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Chapter 6

Hydroponic Cultivation of Tomato

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Additional information is available at the end of the chapter

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Abstract

Mineral substrates used in plant hydroponic cultures should have low contents of the solid phase and good, stable air and water properties. Rockwool is a substrate with such properties, and it has been produced for plant culture systems since 1969 by I/S H.J. Henriksen and V. Kähler (Denmark). The aim of the study is to evaluate the effect of an application of increasing manganese (Mn) and boron (B) concentrations added to a nutrient solution on the yielding, content of macro- and micronutrients in tomato leaves and fruits (*Lycopersicon esculentum* Mill., cv. Alboney F1 and Emotion F1). Plants were grown in rockwool using a nutrient solution with the following content of Mn (mg dm^{-3}): 0.06, 0.3, 0.6, and 1.2 mg dm^{-3} (Experiment I, 2008–2011) and 2.4, 4.8, 9.6, and 19.2 mg dm^{-3} (Experiment II, 2012)—designated the symbols for Mn: Mn-0, Mn-0.3, Mn-0.6, Mn-1.2, Mn-2.4, Mn-4.8, Mn-9.6, and Mn-19.2 and for B: (0.011), 0.4, 0.8, 1.6 in the form of $Na_2B_4O_7 \cdot 10H_2O$ (Experiment I) and boric acid H_3BO_3 (Experiment II) (combinations of the designated symbols, respectively, B-I, B-II, B-III, and B-IV). The influence of Mn and B nutrition on biometric parameters and chemical composition of leaves and fruits of tomato is discussed.

Keywords: *Lycopersicon esculentum* Mill., rockwool, plant nutrition, manganese, boron

1. Introduction

Due to the quantitatively and qualitatively inferior plant yielding, conventional field cultivation of tomato using fertilizer broadcasting and irrigation is less economically viable in comparison with advanced soilless cultivation systems [1]. Such cultures may be run either applying fertigation (hydroponics) or without it [2] (**Figure 1**).

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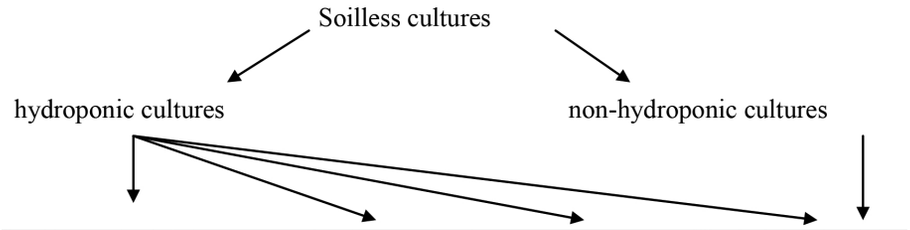

No substrate	Mineral substrate	Synthetic substrates	Organic substrates
Static solution hydroponic system NFT Aeroponics	rockwool (i) glass wool (i) expanded clay (i) perlite (i) volcanic lava (i) gravel (i) sand (i) vermiculite zeolite	polyurethane foam (i) polyphenol foam (i) Biolaston (i) amine foam (i)	peat coir bark straw lignite sawdust wood fiber coconut husks cacao shells

(i)– inert media

Figure 1. Classification of soilless cultures [2].

In horticultural practice, the applications of cultures without a conventional substrate are found, namely aeroponic systems (in which the air is the medium for growth of plant root systems—as the isolated space, periodically filled with injected nutrient solution) [3], the nutrient film technique (NFT; in which a thin film of the surrounding medium is the root growth medium), and the static hydroponic system [4]. In soilless cultures, mineral, synthetic, and organic substrates are used [2,5]. However, currently, mineral substrates, e.g. rockwool, are becoming increasingly popular, among other things, thanks to the precision of plant nutrition in comparison with cultures run in organic substrates, e.g. a mixture of peat and bark or sawdust [6]. Mineral substrates used in plant hydroponic cultures should have low contents of the solid phase and good, stable air and water properties. Rockwool is a substrate with such properties, and it has been produced for plant culture systems since 1969 by I/S H.J. Henriksen and V. Kähler (Denmark). Rockwool, classified to the group of mineral substrates, is produced by melting a natural rock mixture, composed of diabase (60%) and calcium (20%) with coke (20%) at a temperature of 1500–1600°C. Next from such lava rockwool of 0.5 mm in diameter is formed in spinners; it is cooled with air to 200°C; phenolic resins are added (up to 1.3 mg·10 g^{-1} d.m. rockwool) along with binders; and compounds facilitating moisture absorption, providing it with hydrophilic properties. Such prepared rockwool is pressed to form blocks of different sizes, growing mats (e.g. 100 × 20 × 7.5—typically used in cucumber growing; 100 × 15 × 7.5—usually used in tomato culture) or culture cubes for seedling production (e.g. 10 × 10 × 10 cm). Rockwool substrate, thanks to the ultrahigh temperature at which it is produced, is free from pathogens and pests. Companies producing rockwool offer substrates composed of one and two layers, differing in their air and water properties. The fiber arrangement has a significant effect on the distribution of water and electric conductivity (EC) in the growing mat

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because increasing fiber density in the upper section of the mat has an advantageous effect on nutrient medium permeation and thus facilitates a more uniform growth of plant root systems.

