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Studies on increasing manganese nutrition effect of tomato (*Lycopersicon esculentum* Mill.) on differentiation of rhizosphere chemical composition

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Keywords: manganese, nutrient solution, root zone, pH, EC

ABSTRACT

The aim of the conducted studies was to assess the effect of increasing Mn concentrations (within the range from 0.06 mg·dm^{-3} up to 19.2 mg·dm^{-3}) on chemical composition of tomato rhizosphere (*Lycopersicon esculentum* Mill. cvs. 'Alboney F_1' and 'Emotion F_1') grown in rockwool. For plant fertigation was used nutrient solution with the following chemical composition (mg·dm^{-3}): N-NH_4 2.2, N-NO_3 230, P 50, K 430, Ca 145, Mg 65, Cl 35, S-SO_4 120, Fe 2.48, Zn 0.50, Cu 0.07, pH 5.50, EC 3.00 mS·cm^{-1}. It was studied the following contents of manganese in nutrient solution (mg·dm^{-3}): 0.06; 0.3; 0.6; 1.2 (experiment I, years 2008-2011); 2.4; 4.8; 9.6; 19.2 mg·dm^{-3} (experiment II, year 2012) – described as Mn-0; Mn-0.3; Mn-0.6; Mn-1.2; Mn-2.4; Mn-4.8; Mn-9.6; Mn-19.2. Increasing concentration of manganese applied in nutrient solution significantly changed the chemical composition of solution in slabs. Within range of manganese in nutrient solution up to 1.2 mg·dm^{-3} was found significantly increase content of: N-NO_3, Ca, Mg, S-SO_4, Zn (except Mn-1.2), Na, Cl, pH (alkalization) and EC with simultaneous decrease content of: K (except Mn-0), Fe, Mn. Changes of P-PO_4 and Cu were multidirectional. Within range of manganese in nutrient solution from 2.4 to 19.2 mg·dm^{-3} was found significantly increase content of: Ca, Cu, Na, pH (alkalization) and EC (for 'Emotion F_1') with simultaneous decrease content of: N-NO_3, P-PO_4, K, Fe, Mn. Changes of Mg, S-SO_4, Zn, Cl and EC (for 'Alboney F_1') were multidirectional.

Badanie wpływu wzrastającego żywienia pomidora (*Lycopersicon esculentum* Mill.) manganem na skład chemiczny strefy korzeniowej

Słowa kluczowe: mangan, pożywka, strefa korzeniowa, pH, EC

STRESZCZENIE

Celem przeprowadzonych badań była ocena wpływu wzrastających stężeń manganu (w zakresie od 0,06 mg·dm^{-3} do 19,2 mg·dm^{-3}) na skład chemiczny strefy korzeniowej pomidora (*Lycopersicon esculentum* Mill. cvs. 'Alboney F_1' i 'Emotion F_1') uprawianego w wełnie mineralnej. Do fertygacji roślin stosowano pożywkę standardową o następującym składzie chemicznym (mg·dm^{-3}): N-NH_4 2,2; N-NO_3 230; P 50, K 430, Ca 145, Mg 65, Cl 35, S-SO_4 120, Fe 2,48, Zn 0,50, Cu 0,07, pH 5,50, EC 3,00 mS·cm^{-1}. Badano następujące zawartości manganu w pożywce (w mg·dm^{-3}): 0,06; 0,3; 0,6; 1,2 (eksperyment I, lata 2008-2011); 2,4; 4,8; 9,6; 19,2 mg·dm^{-3} (eksperyment II, rok 2012) – opisane jako Mn-0; Mn-0,3; Mn-0,6; Mn-1,2; Mn-2,4; Mn-4,8; Mn-9,6; Mn-19,2. Wzrastające stężenia manganu stosowanego w pożywce istotnie modyfikowały skład chemiczny strefy korzeniowej roślin. W zakresie zawartości manganu w pożywce do 1,2 mg·dm^{-3} stwierdzono istotny wzrost zawartości: N-NO_3, Ca, Mg, S-SO_4, Zn (poza Mn-1,2), Na, Cl, pH (alkalizacja) i EC, przy równoczesnym obniżeniu zawartości: K (poza Mn-0), Fe, Mn. Zmiany zawartości P-PO_4 i Cu były wielokierunkowe. W zakresie zawartości manganu w pożywce od 2,4 do 19,2 mg·dm^{-3} stwierdzono istotny wzrost zawartości: Ca, Cu, Na, pH (alkalizacja) oraz EC (w przypadku 'Emotion F_1'), przy równoczesnym obniżeniu zawartości: N-NO_3, P-PO_4, K, Fe, Mn. Zmiany Mg, S-SO_4, Zn, Cl i EC (dla'Alboney F_1') były wielokierunkowe.

