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EFFECT OF MANGANESE ON NUTRIENT CONTENT IN TOMATO (*LYCOPERSICON ESCULENTUM* MILL.) LEAVES

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Abstract

Manganese (Mn) is a microelement, but it is also a heavy metal whose excess may have a toxic effect on plants. The aim of the study was to evaluate the effect of an application of increasing Mn concentrations added to a nutrient solution on the content of macro- and micronutrients in tomato leaves (*Lycopersicon esculentum* Mill., cv. Alboney F_1 and Emotion F_1). Plants were grown in rockwool using a nutrient solution with the following content of manganese (mg dm^{-3}): 0.06; 0.3; 0.6; 1.2 (experiment I, in 2008-2011); 2.4, 4.8; 9.6; 19.2 mg dm^{-3} (experiment II, in 2012) – designated the symbols Mn-0; Mn-0.3; Mn-0.6; Mn-1.2; Mn-2.4; Mn-4.8; Mn-9.6; Mn-19.2. The nutrient solution used for plant fertigation had 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}. Manganese significantly influenced the content of other macro- and microelements in leaves. In variant Mn-0, the content of N, P, K, Ca, Mg, Mn decreased, while that of of Fe, Zn, Cu was higher; in Mn-1.2, the content of N, Mg, Fe, Zn decreased and that of P, K, Ca, Mn increased compared with the variants which ensured optimal yielding. In the range of manganese nutrition from Mn-4.8 to Mn-19.2, N, K, Mg, Fe, Zn, Cu were lower and the content of P and Mn was higher (above optimal). The cultivar significantly modified the nutrient status of plants concerning nitrogen (for Mn-9.6 and Mn-19.2), phosphorus (for Mn-1.2 and Mn-2.4), potassium (for Mn-4.8 and Mn-9.6), calcium (for Mn-0, Mn-1.2, Mn-9.6), magnesium (Mn-0 and Mn-0.6), iron (Mn-0, Mn-0.3, Mn-9.6), manganese (Mn-0.3, Mn-1.2, Mn-2.4, Mn-19.2), iron (Mn-0, Mn-0.3, Mn-9.6), zinc (Mn-0.6, Mn-1.2, Mn-2.4, Mn-9.6) and copper (Mn-2.4, Mn-4.8, Mn-9.6, Mn-19.2). Briefly, both deficit or excess manganese nutrition could induce disorders in the uptake of other nutrients, which may influence plant yielding.

Key words: manganese, index parts, hydroponic, nutrient status.

INTRODUCTION

Manganese (Mn) is a metallic microelement serving several physiological functions in plants (Lidon et al. 2004, Ducic, Polle 2005, Humphries

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et al. 2007). This nutrient may have both a synergistic and antagonistic effect on the uptake of other nutrients, e.g. iron, zinc and copper. Typically, competition is found between ions of a similar diameter, such as manganese (0.075 nm) and iron (0.065 nm) or calcium (0.099 nm) (MARSCHNER 1998). When present in prevailing amounts, manganese may be a strong antagonist towards many nutrients. The same author claimed that the range of optimal manganese concentrations is very narrow, in which it resembles other microelements. According to HORST (1988), the natural defence process in plant organisms against stress evoked by this element involves accumulation of Mn in cell sites which are physiologically rather inactive. SHENKER et al. (2004) found a significant reduction of zinc translocation in plants under the influence of manganese. Very often manganese leads to symptoms of deficits of other nutrients, i.e. calcium, magnesium and iron (LEE 1972, HORST, MARSCHNER 1978*a*, FOY et al. 1981, FLEMING 1989). KASRAEI et al. (1996) indicated that within a certain nutritional range manganese may have a negative effect on the uptake of potassium and sodium as well as phosphorus. GALVEZ et al. (1989) indicated that a higher level of manganese in a nutrient solution depresses the uptake of potassium, calcium, magnesium, zinc, copper and silicon, causing a simultaneous increase in phosphorus. Excess manganese may reduce the magnesium uptake by as much as 50% (KAZDA, ZNACEK 1989). At the same time, SAVVAS et al. (2009) stated the lack of any effect of manganese on the content of potassium, calcium and magnesium, at a simultaneous reduction of the iron and zinc content. In the Chinese cabbage culture exposed to the influence of manganese LEE et al. (2011) observed a reduced content of magnesium and calcium as well as absence of significant changes in the potassium content in outer leaves; in inner leaves there was an increase in the nitrogen and phosphorus content accompanied by a decrease in potassium. CLARK (1982) reported that intensive nutrition of plants with manganese leads to a decrease in the content of potassium, calcium, magnesium, zinc and silicon together with a simultaneous increase in phosphorus. LANDI, FAGIOLI (1983) showed no effect of manganese on copper uptake by maize roots. KOZIK et al. (2008) stated that an increasing content of manganese in the substrate had a significant effect on the zinc nutrient status in lettuce causing its deterioration, but no such an effect on iron and copper. In certain conditions, some ions (e.g. silicon, iron, calcium, magnesium) may reduce toxicity of manganese to plants (HEENAN, CARTER 1975, HORST, MARSCHNER 1978b, LOHNIS 1960, OSAWA, IKEDA 1976).

