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THE NUTRIENT CONTENT IN SUBSTRATES AND LEAVES OF GREENHOUSE TOMATO

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Abstract. Organic substrata applied in greenhouse cultivations are biodegradable. Decomposition occurs during vegetation and as a waste during composting or ploughed in the field. The aim of the presented studies, conducted in the years 2008 and 2009 was to demonstrate the contents of macrocomponents in the solution from root environment of substrata and in tomato leaves. The tomato of Admiro F_1 cultivar was grown in the following substrata: 1) triticale straw, 2) triticale straw + high peat (3:1 v/v), 3) triticale straw + pine bark (3:1 v/v), 4) rockwool. Straw, cut into 2–3 cm pieces, straw with peat and bark were placed in plastic boxes (height twice as large as width). There was 15 dm^3 of organic substrata and rockwool. During tomato vegetation in organic substrata there was the least of $N\text{-}NO_3$ at the beginning of growing (March), which could be related to biological sorption of nitrogen. In the subsequent months of cultivation the content of this nutrient was normal, according to the leaves recommended for tomato. Mean content of $N\text{-}NH_4$, $N\text{-}NO_3$, K, Ca, Mg in organic substrata did not significantly differ compared to rockwool. The EC value in organic and rockwool substrata was optimal during the whole vegetation period. The correct growth and high yield of tomato grown in organic substrata was obtained at the following mean contents in solution from root environment (mg dm^{-3}): $N\text{-}NH_4$ – 26.8, $N\text{-}NO_3$ – 242.8, P –78.1, K – 295.6, Ca – 315.3, Mg – 107.5.

Key words: triticale straw, rockwool, root environment, tomato

INTRODUCTION

The fact that the greenhouse has got fertigation equipment allows for taking advantage of various materials as substrata. These can be organic, mineral, or synthetic materials, manufactured as substrata, as well as various types of waste, most often prepared in the form of mixtures. Fertigation, i.e. watering and feeding of the cultivated plants, works automatically. The plants are fed 8–14 times a day, and therefore they are optimally nurtured throughout their vegetation period.

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The chemical composition of the medium for tomato has been worked out quite well, but certain modifications have to be considered. They are mainly related to the kind of substratum. The organic and mixed substrata, with a significant share of organic substances undergo decomposition during vegetation and the plants obtain additional nutrients. Another important issue is the reaction of medium and solution in root environment. For tomato the pH value of solution from root environment should range from 5.5 to 6.0. Such conditions guarantee the highest fruit yield. With the increase of pH in the plant the contents of phosphorus, iron and manganese decrease, which indicates retraction of these components [Dyśko et al. 2009]. The inappropriate reaction value (pH 4.0) caused a significant reduction of transpiration, stomatal conductance and evapotranspiration, compared to pH 6.0. At pH 8.0 the fresh and dry plant weight were more reduced than at pH 4.0 [Kang et al. 2011].

Regardless of the type of substratum the concentration of all ions in the root environment solution is important. It is expressed by the EC value. Examining tomato growth and yielding at EC valued 2.8 and 4.7 $dS \cdot m^{-1}$ [Buck et al. 2008] a significant decrease of fruit yield was demonstrated at 4.7 $dS \cdot m^{-1}$ compared to 2.8. The EC value is closely connected with substratum watering. In studies with tomato grown in rockwool [Saha et al. 2008] the best results were obtained when the content of water in substratum did not exceed 70%, whereas the EC value should range from 1.4 to 1.7 $dS \cdot m^{-1}$.

The issue of photosynthesis and transpiration of tomato leaves was examined at the following EC values in the media: 2.3; 4.8; 8.4 $dS \cdot m^{-1}$ [Wu and Kubota 2008]. High EC value (8.4) caused the reduction of stomatal conductance and transpiration by 28% compared to low EC value (2.3 $dS \cdot m^{-1}$). Considering also the cultivars of examined tomatoes the gas exchange in leaves (stomatal conductance, transpiration, photosynthesis) had the most advantageous course at the EC value of 4.8 $dS \cdot m^{-1}$.