1. INTRODUCTION

One of the most important factor influences on plant yielding in case of soilless cultures is quality of water [1, 2]. It is estimated that about 5% of water used to fertigation contain more quantities of manganese than optimal. According with many authors [3-8] optimal content of manganese in nutrient solution use to tomato fertigation range from 0.55 to 0.65 mg·dm^{-3} or 0.8 mg·dm^{-3} [9, 10]. Mentioned authors do not differ the content of manganese depend on cultivar. Previous paper of author [11] showed that optimal content of that microelement apply in nutrient solution is different depend on cultivar. Manganese is a heavy metal, however from the physiological point of view it is a micronutrient. This nutrient is a building block of photosynthetic proteins, lignins, flavonoids and several enzymes [12-14]. Insufficient plant nutrition with this micronutrient disturbs the process of photosynthesis [15], while excessive nutrition may damage the photosynthetic apparatus [15, 16]. Moreover, it may also affect different physiological processes such as enzymatic activity, absorption and translocation of other nutrients, as well as cause oxidative stress [12, 15, 17]. A significant effect on the toxicity threshold on manganese was found for genotype, the environment, temperature, as well as nutrient status, e.g. for calcium, magnesium or iron [18-20].

Because of transpiration dominating over nutrient uptake and selective ion uptake by plants the chemical composition of root zone differed from nutrient solution apply to plants. On the chemical parameters of root zone influence many factors for example: growing medium, level of nutrient or EC of nutrient solution or water quality [4, 7-10, 21, 22]. The aim of the conducted studies was to assess the effect of tomato fertigation with manganese within a wide range of its concentrations (from 0.06 mg·dm^{-3} up to 19.2 mg·dm^{-3}) on changes in the chemical composition of the nutrient solution in the rhizosphere (cultivation slabs).

2. MATERIAL AND METHODS

2.1 The vegetation experiments

Experiments on the effect of tomato nutrition with increasing concentrations of manganese in the nutrient solution applied in its fertigation conducted in the years 2008-2012 (March to end of September each of the year) at a greenhouse of the Department of Plant Nutrition, the Poznań University of Life Sciences. The experiments were conducted using 2 tomato cultivars (*Lycopersicon esculentum* Mill.) cv. 'Emotion F_1' and 'Alboney F_1'. Plants were grown in standard rockwool (Grodan, 100 x 15 x 7.5 cm; V 11.25 dm^3; 60 $kg \cdot m^{-3}$) at a stocking of 2.5 $plants \cdot m^{-2}$. The experiments were established using the randomized complete block design in 4 replications (4 plants were 1 replication) with 2 factors (A – Mn level, B – cultivar). All cultivation measures were conducted in accordance with the recommendations for tomato growing [23].