The aim of this study was to evaluate the effect of increasing manganese concentrations applied in a nutrient solution used for fertigation on the content of macro- and microelements in leaves of tomato.

MATERIAL AND METHODS

In 2008-2012, plant growing experiments were conducted in a greenhouse of the Department of Plant Nutrition, the Poznań University of Life Sciences. The facilities were equipped with a modern, computer-controlled fertigation system and energy-conservation curtains. The detailed methodology was presented earlier (Kleiber 2014). The experiments were conducted on two cultivars of tomato (*Lycopersicon esculentum* Mill.): Alboney F_1 and Emotion F_1, and with 8 levels of manganese nutrition (2 factors: A: manganese nutrition; B: cultivar). Plants were grown in standard rockwool (100 x 15 x 7.5 cm; V 11.25 dm^3; 60 kg m^{-3}) at a stocking density of 2.5 plants m^{-2}. The experiments were set in a completely randomized block design with 4 replications (4 plants were 1 replication). Biological pest control was applied. All cultivation measures were performed in accordance with the current recommendations for tomato growing (Adamicki et al. 2005).

Seeds were sown to cultivation cups in the 1st decade of March in each year of the study. After 2-3 weeks, seedlings were transplanted to rockwool cubes (10×10×10 cm). Transplants were moved to permanent beds in mid -April. The experiment was concluded on 30 September in each year of the study. Following their transplantation to the permanent site, tomato plants were fertigated with a standard nutrient solution of the following chemical composition (in mg dm^{-3}): 2.2 $N\text{-}NH_4$, 230 $N\text{-}NO_3$, 50 P, 430 K, 145 Ca, 65 Mg, 35 Cl, 120 $S\text{-}SO_4$, 2.48 Fe, 0.50 Zn, 0.07 Cu. The pH was 5.50 and EC was 3.00 mS cm^{-1}. The following levels of plant nutrition with manganese were studied: 0.06, 0.3, 0.6, 1.2 mg dm^{-3} (experiment I, in 2008-2011 year), 2.4, 4.8, 9.6, 19.2 mg dm^{-3} (experiment II, in 2012) – 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. The manganese content in Mn-0 corresponds to the content of this ion in water used to prepare the nutrient solution for plant fertigation. Manganese sulfate ($MnSO_4$ H_2O, 32.3% Mn) was the source of manganese in the other tested combinations. The nutrient solution dose depended on the development phase of plants and climatic conditions. In the period of intensive plant yielding and high temperatures (months June – July), 3.0-3.5 dm^3 nutrient solution per plant were applied daily, in 15–20 single doses at 20–30% outflowing of drainage solution.

In the course of the experiments, samples of index parts (8th-9th fully expanded leaves counting from the apex) were collected at monthly intervals (15.06, 15.07 and 16.08 each of the years of the study). One bulk sample comprised 12 leaves. Collected leaves were dried at 45-50°C and then ground. For assays of total nitrogen, phosphorus, potassium, calcium and magnesium, the plant material was mineralized in concentrated sulfuric acid (IUNG 1972). After mineralization of the plant samples, chemical analyses were performed using the following methods: N-total according to Kjeldahl in a Parnas-Wagner distillation apparatus, P by colorimetry with ammonium molybdate, and K, Ca, Mg by atomic absorption spectrometry (in a Carl Zeiss Jena apparatus). For determinations of total iron, manganese, zinc and copper, the plant material was mineralized in a mixture of dioxonitric and tetraoxochloric acids (3:1 v/v). After mineralization, Fe, Mn, Zn and Cu were determined according to ASA. Results of chemical analyses of leaves to determine their content of macro- and microelements were subjected to analysis of variance, independently for each experiment, using the Duncan test at a significance level of $a = 0.05$.

