive alkalization of the nutrient solution collected from the root environment in the case of cultivation in new expanded clay should be sought in the chemical properties of this material. As reported by Sonneveld and Voogt [2009], expanded clay granules are characterized by high original pH_{H2O} (7.7–8.6), which results in alkalization of the root environment of plants growing in this medium during the primary weeks of culture. Should be emphasized, that the lowest amount of phosphorus (0.29% P DW) was found in the leaves of plants grown in new expanded clay compared to plants grown in the other treatments (Tab. 3). Interesting are the results which prove that expanded clay being post-production waste from year-round tomato cultivation reused in plant culture does not have an alkalizing effect on the nutrient solution in the rhizosphere. This is a great benefit derived from reuse of expanded clay as a growing medium in soilless plant culture, since this allows disturbances in phosphorus and micronutrient uptake by plants to be avoided.

Numerous papers draw attention to the possibility of the occurrence of accumulation of phosphate anions and other ions in expanded clay, which is a result of ion exchange sorption and adsorption on the surface of granules [Meinken 1997; Drizo et al. 1999; Cucarella and Renman 2009]. The statistical analysis of the results obtained in the present study relating to changes in the content of phosphorus, potassium, calcium, magnesium, iron, and zinc in the substrates under study does not confirm the occurrence of such relationships. In considering the content of manganese and copper in the nutrient solution collected from the treatments under study, one can see a trend towards an increased content of these nutrients in the root environment of tomato grown in reused media compared to the new material, though differences were confirmed statistically only in the case of expanded clay used with no modifications (IV) (Tab. 2). However, the previously mentioned excessive alkalization of the rhizosphere solution in new expanded clay, which most probably caused a decrease in the content of available forms of manganese and copper, can be an explanation for the results obtained. This thesis seems to be confirmed by the reports of Sonneveld and Voogt [2009] who showed high relationships between plant rhizosphere pH and availability of micronutrients by plants.

An increase in total ion concentration (EC) in the root environment of plants, compared to the nutrient solution, which results from the predominance of water uptake, is a characteristic phenomenon observed in plant culture in inert media [Dyśko and Kowalczyk 2005; Komosa et al. 2009]. The analysis of total ion concentration (EC) in samples collected from expanded clays under study also confirmed the occurrence of this phenomenon (Fig. 1d). The highest EC was recorded in the summer months (June – July), but these values did not exceed 4.20 $mS \cdot cm^{-1}$. In comparison to the current recommendations applicable for tomato culture in inert media, the obtained results should be considered to be correct [Sonneveld and Voogt 2009]. Grava et al. [2001] as well as Hao and Papadopoulos [2004] recommend to periodically increase EC of the root environment of plants in order to improve the taste of fruits and some parameters of the biological value of fruits. Sonneveld and Voogt [2009] are of opinion that such a mode of procedure is justified even despite the risk of lower yields. It should be stressed that a similar distribution of changes in total ion concentration in the root environment of plants growing in the treatments under study during plant growth is a confirmation of the usefulness of post-production expanded clay waste as a reused growing medium.

The content of total nitrogen (3.67–4.38% N DW), potassium (5.02–5.63% K DW), calcium (2.05–3.82% Ca DW), and magnesium (0.30–0.41% Mg DW) in the leaves of tomato plants grown in the treatments under study, as recorded in the present study (Tab. 3), should be considered to be correct for soilless culture of this species [Chohura and Komosa 2003; Sonneveld and Voogt 2009; Jarosz and Dzida 2011]. The contents of iron (111.4–160.4 $mg \cdot kg^{-1}$ DW), manganese (103.7–148.3 $mg \cdot kg^{-1}$ DW), zinc (31.0–50.7 $mg \cdot kg^{-1}$ DW), and copper (9.8–12.3 $mg \cdot kg^{-1}$ DW) shown in the leaves of the studied plants (Tab. 4) are in agreement with the values reported in the literature reports, which is evidence of proper nutrition of tomato plants grown in the treatments in question [De Kreij at al. 1992; Sonneveld and Voogt 2009, Asri and Sonmes 2012].

CONCLUSIONS

1. No significant differences were found in the content of nitrogen, phosphorus, potassium, calcium, manganese, iron, and zinc in the root environment of plants grown in new and reused expanded clay.

2. Total ion concentration (EC) in the root environment of plants during their growth did not differ significantly between the investigated treatments of expanded clay.

3. The adverse phenomenon of alkalization of the root environment, characteristic for new expanded clay, was not found in expanded clay being post-production waste reused as a growing medium.

4. It was not found significant differences in plant nutrition that might prove the uselessness of expanded clay studied as a reused medium in plant cultivation.

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MOŻLIWOŚĆ POWTÓRNEGO WYKORZYSTANIA KERAMZYTU W SZKLARNIOWEJ UPRAWIE POMIDORA. CZĘŚĆ II. ZMIANY ZAWARTOŚCI SKŁADNIKÓW POKARMOWYCH W ŚRODOWISKU KORZENIOWYM I LIŚCIACH

Streszczenie. Jednym z istotnych powodów zakłóceń prawidłowego pobierania i dystrybucji składników pokarmowych przez rośliny uprawiane w podłożach inertnych jest wzrost koncentracji niektórych jonów w środowisku korzeniowym. Zjawisko to wynika ze zwiększonego pobierania wody w stosunku do pobierania składników pokarmowych i jonów balastowych. Badania przeprowadzone w latach 2007–2008 miały na celu określenie zmian składu chemicznego środowiska korzeniowego oraz liści pomidora uprawianego w keramzycie będącym odpadem poprodukcyjnym w bezglebowej uprawie pomidora w cyklu wydłużonym. W badaniach zastosowano keramzyt nowy (I) jako kontrolę oraz keramzyt będący odpadem poprodukcyjnym z całosezonowej uprawy pomidora w następującym układzie: materiał odkażony chemicznie (II), materiał wypłukany w wodzie z usunięciem pozostałości starego systemu korzeniowego roślin i dodatkowo odkażony chemicznie (III) oraz materiał bez jakichkolwiek zabiegów modyfikujących (IV). Keramzyt był umieszczany w rękawach foliowych o objętości 12 dm^3 i formowany na kształt mat uprawowych. Uprawę prowadzono z wykorzystaniem kroplowego systemu nawożenia i nawadniania z zamkniętym obiegiem pożywki, bez recyrkulacji. Do wszystkich roślin dostarczano pożywkę w takiej samej ilości i o takim samym składzie. Nie stwierdzono istotnych różnic w zawartości azotu, fosforu, potasu, wapnia, magnezu, żelaza i cynku w środowisku korzeniowym roślin uprawianych w keramzycie nowym oraz powtórnie użytkowanym. Ogólna koncentracja jonów (EC) w środowisku korzeniowym roślin w trakcie wegetacji nie różniła się znacząco pomiędzy badanymi sposobami przygotowania keramzytu. W keramzycie będącym odpadem poprodukcyjnym używanym ponownie jako podłoże nie odnotowano niekorzystnego zjawiska alkalizacji środowiska korzeniowego, charakterystycznego dla keramzytu nowego. W badaniach nie stwierdzono istotnych różnic w odżywieniu roślin mogących świadczyć o braku przydatności badanego keramzytu w ponownej uprawie.

Słowa kluczowe: uprawa bezglebowa, podłoże powtórnie użytkowane, ryzosfera, stan odżywienia, składniki pokarmowe

Accepted for print – Zaakceptowano do druku: 18.07.2012