At present, rockwool is commonly used in cultivation of various plant species, both vegetables (such as cucumber and tomato) and ornamental plants (such as rose and gerbera). Its primary advantages include low bulk density (depending on the type ranging from 50 to 100 $g \cdot dm^{-3}$) and high overall porosity (92–98%). Rockwool, in contrast to most organic substrates, ensures uniform air and water conditions and the distribution of the nutrient solution within the root systems of plants, which is important in the case of commercial-scale production. Its important advantage is also connected with preventing the development of anaerobic conditions in the root hair zone, through retention of 20% air at total water capacity. Physical properties of growing mats are as follows: water 52%, the solid phase 3%, and air 45% [7]. However, such properties as water retention or air capacity undergo significant changes upon the completion of the plant vegetation cycle [8].

Rockwool is an inert substrate, devoid of the sorption complex, in which no ion exchange may take place. Its chemical composition may be as follows: P_2O_5 0.2–0.9%, K_2O 0.7–1.3%, CaO 17.5–21.2%, MgO 5.2–9.0%, Fe_2O_3 6.4–8.4%, MnO 0.1–0.5%, Na_2O 1.2–2.2%, SiO_2 40.7–42.9%, Al_2O_3 17.8–19.4%, TiO_2 0.7–2.5%, As < 4 $mg \cdot kg^{-1}$, Cd < 0.5 $mg \cdot kg^{-1}$, Pb < 10 $mg \cdot kg^{-1}$, and Hg < 0.01 $mg \cdot kg^{-1}$. Rockwool also exhibits no buffer properties [9]. It is an alkaline substrate (pH in H_2O = 7.0–8.0), and its reaction is determined by high contents of alkaline elements (Ca, Mg, Na, and K). The high Ca content may cause retrogradation, i.e. chemical sorption of phosphorus. To prevent chemical sorption of nutrients by rockwool before the onset of plant culture, it is acidified with a nutrient solution with pH 5.5–6.0.

An advantage of the application of rockwool as a substrate in plant culture is connected with the limited spread of root system diseases because plants are grown in separate, foil-covered growing mats (as a rule with two plants per mat). A potential risk of diseases may be increased in the case of closed systems with nutrient solution recirculation (in which the nutrient solution leaking from the root systems is recycled for fertigation), at potential problems with its effective disinfection. Applicable nutrient solution disinfection methods in practice include thermal methods [10,11], filtration based on reverse osmosis or another type of membrane systems [12,13], UV radiation, or ozone treatment [14,15].

A disadvantage of rockwool as a homogeneous substrate for plant growing is connected with its problematic disposal and management because this substrate is not biodegradable. It is estimated that from 150 to 200 m^3 rockwool remains after 1-hectare culture of greenhouse tomato [16]. However, such substrates may be used to improve physical properties of soils, particularly heavy soils [8,17], or as an additive to mixed substrates [18]. A certain drawback —in view of the problems with water quality in Europe—may also be connected with the quality requirements for the chemical composition of water for the preparation of fertigation nutrient solutions. Maximum ion concentrations in water may not exceed concentrations recommended for a given plant species (the so-called hydroponic concentrations), taking into consideration the optimal value of EC [19]. In turn, locally observed deterioration of water quality affecting its applicability in fertigation may be connected with both macro- and

micronutrients. Response of tomato grown in rockwool to varied concentrations of micronutrients (Mn and B) in nutrient media is presented in the successive chapters.

A serious problem in cultures run in open systems with no nutrient solution recirculation may also be connected with contamination of the natural environment with excess drainage water leaking from the root zone [20]. The greatest contamination is caused by intensive tomato cultures in rockwool run in open systems, which may be as follows: $N–NO_3$ (up to 245 kg·month·ha^{-1}), K (up to 402 kg·month·ha^{-1}), Ca (up to 145 kg·month·ha^{-1}), and $S–SO_4$ (up to 102 kg·month·ha^{-1}), while in the case of micronutrients: Fe (up to 2.69 kg·month·ha^{-1}), Mn (up to 0.19 kg·month·ha^{-1}), Zn (up to 0.52 kg·month·ha^{-1}), and Cu (up to 0.09 kg·month·ha^{-1}). In view of the above, apart from studies aiming at the optimization of nutrition for plants grown in rockwool, studies are also being conducted on the applicability of alternative substrates in plant growing to replace rockwool, such as coir, wood fiber, or aeroponic systems [5,21–24].

2. The influence of selected micronutrient nutrition on plant yielding

2.1. Manganese

2.1.1. The physiological role

Mn, similarly iron (Fe), zinc (Zn), copper (Cu), and nickel (Ni), is a heavy metal (atomic mass = 54.93) and, at the same time, a metallic micronutrient. This nutrient, similarly Fe, may be found in plant tissues at greater concentrations than necessary for appropriate functioning of the organism. Mn serves many physiological functions because it is a component of several enzymes: Mn-catalase and dehydrogenases, and it is an activator of decarboxylases, hydroxylases, acid phosphatase, and dismutase, e.g. SOD [25]. It is also found in lignins, flavonoids, and the PS II-protein complex. It plays an important role in the reactions of water splitting in the light-dependent reactions of photosynthesis. Mn is an activator of citric acid enzymes, reduction of nitrates, and metabolism of proteins, saccharides, and lipids, and it also participates in oxidation of indole-3-acetic acid (IAA) [25]. Mn indirectly controls the level of NADPH, and its extreme deficiency may cause thylakoid membrane dysfunctions. It is also involved in the tricarboxylic acid cycle, in the synthesis of chlorophyll (phosphatidic acid), and in the removal of free radicals formed in chloroplasts.