RESULTS ANS DISCUSSION

In both experiments. a significant influence of manganese nutrition on the nitrogen content in index parts of tomato was found (Table 1). In Experiment I, the lowest content of that macroelement was found in Mn-0 and

Table 1

The influence of manganese nutrition on macroelement content in tomato leaves (express in % in d.m.)

Cultivar	Experiment I				Experiment II			
	Mn-0	Mn-0.3	Mn-0.6	Mn-1.2	Mn-2.4	Mn-4.8	Mn-9.6	Mn-19.2
N								
Alboney F_1	3.52 *ab*	3.85 *b*	3.48 *ab*	3.37 *a*	3.21 *cd*	3.01 *bc*	3.12 *cd*	2.87 *b*
Emotion F_1	3.27 *a*	3.59 *ab*	3.56 *ab*	3.34 *a*	3.27 *d*	3.15 *cd*	2.87 *b*	2.59 *a*
Mean	3.40 *A*	3.72 *B*	3.52 *AB*	3.36 *A*	3.24 *C*	3.08 *B*	3.00 *B*	2.73 *A*
P								
Alboney F_1	0.57 *a*	0.66 *b*	0.73 *bc*	0.93 *d*	1.01 *cd*	0.97 *bc*	0.96 *bc*	1.05 *de*
Emotion F_1	0.49 *a*	0.74 *bc*	0.76 *bc*	0.80 *c*	0.84 *a*	0.91 *ab*	1.04 *c-e*	1.11 *e*
Mean	0.53 *A*	0.70 *B*	0.75 *B*	0.87 *C*	0.93 *A*	0.94 *A*	1.00 *B*	1.08 *C*
K								
Alboney F_1	4.33 *a*	5.12 *b*	5.57 *c*	5.93 *de*	5.48 *e*	5.23 *d*	4.25 *c*	4.14 *a-c*
Emotion F_1	4.56 *a*	4.99 *b*	5.77 *cd*	6.14 *e*	5.42 *de*	4.20 *bc*	3.97 *ab*	3.92 *a*
Mean	4.45 *A*	5.06 *B*	5.67 *C*	6.04 *D*	5.45 *C*	4.72 *B*	4.11 *A*	4.03 *A*
Ca								
Alboney F_1	2.55 *a*	2.94 *bc*	3.32 *ef*	3.44 *f*	3.47 *bc*	3.59 *c*	4.02 *d*	3.45 *a-c*
Emotion F_1	2.83 *b*	3.05 *cd*	3.28 *ef*	3.21 *de*	3.35 *a-c*	3.43 *a-c*	3.25 *ab*	3.19 *a*
Mean	2.69 *A*	3.00 *B*	3.30 *C*	3.33 *C*	3.41 *AB*	3.51 *BC*	3.64 *C*	3.32 *A*
Mg								
Alboney F_1	0.73 *b*	0.79 *b-d*	0.89 *e*	0.77 *b-d*	0.65 *e*	0.61 de	0.55 *cd*	0.46 *ab*
Emotion F_1	0.65 *a*	0.83 *de*	0.80 *cd*	0.73 *bc*	0.64 e	0.62 *de*	0.50 *bc*	0.41 *a*
Mean	0.69 *A*	0.81 *C*	0.85 *C*	0.75 *B*	0.65 C	0.62 *C*	0.53 *B*	0.44 *A*

Key for Tables 1 and 3: within rows, means marked with different capital letters differ significantly (separately for each experiment); within rows and columns, means marked with different small letters differ significantly (separately for each experiment)

Mn-1.2 variants (3.40 and 3.36% N, respectively), while significantly the highest one appeared in Mn-0.3 (3.72 %). Within the studied ranges there were no differences between the cultivars. A decreasing nitrogen tendency was found in Experiment II, including significant differences between the cultivars in variants Mn-9.6 and 19.2. The content of nitrogen in tomato leaves determined by other scientists is varied (Table 2). NURZYŃSKI (2006) and CHOHURA, KOMOSA (2003a), who used standard nutrient solution in tomato cultivation on rockwool, found similar concentrations of the aforementioned nutrient; in contrast, JAROSZ, HORODKO (2004) determined a higher content. In turn, PAWLIŃSKA, KOMOSA (2006) and JAROSZ, DZIDA (2011) studied the EC effect in tomato cultivation in rockwool and also recorded higher levels of nitrogen in tomato leaves.