During tomato vegetation period the concentrations of particular nutrients in substrata change. This especially concerns potassium and nitrogen. Examining various concentrations of potassium in the medium [Caretto et al. 2008, Almeselmani et al. 2010] it was demonstrated that the dose of 300 mg $K \cdot dm^{-3}$ affected the yield and chemical composition of tomato fruit the most favorably. The increased potassium concentration in the media caused the increase of ascorbic acid, lycopene and reducing sugars' contents as well as of acidity in tomato fruit. Differentiating the potassium concentration in the medium also the nitrogen – potassium ratio is considered [Hernandez et al. 2009, Huang and Snapp 2009]. Taking into consideration the fruit yield, as well as nitrogen, phosphorus calcium, magnesium and boron uptake the N:K ratio should equal 1:1.5–1.7.

In tomato growing nitrogen is applied especially in the form of nitrates ($Ca(NO_3)_2$, KNO_3), as the reduced nitrogen (NH_4^+) applied in larger quantities acts toxically [Souri et al. 2009, Souri and Romheld 2009], and the studies demonstrated that the water consumption by plants fertilized with nitrate nitrogen ($Ca(NO_3)_2$) increased, contrary to the ammonium form ($(NH_4)_2SO_4$).

The presented paper comprises studies on changing contents of N, P, K, Ca and Mg in substrata and leaves of greenhouse-grown tomato in the substrata of cut triticale straw, mixture of triticale straw with peat, pine bark and in rockwool.

MATERIAL AND METHODS

Studies were conducted in the glasshouse of Department of Soil Cultivation and Fertilization of Horticultural Plants, University of Life Science in Lublin. The tomato of Admiro F_1 cultivar was grown in the period from 10^{th} February to 21^{st} October 2008 and from 4^{th} February to 15^{th} October 2009 for 22 clusters at the density of 2.4 plants for $1m^2$. The following substrata were examined: 1) triticale straw, 2) triticale straw + high peat (3:1 v:v), 3) triticale straw + pine bark (3:1 v:v), 4) rockwool (100 × 20 × 7.5 cm = 15 dm^3). Straw was cut into pieces (2–3 cm) and placed in rectangular boxes 14 cm high, bottom width: 8 cm and capacity 15 dm^3. During the growing period about 70% straw has been decomposed. Evaluation of straw decomposition was done by comparing the weight of air dry weight of straw before the experiment with the mass after the experiment (after removal of roots). In each box/slab two plants grew. The experiments were conducted with the use of complete randomization method in seven repetitions.

Drip fertigation was applied in closed system without recirculation of nutrient solution that contained ($mg \cdot dm^{-3}$): N-NO_3 – 210; P-PO_4 – 54; K – 340; Ca – 250; Mg – 80; Cl – 20; S-SO_4 – 150; Fe – 2.0; Mn – 0.95; B – 0.54; Cu – 0.09; Zn – 0.56; Mo – 0.09, pH_{H2O} – 5,70–5.90, EC – 2.4 $mS \cdot cm^{-1}$. In the period of high temperatures the nutrient solution was applied in the daily amount of about 4.2 dm^3 per plant in 10–12 single doses with 20% nutrient solution effusion from the box/slab. *Bombus terrestris* used for plant pollination, Greenhouse Whitefly (*Frialeurodes vaporariorum*) was biologically controlled with *Encarsia formosa*.

Chemical analyses of substrates (solution from the root environment) using the following methods: N-NH_4 and N-NO_3 by distillation according to Bremner in Starck`s modification, P – colorimetrically with ammonium vanadomolybdate (Thermo, Evolution 300), K, Ca, Mg by AAS (Perkin-Elmer, Analyst 300), EC – conductometrically, pH – potentiometrically.

Samples of nutrients representing the root zone were taken with using the syringe in mid-distance between the plants, along the central axis of the slab by injecting the syringe needle into one half of slab thickness (rockwool) and 2 cm above of botton of the box (organic substrates).