Mn is absorbed by plants as the Mn^{2+} cation, and it is passively transported through the cell membrane following the electrochemical gradient [26]. In plants, it is mainly transported in the xylem; it is sparcely reutilized; thus, the first symptoms of its deficiency are manifested in the apical parts of plants. Excessive uptake of Mn may damage the photosynthetic organs and therefore leads to reduced contents of chlorophyll and yielding of plants [27–29]. Mn tolerance of plants depends on their genome.

2.1.2. Manganese in human diet

Mn is an essential micronutrient, which has to be supplied with the diet. It plays an important role in many physiological processes, and it is required in the regulation of sugar levels, bone growth and reproduction, or proper functioning of the immune system [30]. However, there are no standards regulating the content of Mn in food. The daily allowance recommended by the National Academies' Institute of Medicine, referred to as adequate intake (AI), for this micronutrient amounts to 1.8 mg for women and 2.3 mg for men [31]. Daily intake causing no toxicity symptoms, defined as tolerable upper intake level (UL), is as high as 11 mg•day^{-1}. European nutrition standards define the optimal intake as 1–15 mg Mn•day^{-1} [32]. No symptoms of Mn deficiency are observed in free living subjects [33], and rational nutrition fully covers the daily requirement for this nutrient [34].

Vegetables are capable of accumulating this nutrient with an increase in the concentration of Mn in nutrient solution used in fertigation. The disturbed Fe/Mn ratio in food may be potentially dangerous for consumers, including vegetables more frequently consumed in season. These micronutrients compete for the same protein in blood serum (transferrin) and the protein divalent metal transporter system DMT 1 [35]. Daily uptake of Fe with food rations is sufficient for men, but very often it does not cover the safe level recommended for women [33]. In addition, it is known that the accumulation of Mn in the human organism—when the consumed diet is one of the routes of absorption of this micronutrient—may be harmful, leading to changes in the central nervous system. However, a detailed mechanism of Mn neurotoxicity is relatively little known [30,36].

2.1.3. Tomato reaction on increasing concentration of Mn in nutrient solution

This chapter shows the multifaceted response to increase Mn concentrations in nutrient solutions, ranging from insufficient to excessive/toxic: chemical changes the root zone of plants, in leaves—focusing on chosen parameters of photosynthetic activity as well as yields of fruits and their quality. It also shows a specific potential applicability of choline-stabilized orthosilicic acid (ch-OSA) in nutrient solution to alleviate Mn stress in tomato. Described studies were conducted on cultivation of two culivars: 'Alboney F_1' (*Enza Żaden*) and 'Emotion F_1' (*S&G*) grown in rockwool. In experiments, a standard nutrient solution with varying contents of Mn was used: Experiment I—control: 0.06 (native content in water), 0.3, 0.6, and 1.2 mg·dm^{-3} and Experiment II—2.4, 4.8, 9.6, and 19.2 mg·dm^{-3} [37].

2.1.3.1. Chemical composition of the root zone

The increase in Mn concentration in nutrient solution use in fertigation of tomato has a significant and multifaceted effect on the chemical composition of the rhizosphere [37]. Generally, Mn content in the root zone is significantly reduced in relation to that in nutrient solution applied in plants, but the response generally significantly varies between cultivars (**Table 1**).

Sampling place	Mn level							
	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
Dripper	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

Notes: Results were subjected to analysis of variance, independently for each experiment; nutrient solution collected from slabs of cv.; [1]'Alboney F_1'; [2] 'Emotion F_1'; values described with identical letters do not differ significantly at α = 0.05.

Table 1. The effect of increasing Mn concentration in nutrient solution (mg•dm^{-3}) on contents of that microelement in cultivation slabs [38].

Increasing concentrations of Mn in nutrient solution significantly modifies the chemical composition of root zone, but the reaction varies depending on cultivar and Mn concentration: in the range of Mn contents up to 1.2 mg•dm^{-3}; a significant increases: N–NO_3, Ca, Mg, S–SO_4, Zn (except for Mn-1,2), Na, and Cl; pH (alkalization) and EC, at a simultaneous reduction of contents of K (except for the control) and Fe.

2.1.3.2. Chemical composition of leaves

Mn nutrition and cultivar significantly influence on the chemical composition of leaves [39]. Mn content in tomato leaves is significantly connected with the contents of this nutrient in nutrient solution used in fertigation of plants and similarly in case of rhizospere generally varies between cultivars (**Table 2**).

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
Mn content in leaves								
'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
Mn content in fruits								
'Alboney F_1'	7.4 a	10.7 b	19.3 e	22.8 f	73.8 a	82.5 b	83.4 b	103.8 d
'Emotion F_1'	6.8 a	16.0 c	17.7 d	34.5 g	97.1 c	106.5 d	110.2 d	132.6 e
Fe content in fruits								
'Alboney F_1'	94.2 e	89.7 d	85.9 cd	71.2 a	66.1 e	51.7 d	49.6 c	39.2 b
'Emotion F_1'	86.8 cd	83.1 c	76.5 b	71.4 a	57.2 d	41.3 c	37.3 b	34.6 a
Total yield of 1 tomato plant								
'Alboney F_1'	6.05 a	6.56 c	6.32 bc	6.21 b	5.77 e	5.51 de	5.04 cde	4.44 bc

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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
'Emotion F_1'	5.81 a	5.82 a	6.32 bc	5.93 a	5.42 de	4.83 cd	4.04 b	2.80 a

Notes: Results were subjected to analysis of variance, independently for each experiment; nutrient solution collected from slabs of cv.: [1]'Alboney F_1'; [2] 'Emotion F_1'; values described with identical letters do not differ significantly at α = 0.05.