2.2 Chemical composition of water and nutrient solution

Plants were grown using fertigation in the closed system without recirculation of the nutrient solution. The chemical composition of tap water, on the basis of which the nutrient solution for plant fertigation was prepared, was as follows (in $mg \cdot dm^{-3}$): $N\text{-}NH_4$ < l.d., $N\text{-}NO_3$ – 3.7, $P\text{-}PO_4$ – 0.3, K – 1.8, Ca – 57.3, Mg – 13.4, $S\text{-}SO_4$ – 58.3, Na – 22.7, Cl – 42.2, Fe – 0.08, Mn – 0.06, Zn – 0.50, Cu < l.d., B – 0.011, Mo < l.d., HCO_3 – 277.5, pH – 7.00, EC – 0.735 $mS \cdot cm^{-1}$. Plants after being transplanted to permanent sites were fertigated using a standard nutrient solution with the following chemical composition (in $mg \cdot dm^{-3}$): $N\text{-}NH_4$ 2.2, $N\text{-}NO_3$ – 230, P – 50, K – 430, Ca – 145, Mg – 65, Cl – 35, $S\text{-}SO_4$ – 120, Fe – 2.48, Zn – 0.50, Cu – 0.07, pH – 5.50, EC – 3.00 $mS \cdot cm^{-1}$.

The following levels of plant nutrition with manganese were studied: 0.06, 0.3, 0.6, 1.2 $mg \cdot dm^{-3}$ (experiment I, 2008-2011 year), 2.4, 4.8, 9.6, 19.2 $mg \cdot dm^{-3}$ (experiment II, 2012 year) – denoted respectively as Mn-0, Mn-0.3, Mn-0.6, Mn-1.2, Mn-2.4, Mn-4.8, Mn-9.6 and Mn-19.2. Manganese content at Mn-0 combination corresponds to the content of this ion in water and traces content in fertilizers used to prepare the nutrient solution for plant fertigation. The fertigation system was controlled by the computer. In the period of intensive growth and yielding of plants (June – August), daily consumption of nutrient solution was $dm^3 \cdot day \cdot plant^{-1}$ in 10-20 single doses applying a 20-30% drip of excess nutrient solution leaching from the beds.

Samples of nutrient solutions from the drippers and rockwool slabs representing the root zone of plants were collected at the same time of the day, using a syringe in the middle of the distance between plants, in the median axis of the slab, inserting the needle to half slab thickness, at the following dates: 15.05, 15.06, 15.07 and 16.08 of each year of the study. The average sample was collected from 8 slabs. Chemical analyses of nutrient solutions were conducted directly in the tested solutions (without their stabilization) using the following methods: $N\text{-}NH_4$, $N\text{-}NO_3$ – by distillation according to Bremner modified by Starck, P – colorimetrically with ammonium vanadium molybdate, K, Ca, Na – by flame photometry, Cl – nephelometrically with $AgNO_3$, $S\text{-}SO_4$ – nephelometrically with $BaCl_2$, B – colorimetrically with curcumin; Mg, Fe, Mn, Zn, Cu – by atomic absorption spectrometry (AAS, on apparatus Carl Zeiss Jena); EC – conductometrically and pH – potentiometrically. Results of chemical analyses of nutrient solutions were carried out by Anova and Duncan test ($\alpha = 0.05$). In case of pH – the values were change into numerical values and then there were done the statistical analysis using the Duncan test ($\alpha = 0.05$). Finally the values was change into logarithmic values (pH).

3. RESULTS AND DISCUSSION

3.1 Contents of macroelements in cultivation slabs

In conducted experiments was no significantly differences in ammonium content between nutrient solution leaching from drippers and cultivation slabs (Table 1). Earlier studies [8, 9] indicated condensation of ammonium, while Komosa et al. [10] showed a reduction of that ion in root medium.

It was found a significant effect in case of: $N\text{-}NO_3$, $P\text{-}PO_4$, K, Ca, Mg and $S\text{-}SO_4$ content (Table 1). In experiment I was found significantly increasing of *$N\text{-}NO_3$* content in nutrient solution collected from slabs, while in experiment II was found different – decreasing trends of nitrates contents. Increasing trend of $N\text{-}NO_3$ determined within the range of manganese contents up to Mn-1.2 was confirmed in earlier investigations [8-10, 24].