Samples of leaves (8^{th} leaf from the top) was determined: N-total by usung Kjeldahl`s method (Tecator), P, K, Ca, Mg were measured by methods for substrates. The contents in substrates and in leaves was analyzed once a month (substrates eight times, leaves six times during vegetation season).

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 P = 0.05.

RESULTS

In growing tomato in organic substrata (triticale straw, triticale straw with added peat and bark), as well as in the mineral substratum (rockwool) the same nutrient solution was applied, in the same amounts and in the same time. In all the objects high yields were obtained, but the differences were not significant. The lowest yield was found in growing in the rockwool substratum (fig. 1).

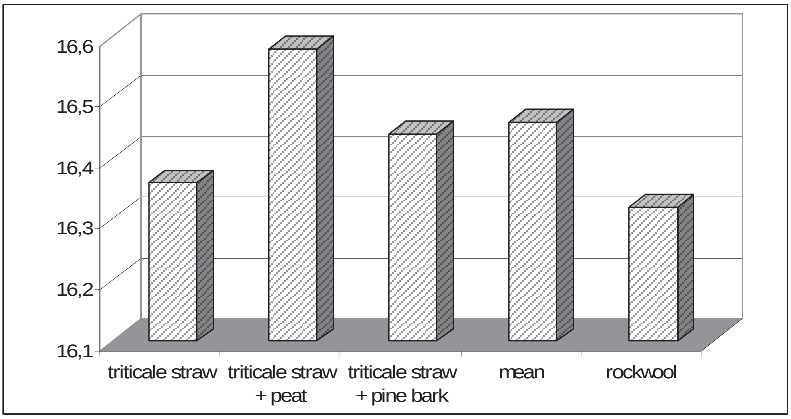

Fig. 1. The effect of the substrate on the total yield of fruit (kg·plant^{-1}). Mean 2008–2009
Ryc. 1. Wpływ podłoży na plon ogólny owoców (kg·roślina^{-1}). Średnie 2008–2009

Table. 1. The nutrient content in substrates (mg·dm^{-3} of solution from root environment)
Tabela 1. Zawartość składników pokarmowych w podłożach (mg·dm^{-3} roztworu ze strefy korzeniowej)

Substrate Podłoże	Triticale straw – Słoma pszenżyta						Mean Średnio	Rockwool Wełna mineralna	
	straw – słoma		+ peat + torf		+ pine bark + kora sosnowa				
Year – Rok	2008	2009	2008	2009	2008	2009		2008	2009
$N-NH_4$	14.0	26.9	21.8	32.1	27.5	38.4		18.8	31.3
Mean – Średnio	20.4a		26.9b		32.9c		26.8	25.0b	
$N-NO_3$	256.2	236.9	262.8	237.5	241.5	222.1		250.8	247.0
Mean – Średnio	246.5a		250.1a		231.8a		242.8	248.9a	
$P-PO_4$	90.8	64.1	90.0	69.0	90.3	64.4		77.5	56.8
Mean – Średnio	77.4a		79.5a		77.3a		78.1	67.1b	
K	315.8	275.1	338.2	267.4	311.3	265.8		321.3	249.3
Mean – Średnio	295.4a		302.8a		288.5a		295.6	285.3a	
Ca	334.8	310.9	336.8	309.8	317.2	282.6		291.7	303.6
Mean – Średnio	322.8a		323.3a		299.9a		315.3	297.6a	
Mg	102.0	112.5	109.5	111.3	108.7	101.0		95.8	113.1
Mean – Średnio	107.2a		110.4a		104.8a		107.5	104.4a	

Note: means in the row followed the same letter are not significant different at P = 0.05
średnie w wierszach oznaczone tą samą literą nie różnią się istotnie przy P = 0,05

The nutrient contents in the substrata were not very differentiated (tab. 1). Mean contents of mineral nitrogen (N-NH_4, N-NO_3) in organic substrata and rockwool were similar and were in the optimal interval, despite the fact that straw, peat and bark underwent decomposition during vegetation, mainly through mineralization. Comparing the obtained results in the subsequent vegetation months (March-October), there was the least of the nitrogen in March, especially in the organic substrata (fig. 2). This should be explained by the substantial need for this nutrient at the beginning of vegetation, and with reference to organic substrata, also by the intensified biological sorption. However, this had no adverse effect upon plant growth, because the nutrient solution was dosed several times (7–9 times) a day. In the subsequent months of vegetation the contents of mineral nitrogen in organic substrata and in rockwool were not differentiated, and in the last months of growing (September–October) lower values were reported, regardless of the kind of substratum.