Table 2. The influence of Mn nutrition on content of Mn in leaves, Fe and Mn in fruits (in mg kg^{-1} d.m.) and on total yield of 1 tomato plant (kg) [40–42].

Increasing intensity of Mn nutrition may vary the plant nutrient status in the case of Mn-0 reduces the contents of macroelements with a simultaneous increase in the contents of Fe, Zn, and Cu, whereas in the case of the Mn-1.2 combination a decrease in the contents of N, Mg, Fe, and Zn with an increase in the contents of P, K, and Ca in relation to the combination of optimal yielding [37,38,43]. Kleiber et al. [38] claimed that variation in contents of micronutrients is greater than that of macronutrients. The same authors [44] also found that the contents of trace elements (Al, Ba, Co, Cr, and Ni) in leaves of tomato grown under strong Mn stress are decreasing.

2.1.3.3. Chosen parameters of photosynthetic activity

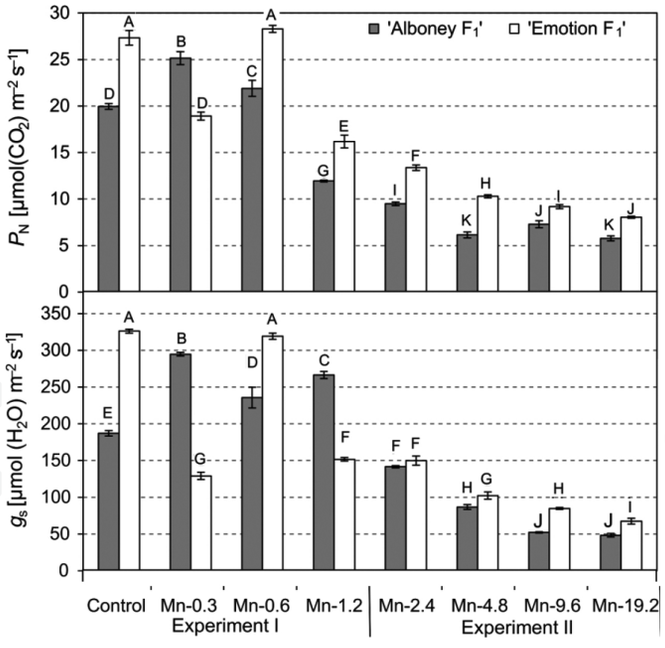

Figure 2. Means ±SE of net photosynthesis rate (PN) and stomatal conductance (gs) in tomato cultivated with different Mn in nutrient solution. Letters denote significant differences between means at p=0.05 (Kleiber et al. 2014 a).

Excessive Mn nutrition causes a toxic effect, which is observed morphologically in plants at a Mn concentration in nutrient solution ≥4.8 mg•dm^{-3} (**Figure 2**) [38, 40]; however, already at a Mn concentration of 1.2 mg•dm^{-3}, changes are observed in their photosynthetic activity. The

first symptom of excessive Mn nutrition in plants is a reduction of net photosynthetic activity (P_N), although plant yielding is still visually similar to that obtained at hydroponic concentrations. With an increased intensity of Mn nutrition of plants, the values of P_N and stomatal conductance (g_s) are increasing (to 0.6 mg Mn•dm^{-3}), which indicates an adequate level of CO_2 consumption in the process of assimilation. Those parameters of photosynthetic activity significantly vary depending on the cultivar, which confirm significant variation between cultivars in relation to Mn nutrition [38].

2.1.3.4. The morphology of aboveground parts and yielding of plants

Morphological symptoms of toxic effects of Mn in the form of midrib and lateral veins browning in leaflets of a compound leaf and next necroses of compound leaves and plant apexes and inflorescence withering could be observed at the earliest after 6 weeks of culture (at Mn-19.2) and 10 weeks of exposure (at Mn-9.6) to the nutrient solution (**Figure 2**) [42,43]. For those combinations, a significant reduction in the photosynthetic activity of plants is present [38]. Symptoms of Mn deficiency on leaves could be observed earlier than toxicity—after 3 weeks (in the case of control).