Also KOWALSKA (2004) in her studies on the effect of nutrition levels with sulfate sulfur in tomato detected a higher mean content of nitrogen (for the analysed substrates) at the phase of 4^{th} cluster fruit setting. A wider range of nitrogen content in tomato leaves was given by KREIJ et al. (1990), PLANK (1999), CAMPBEL (2000) and the AGRIC. SERVICE (2001). Generally, when confronting results of my study with the cited literature, it may be stated that at the most intensive plant manganese nutrition the nitrogen nutrient status is reduced below optimal levels recommended for tomato.

In contrast to nitrogen, significant upward trends were shown in both experiments for the content of phosphorus in index parts (Table 1). The cultivars significantly influenced the nutrient status only in the case of Mn-1.2 and Mn-2.4. Some authors found a lower content of that nutrient than determined herein ensuring optimal plant yielding (KLEIBER 2014) – 0.70-0.75% P. Similar concentrations of phosphorus in tomato leaves were reported by PAWLIŃSKA, KOMOSA (2006) and JAROSZ (2006) while a wider range was reported

Table 2

Content of macroelements according to other authors (express in % in d.m. of leaves)

Source	Nutrient content (average or range)				
	N	P	K	Ca	Mg
Agric. Service... (2001)	3.5-5.0	0.3-0.65	3.5-4.5	1.0-3.0	0.35-1.00
CAMPBEL (2000)	3.5-5.0	0.3-0.7	3.0-4.5	1.0-2.0	0.3-0.8
CHOHURA, KOMOSA (2003a)	3.31-3.89	0.36-0.47	5.02-5.54	7.08-7.47	0.45-0.69
JAROSZ (2006)	2.95-2.96	0.82-0.83	4.41-4.42	5.26-5.41	0.55-0.59
JAROSZ, HORODKO (2004)	4.20	0.85	5.32	3.31	0.60
JAROSZ, DZIDA (2011)	3.97-4.27	0.47-0.51	4.30-5.11	2.12-2.98	0.27-0.36
KOWALSKA (2004)	4.83-4.99	0.51-0.74	3.99-4.08	3.13-3.36	0.65-0.69
KREIJ et al. (1990)	2.8-4.2	0.30-0.46	3.5-5.1	1.6-3.2	0.36-0.50
NURZYŃSKI (2006)	3.83	0.41	5.45	2.97	0.28
PAWLIŃSKA, KOMOSA (2006)	4.22-4.27	0.74-0.78	6.15-6.27	-	-
PLANK (1999)	3.5-5.0	0.5-1.0	3.5-5.0	0.9-1.8	0.5-1.0

by Plank (1999), Campbel (2000). The cited findings indicate that the tomato nutrition tested in this study (above 1.00% P at Mn-19.2) has not been recorded in the research conducted to date.

Contrary tendencies of the potassium content in tomato leaves were found in this study: within the range of manganese nutrition up to Mn-1.2, the potassium content was significantly increasing, but from Mn-2.4 to Mn-19.2 it was significantly decreasing (Table 1). The cultivar factor significantly modified the nutrient status only in case of Mn-4.8 and 9.6. Generally, the best yielding plants contained between 5.06-5.67% K in index parts (mean values). Similar concentrations of potassium in leaves were reported by Jarosz, Horodko (2004) and Nurzyński (2006) – Table 2. Most of the cited authors showed a lower content of that nutrient (Table 2). More potassium in leaves was found only by Pawlińska, Komosa (2006). Despite the contradictory trends for potassium in leaves, depending on the level of manganese, the plant nutrition level with this nutrient was appropriate within the analysed range.

A significant upward trends was observed in both experiments for the content of calcium in index parts of tomato (Table 1) – except Mn-19.2 in Exp. II. The cultivars significantly varied the calcium content for Mn-0, Mn-1.2 and Mn-9.6. The best plant yielding occurred within 3.00 to 3.30% Ca in index parts (mean from 2 cultivars). Many authors showed a different content of calcium in tomato leaves (Jarosz, Horodko 2004, Nurzyński 2006) (Table 2). Similar calcium concentrations were cited by Jarosz, Dzida (2011). In turn Chohura, Komosa (2003a) and Jarosz (2006) cited higher levels of that nutrient. Kowalska (2004) claimed that intensive tomato nutrition with sulfate sulfur has a significant effect reducing the calcium content in leaves. Markedly lower contents of calcium in leaves of tomato were cited by other authors (Kreij et al. 1990, Plank 1999, Campbel 2000, Agric. Service... 2001).