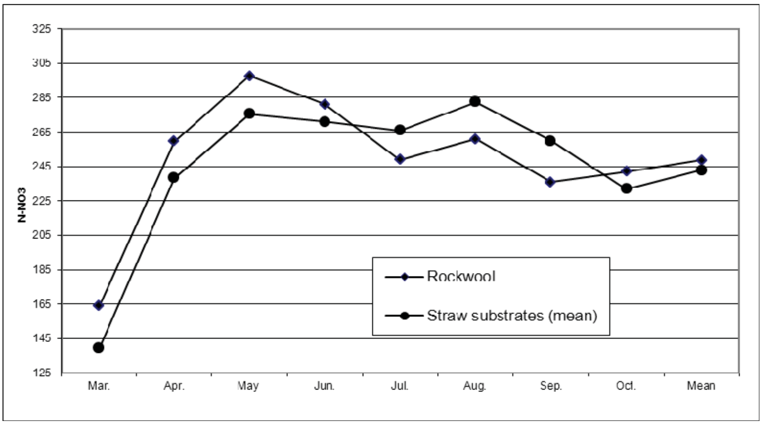

Fig. 2. The N-NO_3 content in substrates (mg·dm^{-3} of solution from the root environment) during vegetation season. Mean 2008–2009

Ryc. 2. Zawartość N-NO_3 w podłożach (mg·dm^{-3} roztworu ze strefy korzeniowej) w okresie wegetacji. Średnie 2008–2009

The phosphorus contents in particular substrata were not very differentiated. In the organic substrata it was on average 78.1 mg P·dm^{-3}, whereas in rockwool it was significantly less (67.1 mg P·dm^{-3}). No substantial changes were found during vegetation. Mean potassium content in organic substrata was 295.6, whereas in rockwool it was 285.3 mg K·dm^{-3}, but these differences are not significant (tab. 1).

Calcium is very important for tomato, because in its deficiency the blossom end rot disease occurs on the fruit. Mean calcium content in the nutrient solution was 250 mg Ca·dm^{-3}, whereas in the substrata it was 306.4 mg Ca· dm^{-3}. Comparing rockwool substrata, similar amounts of calcium were found as in the organic substrata. In all the terms of analyses there was more calcium in the substrata compared to the amount contributed with the nutrient solution.

The need for magnesium in tomatoes is average, but its insufficient content in the substratum shortly causes the occurrence of characteristic stains on the leaves, which means the deficiency of this nutrient. In the presented studies the magnesium content in all the substrata was in the optimal interval.

The pH value of substrata at the beginning of cultivation was too high (6.8–7.2 pH), but already from mid April to the end of growing it ranged from 5.8 to 6.2 pH, which, for tomato, is defined as the optimal value.

As it has already been remarked, the same nutrient solution was applied to all the substrata. The factor that differentiated the concentrations of particular nutrients was also the air temperature. On hot days, when the temperature reached even 40°C, fertigation was set in motion even more frequently (11–14 times a day), which is connected with supplying more nutrient salts to the substrata. However, because of about 20% nutrient solution effusion from the boxes/slabs the changes in nutrient contents were not very significant. This is confirmed by the EC value, measured every week, which was on the optimal level, from 1.6 to 2.8 mS·cm^{-1}, assuming lower values in March and April, as well as in September and October (fig. 3). It has to be emphasized as an interesting fact that this advantageous salt concentration remained in the substrata containing a very small sorption complex. For straw during vegetation undergoes systematic decomposition, mainly through mineralization and after experiment liquidation there remained only 30% of it.