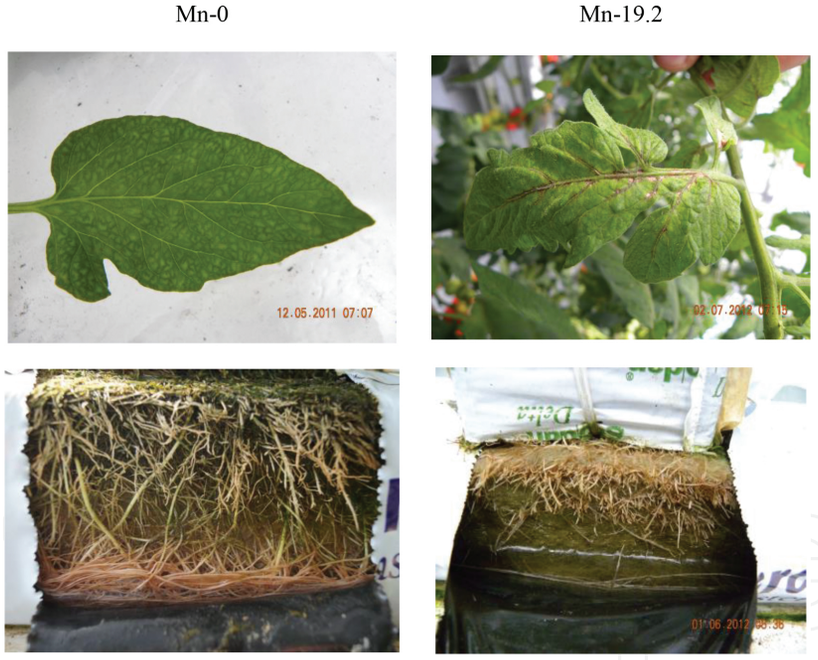

Figure 3. Morphological appearance of leaves and roots at manganese deficiency (at Mn-0) and toxicity (at Mn-19.2) Fot. Kleiber.

The hydroponic concentration of Mn for fertigation of tomato varies depending on cultivar. The greatest marketable yield of fruits in cv. 'Alboney F_1' is obtained at the Mn contents of 0.3–0.6 mg•dm^{-3} nutrient solution, but in the case of cv. 'Emotion F_1' yield for the range of maximum Mn-0.3 is lower than Mn-0.6 (**Table 2**). The content of Mn in nutrient solution amounting to 1.2 mg•dm^{-3} is excessive and contributed to a significant deterioration of yielding, at the simultaneous lack of morphological toxicity symptoms on plants. Mn stress

significantly reduces not only mass of fruits but also leaves and shoots [42]. Significantly, the greatest contents of Mn are characterized leaves, whereas lowest contents are characterized fruits. There is a marked correlation between increasing contents of Mn in nutrient solutions used in fertigation of plants and its contents in leaves, stems, and fruits (R^2 = 0.94–0.99). A high correlation could also be observed for Mn contents between examined plant parts (R^2 = 0.89–0.98).

Tomato cultivars may significantly differ in relation to the requirement and tolerance to Mn concentration in nutrient solutions used in fertigation, but, generally, those species may be classified as a medium tolerance to excessive Mn concentrations in nutrient solution.

2.1.3.5. Chemical composition of fruits

Increasing intensity in Mn nutrition causes increasing in Mn concentration in fruits—but the response similarly in case of leaves generally significantly varies between cultivars (except Mn-0; Table 2) [41,44]. The range of hydroponic concentrations of Mn in fruits that are determined for cv. 'Alboney F_1' is 10.7–19.3 mg Mn•kg^{-1} d.m., whereas for cv. 'Emotion F_1,' it is 17.7 mg Mn•kg^{-1} d.m. At the greatest tested concentration of Mn for these cultivars, they are 103.8 and 132.6 mg Mn•kg^{-1} d.m. Mean Fe/Mn ratios in fruits recorded at the applied hydroponic concentrations are 1.00 : 0.15–0.22, while at the application of 19.2 mg Mn•dm^{-3}, it is 1.00 : 3.20, whereas at the nutrient solution of Mn-1.2, these ratios are 1.00 : 0.40. This indicates a marked and adverse reduction in relative Fe contents. In view of the recommended daily allowances for Mn in the human diet, it seems potentially undesirable to consume tomato fruits from plants supplied excessive or toxic levels of this nutrient.

Mn nutrition significantly impacts on the nutritive value of tomato fruits. A significant reduction is generally recorded for the contents of P, K, Ca, and Mg and the other metallic micronutrients (Fe, Zn, and Cu). Significant variation, depending on the cultivar, is shown generally for N, Ca, Mg Fe, Zn, and Cu. The greatest contents of N, Ca, and Mg in fruits are in the control, while those of P and K—at 0.3 mg Mn dm^{-3}, whereas the lowest contents of nutrients (except for N) are in the case of Mn-19.2.

The increasing intensity in Mn nutrition significantly modifies contents of trace elements (Al, Ba, Co, and Pb) in fruits, at the same time, having no effect on Cr and Cd [41]. A series of those metals in tomato fruits within the range of hydroponic concentrations of Mn are in the following: Ba 4.340–6.180 mg•kg^{-1} d.m. > Ni 4.746–5.198 mg•kg^{-1} d.m. > Co 1.014–1.064 mg•kg^{-1} d.m. > Pb 0.854–0.887 mg•kg^{-1} d.m. > Cd 0.379–0.395 mg•kg^{-1} d.m. > Cr 0.120 mg•kg^{-1} d.m. > Al 0.066–0.081 mg•kg^{-1} d.m. In the range of hydroponic Mn concentrations, contents of analyzed trace elements generally did not vary significantly between cultivars.

2.1.3.6. Use of choline-stabilized orthosilicic acid (ch-OSA) in nutrient solution to alleviate Mn stress

Studies conducted so far have indicated a significant role of silicon (Si) as an element alleviating the toxic effect of Mn [27,45–50]. Previous studies on that subject are concerned with various species, e.g. beans, barley, cucumber, rice, and cowpea. The highest Mn concentrations in nutrient solution (9.6 and 19.2 mg•dm^{-3}) cause the strongest Mn stress of tomato. One of the

available forms of Si, which may be used in fertigation, is ch-OSA. Ch-OSA is also used in medicine; e.g. in combination therapy, ch-OSA/vitamin D_3 is used as a preparation affecting bone collagen in the treatment of osteoporosis [51].