Like potassium, the magnesium content in tomato leaves demonstrated oposing tendencies (Table 1). Within the manganese nutrition range from Mn-0 to Mn-0.6 it was significantly increasing, while from Mn-2.4 to Mn-19.2, there was a significant decrease in the Mg in tomato leaves. The cultivar factor significantly varied the magnesium content for Mn-0 and Mn-0.6. The best yielding of tomato was recorded for 0.81%-0.85% Mg (mean). Many authors found a lower content of magnesium in tomato leaves (Table 2) while a wider range was determined by Campbel (2000) and Agric. Service ... (2001). The literature data implicate that even in the case of toxic manganese nutrition, the content of magnesium in tomato leaves did not drop below the level observed in studies conducted to date.

In both experiments, a significant decreasing trend of the iron content in index parts was found (Table 3). The cultivar significantly differentiated the iron content in the case of Mn-0, Mn-0.3 and Mn-9.6. The best plant yielding was recorded at the content of iron from 159.6 to 181.0 mg Fe kg^{-1} (mean from 2 cultivars). The determined iron content in leaves up to Mn-1.2 was similar to the results most frequently reported in literature (Table 4). References show a wider (Chohura, Komosa 2003b, Chohura et al. 2006) as well as a narrower range of the iron content (Kreij et al. 1990, Kowalska 2004). In turn, Atherton et al. (1986) recommended the content of this nutrient exceeding 60.0 mg Fe kg^{-1}, which was met in both experiments (except for Mn-19.2). A much wider optimal range for this microelement was reported by Plank (1999), Campbel (2000) and Agric. Service… (2001).

Increasing manganese nutrition caused the accumulation of that micronutrient in leaves (Table 3). The cultivar significantly modified the manganese status for Mn-0.3, Mn-1.2, Mn-2.4 and Mn-19.2. The optimal plant yielding was achieved for Alboney F_1 when manganese ranged from 175.3-260.7 mg kg^{-1}. An optimal content of manganese for Emotion F_1 was 263.8 mg kg^{-1}. In this study, the content of manganese determined in leaves within the range up to Mn-1.2 was similar to the one reported by Campbel (2000), Uchida (2000) and Chohura, Komosa (2003*b*) – Table 4. The manganese content up to Mn-0.3 was consistent with the range of this nutrient shown by Agric. Service ... (2001), while for Mn-0 it resembled that given by Kreij et al. (1990) and Plank (1999). In turn, Breś, Ruprik (2007) detected a lower content of manganese in leaves of small-fruited tomatoes grown on coir. Chohura et al. (2006) determined the manganese content of 338.9 mg kg^{-1}

Table 3

The influence of manganese nutrition on content of chosen microelements in tomato leaves (express in mg kg^{-1} d.m.)

Cultivar	Experiment I				Experiment II			
	Mn-0	Mn-0.3	Mn-0.6	Mn-1.2	Mn-2.4	Mn-4.8	Mn-9.6	Mn-19.2
Fe								
Alboney F_1	202.7 *e*	187.2 *d*	162.7 *b*	130.9 *a*	77.8 *c*	76.9 *c*	77.6 *c*	57.9 *a*
Emotion F_1	227.5 *f*	174.9 *c*	156.4 *b*	125.5 *a*	77.6 *c*	74.5 *c*	64.0 *b*	53.8 *a*
Mean	215.1 *D*	181.0 *C*	159.6 *B*	128.2 *A*	77.7 *C*	75.7 *C*	70.8 *B*	55.9 *A*
Mn								
Alboney F_1	62.9 *a*	175.3 *b*	260.7 *d*	290.8 *e*	424.0 *a*	464.4 *c*	472.0 *c*	471.4 *c*
Emotion F_1	71.1 *a*	229.7 *c*	263.8 *d*	313.3 *f*	446.2 *b*	459.4 *bc*	465.9 *c*	489.5 *d*
Mean	67.0 *A*	202.5 *B*	262.3 *C*	302.1 *D*	435.1 *A*	461.9 *B*	469.0 *B*	480.5 *C*
Zn								
Alboney F_1	43.90 *e*	40.20 *d*	31.50 *c*	30.10 *bc*	26.50 *e*	19.40 *c*	18.90 *c*	12.80 *a*
Emotion F_1	45.10 *e*	37.80 *d*	27.00 *ab*	25.50 *a*	23.30 *d*	17.20 *bc*	15.30 *b*	10.40 *a*
Mean	44.50 *C*	39.00 *B*	29.30 *A*	27.80 *A*	24.90 *C*	18.30 *B*	17.10 *B*	11.60 *A*
Cu								
Alboney F_1	25.42 *e*	19.10 *d*	14.70 *ab*	13.20 *a*	13.65 *d*	13.10 *cd*	13.45 *d*	8.12 *a*
Emotion F_1	24.40 *e*	17.35 *cd*	15.94 *bc*	15.00 *ab*	14.86 *e*	14.78 *e*	12.35 *c*	10.99 *b*
Mean	24.91 *C*	18.23 *B*	15.32 *A*	14.10 *A*	14.26 *C*	13.94 *C*	12.90 *B*	9.56 *A*