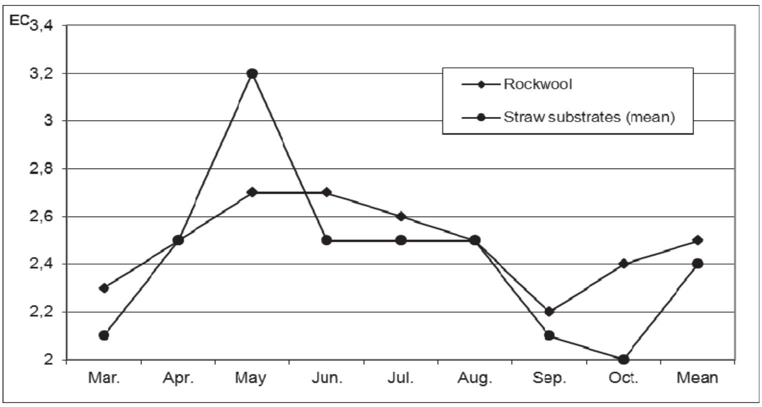

Fig. 3. EC in substrates (mS·cm^{-1}) during vegetation season. Mean 2008–2009
Ryc. 3. Wartość EC w podłożach (mS·cm^{-1}) w okresie wegetacji. Średnie 2008–2009

The results of chemical analyses of leaves for the contents of N, P, K, Ca, Mg were juxtaposed in Table 2. In the substrata we focused on certain differentiation of the particular nutrient contents, whereas the results of chemical analyses of leaves are distinctly stable. Mean total nitrogen content in leaves of plants grown in organic substrata equals 3.94 and in rockwool – 3.96% N D.M. There was significantly less nitrogen in leaves from the objects in triticale straw and in triticale straw + peat. During vegetation the least nitrogen was found in September term of analyses.

Table. 2. The nutrient content of tomato leaves (% of dry matter)
Tabela 2. Zawartość składników pokarmowych w liściach pomidora (% suchej masy)

Substrate Podłoże	Triticale straw – Słoma pszenżyta						Mean Średnio	Rockwool Wełna mineralna	
	Straw – Słoma		+ peat + torf		+ pine bark + kora sosnowa				
Year – Rok	2008	2009	2008	2009	2008	2009		2008	2009
N-Total	3.91	3.92	3.81	3.97	9.91	4.10		3.99	3.94
Mean – Średnio	3.91a		3.89a		4.00b		3.94	3.96b	
P	0.36	0.46	0.39	0.44	0.36	0.42		0.34	0.38
Mean – Średnio	0.41a		0.41a		0.39a		0.40	0.36a	
K	4.56	4.89	4.61	4.56	4.43	4.70		4.84	4.58
Mean – Średnio	4.72a		4.58a		4.56a		4.62	4.71a	
Ca	3.65	4.52	3.84	4.48	3.41	3.97		3.44	4.36
Mean – Średnio	4.08b		4.16b		3.69a		3.98	3.90b	
Mg	0.30	0.52	0.33	0.50	0.28	0.46		0.29	0.51
Mean – Średnio	0.41a		0.41a		0.37a		0.40	0.40a	

Note: see Table 1

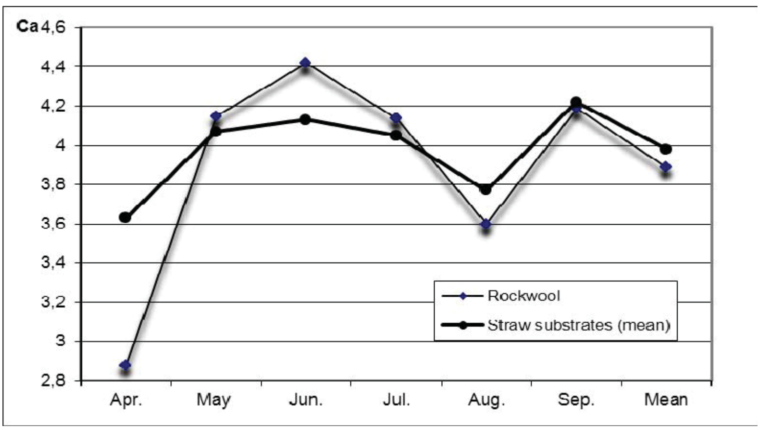

Fig. 4. The calcium content of tomato leaves (% d.m.) during vegetation season. Mean 2008–2009
Ryc. 4. Zawartość wapnia w liściach pomidora (% s.m.) w okresie wegetacji. Średnie 2008–2009