The application of the tested bioavailable Si compound (ch-OSA at a scaled concentration of 0.3 mg Si•dm^{-3}) improves photosynthetic activity (**Table 3**) and results in improving plant yielding—especially for lower levels of Mn. All the factors—(i) content of Mn in nutrient solution, (ii) the application of ch-OSA, and (iii) the cultivar—significantly affect the chemical composition of leaves and tomato fruits [45,46]. Increasing in Mn stress modifies the concentration of microelements and Si in tomato leaves. Application of ch-OSA also influences the concentration of nutrients, but the determined changes were generally multidirectional and vary depending on Mn level and cultivar. Ch-OSA treatment does not influence on the Mn concentrations in fruits.

Mn level	Ch-OSA treatment			Ch-OSA treatment		
	–	+	Mean	–	+	Mean
	'Alboney F_1'			'Emotion F_1'		
	P_N [μmol (CO_2) m^{-2} s^{-1}]					
9.6	8.46 a	11.58 c	10.02 A	8.14 a	17.03 c	13.11 A
19.2	6.92 b	10.38 d	8.65 B	9.44 b	13.16 d	11.47 A
	g_s [μmol (H_2O) m^{-2} s^{-1}]					
9.6	80.05 b	113.83 b	96.94 A	80.26 a	151.31 c	119.00 A
19.2	69.77 a	114.40 b	92.09 A	99.50 b	122.97 d	112.31 A
	Marketable yield of 1 tomato plant					
9.6	4.88 a	5.80 b	5.35 A	4.53 b	4.89 c	4.71 B
19.2	4.78 a	4.85 a	4.80 A	4.06 a	3.85 a	3.96 A

Notes: Means in rows marked with various big letters differ significantly; means in columns marked with various big letters differ significantly; means in rows and columns marked with various small letters differ significantly.

Table 3. The influence of Mn and ch-OSA nutrition on the photosynthetic activity in leaves (P_N—net photosynthetic rate, g_s—stomatal conductance) and marketable yield of 1 tomato plant (kg) [46].

2.2. Boron

2.2.1. Physiological role of boron

B is an essential micronutrient for plant growth and development. It is classified as a biophilic non-metal [52]. It participates in the formation of cell–wall structures and cell divisions [53], pollen tube development [54], and saccharide metabolism [55]. Plants accumulate B through their root system [56] or through leaves [54]. B content affects nitrogen metabolism of plants, although a deficit of this micronutrient results in an increased content in nitrates in plants. Boron also plays a role in phenolic metabolism [57] and in the ascorbate–glutathione metabolic

cycle [53]. It also participates in the formation and functioning of the cell wall [58]. B deficit results in the inhibition of cell–wall synthesis and affects cell elasticity [59], leading to an increase in pore size, resulting in cell–wall rupture [53]. B may form complex compounds with sugars, phenols, organic acids, and polymers [60]. Most frequently, B is found in complex combinations with mannitol, sorbitol, glucose, and fructose [60]. B may also form complex compounds with the RG-II polysaccharide [61–64] stabilized with calcium ions [53,61], the most important boron-binding compound in the cell wall. This complex is found in mono- and dicotyledonous plants [65,66].

2.2.2. The effect of boron on human health

The role of B in the human organism has not been fully clarified. This micronutrient determines appropriate bone development, preventing osteoporosis. An adequate B uptake with the human diet prevents arthritis [61]. B was shown to affect the activity of brain cells, the metabolism of calcium and magnesium, and the immune system [67,68]. According to Kurtoğlu et al. [69] and Li et al. [70], the interaction of B and calcium influences hormonal functions in the human. The daily dose of B absorbed by humans through the respiratory and the alimentary systems as well as the skin varies, ranging from 0.25 to 20 mg a day [71–73]. B is not accumulated in tissues, and it is excreted with urine [72], but its excess is dangerous for human health [52]. The most important sources of B in the human diet include drinks, vegetables, and fruits [74]. According to Castillo et al. [75], the greatest amounts of B are contained in beets (250 mg kg^{-1}), lemons (150 mg kg^{-1}), and apples (110 mg kg^{-1}).

2.2.3. Boron content in water

Natural and anthropogenic factors are sources of B in underground waters. Natural concentrations of B in fresh water result from the contents of borates in soils and rocks, mixing of waters at different aquifer levels as well as the effect of marine intrusion. During rock weathering, B penetrates to the solution forming a series of anions: BO_2^-, $B_4O_7^{-2}$, BO_3^{-3}, $H_2BO_3^-$, and $H_4BO_4^-$ [76]. Most frequently, B is found in water in the form of boric acid [77], less commonly in anions and organic compounds [71]. B content in surface and underground waters may range from 5 to 100 mg dm^{-3} [78]. Natural B content in underground waters in Poland amounts to 0.01–0.5 mg dm^{-3} [79]. According to Breś et al. [19], B content in water used in horticulture does not exceed 0.1 mg dm^{-3}; however, in areas with high intensity of horticultural production, the content of B may exceed 0.6 mg dm^{-3} [80]. Many authors [81–84] recommend an optimal B content in the nutrient solution for fertigation of tomato at 0.3 mg dm^{-3}. In studies presented by other authors, the recommended B content in the nutrient solution for tomato growing is 0.2–0.7 mg dm^{-3} [3,85–91].