Trends of *$P\text{-}PO_4$* content in rockwool slabs in experiment I was varied: significantly increased for Mn-0 and for 'Emotion F_1' (in case of Mn-0.6 and Mn-1.2). Decreasing trends of phosphorus content was found in experiment II, where the highest detardation was found for 'Alboney F_1' in case of Mn-9.6 and Mn-19.2. There were significantly differences between cultivars in case of Mn-0,

Table 1 The effect of manganese on contents of macroelements in nutrient solution applied to plants and nutrient solution in cultivation slabs

Tabela 1 Wpływ manganu na zawartość makroskładników w pożywce aplikowanej roślinom i w pożywce w matach uprawowych

Sampling place Miejsce pobierania próby	Mn-level – Poziom Mn ($mg\cdot dm^{-3}$)							
	Experiment I – Doświadczenie I				Experiment II – Doświadczenie II			
	Mn-0	Mn-0.3	Mn-0.6	Mn-1.2	Mn-2.4	Mn-4.8	Mn-9.6	Mn-19.2
mg $N\text{-}NH_4\cdot dm^{-3}$								
Dripper - Kroplownik	2.1 a	2.2 a	2.0 a	2.3 a	2.4 a	2.1 a	2.2 a	2.3 a
'Alboney F_1'[1]	1.1 a	1.3 a	1.7 a	1.5 a	1.2 a	1.4 a	1.6 a	1.2 a
'Emotion F_1'[2]	0.8 a	1.5 a	1.6 a	1.2 a	1.0 a	1.4 a	1.2 a	1.3 a
mg $N\text{-}NO_3\cdot dm^{-3}$								
Dripper - Kroplownik	225.3 a	221.7 a	227.5 a	233.4 a	232.1 e	228.4 e	223.9 e	226.4 e
'Alboney F_1'[1]	301.7 b	318.7 b	298.3 b	297.7 b	205.0 d	187.5 c	142.6 b	139.4 b
'Emotion F_1'[2]	287.3 b	318.8 b	295.5 b	306.5 b	202.4 d	194.5 c	140.0 b	130.0 a
mg $P\text{-}PO_4\cdot dm^{-3}$								
Dripper - Kroplownik	49.3 a	50.9 ab	50.9 ab	49.0 a	53.2 f	54.1 f	53.3 f	53.3 f
'Alboney F_1'[1]	55.0 c	50.9 ab	50.7 ab	51.1 ab	47.3 e	45.2 cd	31.4 a	31.4 a
'Emotion F_1'[2]	59.4 d	50.6 ab	54.3 c	52.0 b	44.3 cd	43.4 c	46.0 de	36.0 b
mg $K\cdot dm^{-3}$								
Dripper - Kroplownik	440.3 a	440.3 a	434.7 a	436.1 a	424.0 g	437.4 g	434.5 g	427.8 g
'Alboney F_1'[1]	412.1 ab	387.9 b	392.3 b	390.5 b	290.7 e	236.7 cd	230.2 bc	211.0 a
'Emotion F_1'[2]	423.0 ab	382.2 b	403.0 b	398.7 b	321.2 f	247.3 d	235.2 cd	217.9 ab
mg $Ca\cdot dm^{-3}$								
Dripper - Kroplownik	143.0 a	142.5 a	142.4 a	146.1 a	147.7 a	145.1 a	143.2 a	150.4 a
'Alboney F_1'[1]	188.5 c	183.2 bc	177.9 b	180.2 b	179.5 c	179.0 c	160.8 b	159.9 b
'Emotion F_1'[2]	180.6 b	182.3 bc	182.8 bc	189.6 c	200.0 d	216.1 e	217.6 e	241.6 f
mg $Mg\cdot dm^{-3}$								
Dripper - Kroplownik	65.2 a	65.5 a	64.8 a	66.4 ab	65.3 bcd	67.0 cde	65.4 bcd	64.4 bc
'Alboney F_1'[1]	72.6 de	75.3 e	72.9 de	71.3 cd	68.2 def	63.5 ab	63.0 ab	60.9 a
'Emotion F_1'[2]	69.3 bc	69.0 bc	71.9 cd	71.7 cd	69.6 ef	70.9 f	70.1 f	70.1 f
mg $S\text{-}SO_4\cdot dm^{-3}$								
Dripper - Kroplownik	115.6 a	115.0 a	115.6 a	116.5 a	120.5 cd	118.3 bcd	119.8 cd	120.3 cd
'Alboney F_1'[1]	127.9 def	124.0 cd	122.4 c	121.0 bc	119.9 cd	118.5 bcd	117.4 abc	114.0 ab
'Emotion F_1'[2]	126.1 cde	132.1 f	129.5 ed	130.7 ed	128.9 e	123.3 d	116.7 abc	112.8 a