in tomato leaves, with no symptoms of its toxicity on plants. Savvas et al. (2009) showed that within the range up to 5.5 mg Mn dm^{-3} nutrient solution, the content of this micronutrient in leaves increases significantly from 36 to 280 mg Mn kg^{-1}, at a simultaneous significant deterioration of the iron and zinc nutrient status of plants.

Similarly to iron, a significant decrease in the zinc content under the tested Mn nutrition was found (Table 3). The cultivar significantly differed the zinc status for Mn-0.6, Mn-1.2, Mn-2.4 and Mn-9.6. The best plant performance was obtained with the zinc content between 29.30-39.00 mg kg^{-1} of leaves. Literature shows a wider range of zinc in leaves (Kreij et al. 1990, Plank 1999, Campbel 2000, Agric. Service… 2001, Chohura, Komosa 2003*b*) (Table 4). A similar content of zinc was shown by Kowalska (2004). The content of this nutrient in leaves found in the present study up to the level of Mn-2.4 fell within the ranges of content cited in literature; however, above this level it fell within a lower range than recommended for tomato.

Table 4

Content of microelements according to other authors (express in mg kg^{-1} d.m. of leaves)

Source	Nutrient content (average or range)			
	Fe	Mn	Zn	Cu
Agric. Service…(2001)	50-300	25-200	18-80	5-35
Atherton et al. (1986)	>60	237.0	38.0	9.68
Breś, Ruprik (2007) mod.	80.0-120.4	70.6-190.9	66.9-102.1	8.70-15.62
Campbel (2000)	45-300	30-300	18-75	5-30
Chohura, Komosa (2003b)	85.5-161.9	252.0-273.3	33.8-75.8	10.23-13.84
Chohura et al. (2006)	97.1-205.3	338.9	28.3-53.7	7.73-12.65
Kowalska (2004) mod.	136.7-141.6	115.6-137.0	40.6-47.5	33.02-36.60
Kreij et al. (1990)	84-112	54-165	54-76	6
Plank (1999)	50-300	50-100	20-100	8-20
Uchida (2000)	60-300	50-250	-	-

Analogously to iron and zinc, a significant decreasing content of copper was found (Table 3) with significant differences between the cultivars in experiment II. The best yielding of plants was accompanied by a copper content within the range of 15.32-18.23 mg Cu kg^{-1}. Chohura et al. (2006) and Chohura, Komosa (2003b) recorded less copper in leaves (Table 4). Markedly wider ranges of concentrations of this nutrient were given by Plank (1999), Campbel (2000) or Kowalska (2004).