2.2.4. Material and methods

The vegetation experiment was conducted in the years 2009–2012 (Experiment I) and 2013–2014 (Experiment II). Analyses were conducted on the effect of B fertigation on yielding and macronutrient content in leaves and fruits of tomato grown on rockwool. Vegetation experiments were run in a specialist culture greenhouse equipped with the modern climate control

system. Climate parameters (such as temperature, CO_2 content, and % RH) were recorded using the Synopta software. The facilities were equipped with a modern computer-controlled fertigation system and energy-conservation curtains. Plants were grown at a density of 2.7 plants·m^{-2}.

The experiment was conducted on two tomato cv. Alboney F_1 and Emotion F_1. Plants were grown in standard rockwool (density of 60 kg·m^{-3}, mats of 100 × 15 × 7.5 cm). Experiment was established in a completely randomized system, in six replications with two plants in each. Biological pest control was applied in that culture. All cultivation measures were performed in accordance with the current recommendations for tomato growing [92]. Seeds were sown to cultivation plugs in the first half of March in each year of the study. After 2 weeks, seedlings were transplanted to rockwool cubes (10 × 10 × 10 cm). Plants were transplanted to permanent beds in the second half of April in each year of the study. The experiment was concluded on 30 September in each year of the study. The experiments were conducted in two factors (factor A—B concentration and factor B—cultivar) in five replications with four plants in each.

Plants were grown using fertigation in the closed system with no recirculation of the nutrient solution. A standard nutrient solution for tomato growing was used with the following nutrient contents: $N–NH_4$—2.0 mg·dm^{-3}, $N–NO_3$—230 mg·dm^{-3}, P—50 mg·dm^{-3}, K—420 mg·dm^{-3}, Ca—140 mg·dm^{-3}, Mg—60 mg·dm^{-3}, Cl—30 mg·dm^{-3}, $S–SO_4$—120 mg·dm^{-3}, Fe—1.80 mg·dm^{-3}, Mn—0.3 mg·dm^{-3}, Zn—0.50 mg·dm^{-3}, and Cu—0.07 mg·dm^{-3}. The nutrient solution of B was prepared and added individually to the respective tanks with a capacity of 1000 dm^{-3} in the following combinations: control (0.011), 0.4, 0.8, and 1.6 mg·dm^{-3} in the form of $Na_2B_4O_7·10H_2O$ (Experiment I) and boric acid H_3BO_3 (Experiment II; combinations of the designated symbols, respectively, B-I, B-II, B-III, and B-IV). 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 solutions per plant were applied daily, in 15–20 single doses at 20–30% drip from mats.

In the vegetation period, the yield of fruits was recorded in terms of fruit quality grades: I—over 10.2 cm; II—10.2–8.2 cm; III—8.2–6.7 cm, IV—6.7–5.7 cm, V—5.7–4.7 cm, and VI—less than 4.7 cm. Marketable yield comprises fruits classified to Grades I–V.

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 eight slabs. Chemical analyses of nutrient solutions were conducted directly in the tested solutions (without their stabilization) using the following methods: $N–NH_4$, $N–NO_3$—by distillation according to Bremner modified by Starck, P—colorimetrically with ammonium vanadium molybdate, K, Ca, Na—by flame photometry, Cl—nephelometrically with $AgNO_3$, $S–SO_4$—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.

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Leaf samples for chemical analyses were collected on 15.06, 15.07, and 16.08 in each of the years of the study. Index parts comprised 8–9 leaves counting from the top of the plant. One bulk sample was composed of 12 leaves collected from plants within a given combination. Representative samples of fruits were harvested in the second half of August in each year of the study. Collected plant material was dried at a temperature of 45–50°C and then ground. To determine total nitrogen, phosphorus, potassium, calcium, and magnesium contents, plant material was mineralized in concentrated sulfuric acid. Nutrient contents were determined using the following methods: N—total—by the distillation method according to Kjeldahl in a Parnas–Wagner apparatus, P—by colorimetry with ammonium molybdate (according to Schillak), while K, Ca, and Mg—by atomic absorption spectrometry (AAS). To determine total contents of iron, manganese, zinc, and copper, the plant material was mineralized in a mixture of acetic and perchloric acids (3:1 v/v), B—dry mineralization with calcium oxide (CaO). After mineralization, Fe, Mn, Zn, and Cu were determined according to AAS and B colorimetrically with curcum.

Results of biometric measurements and laboratory analyses were analyzed statistically using the Duncan test, with inference at $\alpha = 0.05$.