For tables 1-2. [1] Nutrient solution collected from slabs of cv. 'Alboney F_1' – Pożywka pobrana z mat odm. 'Alboney F_1'; [2] Nutrient solution collected from slabs of cv. 'Emotion F_1' – Pożywka pobrana z mat 'Emotion F_1'; Values described with identical letters do not differ significantly at α = 0.05; Wartości opisane tymi samymi literami nie różnią się od siebie istotnie przy α=0,05.

Mn 2.4-19.2. It was prove that the content of phosphorus is closely related to the reaction of root zone [25]. Earliest studies [9, 10] reported that content of $P\text{-}PO_4$ in growing slabs did not change significantly from dripper. However, the upward trend for contents of this nutrient was also found [8].

In both of experiments it was found significantly decreasing of *potassium* content in solution from slabs comparing with nutrient solution supply to plants (except Mn-0) with simultaneous *calcium* content increasing. Opposite – than in described studies – trends of potassium contents in the root zone of tomato plants are reported in literature [8-10]. Similarly as most of combination of this study a significant increase in Ca contents in the rhizosphere were found [8-10].

It was found different trends of *magnesium* content depend of manganese nutrition. In experiment I it was significantly increasing trend of that ion but in case of experiment II it was varied depended on cultivar. In tomato cultivation in rockwool significant condensation in the rhizosphere was observed in case of that ion [8-10].

S-SO$_4$ content significantly increased in solution from slabs in case of experiment I, while in case of experiment II determined changes were varied. Significant condensation of mentioned ion was found in previous studies [8, 9].

3.2 Contents of microelements and sodium in the rhizosphere

In both of experiments it was found significantly decreasing trend of *iron* content in solution collected from cultivation slabs comparing with nutrient solution applied to the plants (Table 2). There were significantly differences between cultivars. In contrast to described studies early there were recorded a significant increase of Fe in rhizosphere [9, 10, 26].

Increasing concentration of *manganese* changed significantly content of that ion in rhizosphere. In case all the combination it was found retardation of manganese in root zone solution comparing with nutrient solution. Similar, like in case of iron, there were significant differences between cultivars (except Mn-2.4). Similar, decreasing trend of manganese in root zone was recorded early [10].

Within range of Mn-0 to Mn-0.6 was found increasing trends of *zinc* content in slabs comparing with nutrient solution applied to the plants. In case of other combinations it was found significantly lower content of zinc in root zone solution vs. nutrient solution used to fertigation (expect 'Emotion F_1' Mn-2.4 and Mn-9.6). Early studies recorded a lack of significant changes in Zn content in rhizosphere comparing with nutrient solution [9, 10].

In case of *copper* was found increasing content in nutrient solution from growing slabs (for 'Alboney F_1' within range 1.2-19.2 mg·dm^{-3} Mn; and for 'Emotion F_1' within range 2.4-19.2 mg·dm^{-3} Mn). It is reported that this nutrient is condensed most strongly in the rhizosphere of tomato [4]. In turn Komosa et al. [9, 10] did not found significant changes in copper content in nutrient solutions from beds.

It was found increasing trend of *chlorine* content in root zone in case of Experiment I and for: 'Emotion F_1' within range Mn-2,4-19.2 while in case of 'Alboney F_1' was found decreasing trend of content.

In case of all the studied combinations was found increasing content of *sodium* in rhizosphere comparing with nutrient solution. Many authors [9, 10, 24, 26, 27] reported significant condensation of Na in the root zone, while Jarosz et al. [8] stated that the concentration of this ion decreases in drainage waters.