There is more than one reason for decreased tomato yielding under Mn -stress caused by the accumulation of manganese. Generally, excessive or toxic manganese concentrations influence negatively the plant nutrition. The highest Mn-concentrations cause the accumulation of this ion, toxic symptoms on the plants and probably symptoms of the deficit of other nutrients, occurring for example on leaves (Kleiber 2014). Marschner (1998) showed that manganese is an antagonistic ion to iron and calcium. This study confirmed a decreasing content of iron, whereas calcium generally presented increasing trends. In turn. Galvez et al. (1989) claimed that higher manganese levels reduced the uptake of potassium, calcium, magnesium, zinc, copper, which is generally verified for zinc and copper. As for magnesium, both increasing (Exp. I – lower concentration of Mn) and decreasing (Exp. II – higher concentration of Mn) trends were found. The findings were similar for potassium, whose content grew up to Mn-1.2 and decreased under higher Mn-levels. Excess manganese may reduce the magnesium (Kazda, Znacek 1989) or magnesium/calcium uptake (Lee et al. 2011). In contrast to my results, Savvas et al. (2009) did not find anu effect of manganese on the content of potassium, calcium and magnesium, although they confirmed a reduction of the iron and zinc content. A lower zinc content under manganese stress was also found by Shenker et al. (2004). Similarly to the current research, a positive effect of manganese on the phosphorus status was found by Clark (1982) and Galvez et al. (1989). Clark (1982) reported also that intensive Mn nutrition reduced the uptake of potassium, calcium, magnesium and zinc. In contrast to my studies, Landi, Fagioli (1983) found no Mn-related effect on the copper uptake by maize roots. Breś et al. (2012) demonstrated an antagonistic effect between manganese and potassium, iron and zinc.

Savvas et al. (2009) and Kleiber (2014) reported that manganese nutrition had a significant influence on tomato yielding, while Chohura et al. (2009) and Kołota et al. (2013) claimed that in research on microelements the form of ions is also important. An optimal content of manganese in a nutrient solution is varied depending on a cultivar (Kleiber 2014). The highest marketable fruit yield of cv. Alboney F_1 is obtained using a nutrient solution with the manganese content in the range 0.3-0.6 mg Mn dm^{-3}, but in the case of cv. Emotion F_1, the yield for Mn-0.3 was significantly lower than for Mn-0.6. Regarding the content of Mn in water used to prepare the nutrient solution (without addition of manganese sulphate), the author found visual deficit symptoms on leaves. Within the range of Mn from 4.8 to 19.2 mg dm^{-3} toxicity symptoms appeared on the plants. The content of manganese in a nutrient solution equal 1.2 or 2.4 mg dm^{-3} is excessive, while that of 4.8 mg dm^{-3} and higher is toxic. In experiment I, the most possible chemical reasons of yield decrease in Mn-0 variant was a significant decrease of N, P, K, Ca, Mg, Mn with a simultaneous significant increase of Fe, Zn, Cu compared with the variants ensuring optimal yielding. In treatment Mn-1.2, N, Mg, Fe, Zn were found to have decreased significantly, while P, K, Ca, Mn were significantly increased in relation to the variants providing optimal yielding. In the case of combinations $\geq$ 4.8 mg Mn dm^{-3} a lower content of N, K, Mg, Fe, Zn, Cu was determined together with a higher (above optimal) content of P and Mn. Visual symptoms on the plants could be the result of disorders in the uptake of the mentioned nutrients.

Manganese is taken up by plants as Mn^{2+} cations. Although it is a heavy metal, it may appear in plant tissues in concentrations higher than necessary for the proper functioning of organisms. Manganese as a nutrient has many physiological functions, including participation in a number of enzymes: Mn-catalase, dehydrogenase, decarboxylases, hydroxylases, acid phosphatases, transferases, SOD superoxide. Furthermore, it is present in xylogens, flavanols, and PS II complex-protein. Of particular importance is the share of micro-fission reactions of water in the light phase of photosynthesis (Ducic, Polle 2005, Humphries et al. 2007, Kozłowska et al. 2007, Breś et al. 2012). Excessive manganese nutrition may interfere with this physiological process and with the nutrient uptake, wich could be a reason for worse yielding.

CONCLUSIONS

1. Manganese nutrition significantly influenced the content of macro- and microelements in leaves.

2. Tomato cultivars significantly modified the content of nitrogen (for Mn-9.6 and Mn-19.2) phosphorus (for Mn-1.2 and Mn-2.4), potassium (for Mn-4.8 and Mn-9.6), calcium (for Mn-0, Mn-1.2, Mn-9.6), magnesium (Mn-0 and Mn-0.6), iron (Mn-0, Mn-0.3, Mn-9.6), manganese (Mn-0.3, Mn-1.2, Mn-2.4, Mn-19.2), iron (Mn-0, Mn-0.3, Mn-9.6), zinc (Mn-0.6, Mn-1.2, Mn-2.4, Mn-9.6) and copper (Mn-2.4, Mn-4.8, Mn-9.6, Mn-19.2) in leaves.

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