The phosphorus contents in the leaves from particular objects did not differ significantly, and the least of this component was found in plants grown in rockwool.

Tomato needs a lot of potassium. Its mean content in leaves from plants grown in organic substrata equals 4.62%, and in rockwool – 4.71% K D.M. In spite of high potassium concentration, no disturbances were reported in the uptake of magnesium, the mean content of which – 0.40% Mg D.M. is defined as optimal for tomato.

The significance of calcium for greenhouse grown tomato has already been emphasized. At mean content of 306.4 mg Ca·dm^{-3} in substrata, the content in leaves was 3.94% Ca D.M. This allows for correct supplying of the fruit with this nutrient during fructification period (fig. 4).

DISCUSSION

Applying fertigation in growing tomato in greenhouse allows for using various materials for preparing the substratum. The materials can be organic, mineral and synthetic. Thanks to the fact that the nutrient solution can be supplied to the plants in 10, 15 or 20 single doses a day, the sorption complex of substrata seems to be less important.

In studies on evaluation of particular substrata rockwool is used as the comparative substratum. In spite of precise dosing of nutrient solution in the grown plants by means of fertigation the nutrients contents in various substrata (peat, perlite, coco coir, foamed glass, pine bark, rockwool) were not equal. The differences concern the pH values, contents of potassium, calcium, magnesium, iron and manganese [Choi et al. 2007, Lopez et al. 2008, Hanna 2009, Blok et al. 2011]. In the studies with tomato grown in wood fiber [Domeno et al. 2009, Komosa et al. 2009, Komosa et al. 2010] the importance of substratum density was emphasized. The increase of wood fiber density from 60 to 100 g·dm^{-3} caused significant decrease the contents of N-NO_3, P, K, Ca, and Fe in root environment solution and the increase of N-NH_4 and Mg contents. Besides, in spite of the broad ratio of carbon to nitrogen in wood fiber and the possibility of biological sorption, no significant decrease of mineral nitrogen content in the substratum was demonstrated.

In the presented studies in cut triticale straw substrata, as well as in these of triticale with addition of peat and bark, the least of mineral nitrogen (N-NH_4, N-NO_3) there was at the beginning of growing, in March. This was caused by high demand for this nutrient in tomatoes, as well as by the increased biological sorption, because of broad C:N ratio in the straw. In spite of the fact that straw during vegetation of tomato decomposes, in the last month only 30% of it was left, the contents of nitrogen, as well as of the remaining nutrients was in the optimal interval.

Straw contains certain amounts of organic compounds, which, in result of transformations, may be taken up by plants and positively affect the uptake of nutrients. This is emphasized by Olfati et al. [2010], who, adding synthetic humic acid to the nutrient solution, obtained the advantageous effect upon the yield and nutrient uptake. Also the effect of aminoacids (alanine, serine, phenylalanine, tyrosine) was examined, as they were added to the medium in tomato growing [Garcia et al. 2010] demonstrating changes in the contents of Ca, K, Mg, Fe, Cu, Mn in plant leaves. Also the advantageous effect of various kinds of organic waste composted in oxygen conditions is emphasized [Raviv 2011a, b], as they are added to peat for substratum preparation. The advantages of such substratum are: cost decrease, contributing nutrients, as well as restricting the development of certain pathogenic microorganisms.

In the conducted studies, despite certain differentiation in nutrient contents in substrata, small differences were found in the leaves. Such dependences are also confirmed by studies conducted in other substrata, such as perlite [Neocleous 2010] and sand [Nurzyński et al. 2001, 2003, Nurzyński 2005]. In sand substratum the contents of N, K, Ca, Mg were significantly lower compared to peat, whereas no significant differences were demonstrated in peat and the tomato fruit yield was not differentiated.