In experiment I and in case of 'Emotion F_1' in experiment II were found increasing trends of *EC* (*Electrical conductivity*) while in case of experiment II was found decreasing trends of EC for 'Alboney F_1'. In both of experiments were found trend of *alkaline* of nutrient solution in root zone. Recorded changes in pH of nutrient solutions sampled from the rhizosphere of plants were typical of tomato growing in rockwool. As a result of a general trend for alkaline nutrient contents to increase in slabs, pH of the nutrient solution increased in the rhizosphere. Other authors [9, 10, 26] confirmed an increase in electrolytic conductivity and pH in the nutrient solution from the rhizosphere. Chemical composition of the nutrient solution in the rhizosphere is significantly influenced by the development of root systems of plants as well as interactions between individual nutrients [24]. Changes in nutrient contents in nutrient solutions from the root medium are also dependent on the chemical composition of the nutrient solutions applied in plant fertigation as well as the applied substrate [8-10]. As optimal EC for tomato growing was define the range of 2.8-4.2 mS·cm^{-1} [28].

Table 2 The effect of manganese on contents of microelements, sodium, chlorine, pH and EC in nutrient solution applied to plants and nutrient solution in cultivation slabs

Tabela 2 Wpływ manganu na zawartość mikroskładników, sodu, chlorków, pH i EC w pożywce aplikowanej roślinom i w pożywce w matach uprawowych

Sampling place Miejsce pobierania próby	Mn-level – Poziom Mn ($mg \cdot dm^{-3}$)							
	Experiment I – Doświadczenie I				Experiment II – Doświadczenie II			
	Mn-0	Mn-0.3	Mn-0.6	Mn-1.2	Mn-2.4	Mn-4.8	Mn-9.6	Mn-19.2
mg $Fe \cdot dm^{-3}$								
Dripper - Kroplownik	2.49 fg	2.52 g	2.53 g	2.48 fg	2.51 g	2.44 g	2.46 g	2.50 g
'Alboney F_1'[1]	1.89 d	1.52 bc	1.55 bc	1.59 c	1.57 f	1.39 e	1.25 d	1.24 d
'Emotion F_1'[2]	2.17 e	1.85 d	1.36 a	1.48 b	1.31 d	1.05 c	0.54 b	0.25 a
mg $Mn \cdot dm^{-3}$								
Dripper - Kroplownik	0.06 c	0.31 e	0.57 i	1.16 j	2.45 b	4.88 e	9.78 g	19.91 j
'Alboney F_1'[1]	0.04 b	0.06 c	0.36 f	0.53 h	1.14 a	3.92 c	6.55 f	17.98 i
'Emotion F_1'[2]	0.02 a	0.14 d	0.14 d	0.42 g	1.04 a	4.40 d	10.02 g	16.66 h
mg $Zn \cdot dm^{-3}$								
Dripper - Kroplownik	0.48 cd	0.47 cd	0.49 d	0.48 cd	0.51 d	0.50 d	0.51 d	0.51 d
'Alboney F_1'[1]	0.71 g	0.66 f	0.53 e	0.44 b	0.43 b	0.47 c	0.43 b	0.43 b
'Emotion F_1'[2]	0.69 g	0.54 e	0.52 e	0.38 a	0.54 e	0.49 d	0.50 d	0.41 a
mg $Cu \cdot dm^{-3}$								
Dripper - Kroplownik	0.07 b	0.07 b	0.07 b	0.07 b	0.07 a	0.07 a	0.07 a	0.07 a
'Alboney F_1'[1]	0.10 d	0.11 e	0.09 c	0.08 b	0.08 b	0.09 c	0.08 b	0.09 c
'Emotion F_1'[2]	0.07 b	0.06 a	0.06 a	0.08 b	0.08 b	0.10 d	0.10 d	0.12 e
mg $Na \cdot dm^{-3}$								
Dripper - Kroplownik	34.1 a	34.6 a	36.2 a	35.4 a	32.7 a	33.9 a	34.7 a	33.7 a
'Alboney F_1'[1]	57.1 c	63.9 e	56.8 c	54.6 b	64.3 e	59.2 d	50.8 c	47.8 b
'Emotion F_1'[2]	64.5 e	59.9 d	64.4 e	68.9 f	72.1 f	73.0 f	76.2 g	77.2 g
mg $Cl \cdot dm^{-3}$								
Dripper - Kroplownik	36.1 ab	38.0 b	35.7 a	36.5 ab	35.8 c	36.6 c	36.1 c	37.2 c
'Alboney F_1'[1]	41.3 c	44.3 d	42.7 cd	43.0 cd	30.7 b	26.1 a	26.1 a	25.8 a
'Emotion F_1'[2]	55.3 f	53.1 e	57.2 g	57.7 g	52.7 f	51.9 f	40.9 e	38.9 d
pH								
Dripper - Kroplownik	5.56 a	5.58 a	5.57 a	5.56 a	5.59 a	5.65 a	5.51 a	5.56 a
'Alboney F_1'[1]	6.33 b	6.44 b	6.23 b	6.38 b	6.31 c	6.26 c	6.24 bc	6.20 bc
'Emotion F_1'[2]	6.26 b	6.25 b	6.31 b	6.25 b	6.13 bc	6.12 bc	6.05 bc	5.98 b
EC $mS \cdot cm^{-1}$								
Dripper - Kroplownik	3.01 a	3.04 a	3.01 a	3.04 a	3.05 b	3.07 b	3.04 b	3.03 b
'Alboney F_1'[1]	3.79 de	3.94 e	3.63 bc	3.60 b	2.98 b	2.98 b	2.79 a	2.78 a
'Emotion F_1'[2]	3.72 bcd	3.74 bcd	3.77 cd	3.83 de	3.67 d	3.51 c	3.46 c	3.42 c