In the conducted studies the mean potassium content in organic substrata equaled 295.6 mg $K \cdot dm^{-3}$. In such a concentration not only high fruit yield is obtained, but also very good quality [Ramirez et al. 2009, Almeselmani et al. 2010]. Besides, the N:K ratio in the substratum is important, which, during vegetation ranges from 1:1.4 to 1.7 [Hernandez et al.2009, Huang and Snapp 2009].

Triticale straw as substratum in vegetation period undergoes decomposition, mainly through mineralization. After completion of the studies about 30% of straw remained. Maintaining the optimal nutrient contents in such substratum is possible only through applying fertigation.

CONCLUSION

1. During vegetation of tomato in organic substrata there was the least of $N\text{-}NO_3$ at the beginning of growing (March), which could be connected with the biological sorption of nitrogen. In the subsequent months of growing the content of this nutrient was correct.

2. Mean contents of $N\text{-}NH_4$, $N\text{-}NO_3$, K, Ca and Mg in organic substrata did not significantly differ compared to rockwool.

3. The EC value in organic substrata and rockwool was optimal throughout the whole vegetation period.

4. The appropriate growth and high yield of tomato grown in organic substrata (triticale straw, triticale straw + high peat (v:v 3:1), triticale straw + pine bark (v:v 3:1) were obtained at mean contents in solution from root environment ($mg \cdot dm^{-3}$) of: $N\text{-}NH_4$ – 26.8; $N\text{-}NO_3$ – 242.8; P – 78.1; K – 295.6; Ca – 315.3; Mg – 107.5.

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ZAWARTOŚĆ SKŁADNIKÓW POKARMOWYCH W PODŁOŻACH I LIŚCIACH POMIDORA SZKLARNIOWEGO

Streszczenie. Podłoża organiczne stosowane w uprawach szklarniowych są biodegradowalne. Rozkład następuje zarówno w okresie wegetacji roślin, jak i jako odpad w czasie kompostowania lub przyorane w polu. Celem badań przeprowadzonych w szklarni w latach 2008 i 2009, były zmiany zawartości makroskładników w wyciągu ze środowiska korzeniowego roślin uprawianych w badanych podłożach oraz w liściach pomidora. Pomidor odm. Admiro F_1 uprawiany był w podłożach: 1) słoma pszenżyta, 2) słoma pszenżyta + torf wysoki (3:1 v/v), 3) słoma pszenżyta + kora sosnowa (3:1 v/v), 4) wełna mineralna. Słomę pociętą na 2–3 cm kawałki, słomę z torfem oraz korą umieszczono w skrzynkach plastykowych (wysokość skrzynki około dwa razy większa od szerokości), o pojemności 15 dm^3. W okresie wegetacji pomidora, w podłożach organicznych najmniej $N\text{-}NO_3$ było na początku uprawy (marzec), co mogło być związane z sorpcją biologiczną azotu. W następnych miesiącach uprawy zawartość tego składnika pokarmowego była prawidłowa, stosownie do zaleceń dla pomidora. Średnia zawartość $N\text{-}NH_4$, $N\text{-}NO_3$, K, Ca, Mg w podłożach organicznych nie różniła się istotnie w porównaniu z wełną mineralną. Wartość EC w podłożach organicznych i wełnie mineralnej przez cały okres wegetacji była optymalna. Prawidłowy wzrost i wysoki plon pomidora uprawianego w podłożach organicznych otrzymano przy średniej zawartości roztworu ze środowiska korzeniowego ($mg \cdot dm^{-3}$): $N\text{-}NH_4$ – 26,8; $N\text{-}NO_3$ – 242,8; P –78,1; K – 295,6; Ca – 315,3; Mg – 107,5.

Słowa kluczowe: słoma pszenżyta, wełna mineralna, środowisko korzeniowe, pomidor

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