Change of chemical composition in root zone comparing with nutrient solution apply to plants within optimal range of manganese (depend on cultivar: 0.3-0.6 mg·dm^{-3}) [11] were common: increasing content of N-NO_3, K, Ca, Mg, S-SO_4, Zn, Na, Cl and pH, EC, with simultaneous decreasing content of: Fe, Mn and stable in case of N-NH_4. Contents of P-PO_4 and copper were varied.

Application to nutrient solution water with excessive content of manganese is undesirable because of the significant changes in the chemical composition of the medium in the root zone of plants, which may affect on the plant nutrition of them [11]. The highest marketable fruit yield of 'Alboney F_1' was obtained using nutrient solution with manganese content in the range 0.3-0.6 mg Mn·dm^{-3} while in the case of 'Emotion F_1' the yield in range to Mn-0.3 was significantly lower than in case Mn-0.6. In the application of the nutrient solution containing 1.2 mg Mn·dm^{-3} was found significant reduced of yielding while the plants were not observed for symptoms resulting from excessive of that ion nutrition. Within range of manganese from 4.8 to 19.2 mg·dm^{-3} were observed toxicity symptoms on the plants.

4. CONCLUSIONS

1. Increasing concentration of manganese applied in nutrient solution significantly changed the chemical composition of root zone.
2. Within range of manganese in nutrient solution up to 1.2 mg·dm^{-3} was found significantly increase content of: N-NO_3, Ca, Mg, S-SO_4, Zn (except Mn-1.2), Na, Cl, pH (alkalization) and EC with simultaneous decrease content of: K (except Mn-0), Fe, Mn. Changes of P-PO_4 and Cu were multidirectional.
3. Within range of manganese in nutrient solution from 2.4 to 19.2 mg·dm^{-3} was found significantly increase content of: Ca, Cu, Na, pH (alkalization) and EC (for 'Emotion F_1') with simultaneous decrease content of: N-NO_3, P-PO_4, K, Fe, Mn. Changes of Mg, S-SO_4, Zn, Cl and EC (for 'Alboney F_1') were multidirectional.

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