2.2.5. Results and discussion

2.2.5.1. Yielding

The effect of B fertigation on the marketable yield of tomato fruit was found in a vegetation experiment conducted in the years 2009–2012 (Experiment I) and 2013–2014 (Experiment II; Table 4). The mean marketable yield differed significantly depending on the level of B in the nutrient solution. The largest yield marketable varieties Alboney F1 (Experiment I) obtained in combinations of B-I and B-II (5.55 and 5.52 kg · plant^{-1}). Increasing the B content of the medium had a significant effect on reducing the commercial yield in combinations of B-III and B-IV (5.09 and 5.18 kg · plant^{-1}) when compared to combinations of B-I and B-II. The highest yield of marketable varieties obtained Emotion F1 in combination of B-II (5.57 kg plant^{-1}). There were no significant differences in yield trading between combinations of B-I, B-III, and B-IV, average marketable yield of these varieties did not differ significantly. In the conducted in the years 2013 – 2014 found the experience of growing influence of fertigation boron on the marketable yield of tomato fruit. The resulting average yield commercial differ significantly depending on the level of B in the medium. In the performed experiment, no significant changes were found in the shares of the marketable yield in the total yield (99.6–100.0%). When analyzing the produced marketable yield, it needs to be stressed that the optimal level of B in the nutrient solution for cv. Alboney F_1 amounts to 0.011–0.40 mg dm^{-3}, whereas for cv. Emotion F_1 0.40 mg B · dm^{-3}. Increased B content in the nutrient solution caused a significant reduction of the marketable yield in both cultivars. Cultivar Emotion F_1 responded with a decrease in the marketable yield both to a deficit and excess B in the nutrient solution. Recorded results indicate a greater optimal content range in cv. Alboney F_1 for this micronutrient in the nutrient solution used in fertigation. In this study, when applying a nutrient solution considered to be standard (0.40 mg dm^{-3}), a similar marketable yield was found for cv. Emotion F_1

(5.85 kg plant^{-1}) to that obtained by Kleiber [43] when using a standard nutrient solution (5.82 kg plant^{-1}). No differences were observed between cultivars, and the produced marketable yield of cv. Alboney F_1 was lower by ±0.7 kg plant^{-1}. The effect of B on yielding in tomato was confirmed by a study conducted by Oyinlola [93]. In comparison with the experiment carried out by Piróg and Komosa [94], the produced marketable yield in both cultivars in this experiment at B contents in the nutrient solution of 0.0, 0.4, and 0.8 mg dm^{-3} was greater, it may have a significant effect at mass-scale tomato production. In an experiment conducted by Jarosz and Dzida [81], the greatest total yield of cv. 'Cunero F1' was 14.7 kg m^{-2} (2.7 plant m^{-2}), whereas studies carried out in 2004 on the same cultivar showed a yield of 4.39 kg plant^{-1} [9].

Variety	B-I	B-II	B-III	B-IV	Mean
			Experiment I		
			Marketable field (kg plant^{-1})		
Alboney F_1	5.55 c	5.52 c	5.09 ab	5.18 b	5.34 A
Emotion F_1	5.00 a	5.57 c	4.92 a	4.74 a	5.06 A
Średnia Mean	5.28 AB	5.55 B	5.01 A	4.96 A	
			Contribution of marketable yield in total yield (%)		
Alboney F_1	99.5	99.5	99.2	99.4	99.4
Emotion F_1	99.6	99.1	99.2	99.4	99.3
Średnia Mean	99.6	99.3	99.2	99,4	
			Experiment II		
			Marketable field (kg plant^{-1})		
Alboney F_1	5.73 bc	5.87 c	5.65 b	5.46 a	5.68 A
Emotion F_1	5.24 a	5.85 c	5.60 b	5.41 a	5.52 A
Mean	5.48 A	5.86 C	5.63 B	5.43 A	
			Contribution of marketable yield in total yield (%)		
Alboney F_1	99.8	100.0	99.8	99.6	99.8
Emotion F_1	99.8	99.7	99.8	99.6	99.7
Mean	99.8	99.8	99.8	99.6	

Notes: Means in rows marked with various big letters differ significantly; means in columns marked with various big letters differ significantly; means in rows and columns marked with various small letters differ significantly.

Table 4. The influence of B nutrition on total yield of 1 tomato plant (kg).

2.2.5.2. Chemical composition of the root zone

The effect of increasing B concentrations in nutrient solutions is shown (**Table 5**). In all the combinations, an increase was shown for B contents in nutrient solutions absorbed from mats in comparison with the nutrient solution applied to plants. The greatest B content in nutrient

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solutions for both cultivars was recorded in mats applying B at 1.60 mg dm^{-3}. Differences between cultivars were shown in terms of B content in nutrient solutions collected from mats in combinations of B-I and B-IV (Experiment I) and B-II and B-IV (Experiment II). An increase in B content in the nutrient solution in combinations of B-III and B-IV caused a significant decrease in the marketable yield, which may have been caused by the toxic individual effect of this ion on plants [95]. In this experiment, the phenomenon of B condensation was observed in growing mats, confirming the results reported by other authors [24]. It needs to be stated that B content in growing mats exceeding 0.93 mg dm^{-3} (Experiment I) causes a significant reduction of plant yielding. However, a further increase in the content of B in nutrient solutions in the rhizosphere up to 1.87 mg dm^{-3} does not cause a significant reduction of the marketable yield between these combinations. The conducted Experiment II using boric acid as a source of B in the nutrient solution showed identical dependencies in the case of the greatest marketable yield; however, the content of B in mats close to 2.00 mg dm^{-3} caused a significant reduction of yielding in comparison with combination of B-III (±1.00 mg·dm^{-3}). The highest marketable yield varieties Emotion F1 obtained when the boron content of mats 0.58 (Experiment I) and 0.67 mg·dm^{-3} (Experiment II). At the application of the same B levels in hydroponic culture of butter lettuce, a yield-modifying effect of increasing B concentrations in the nutrient solution was found for the mean weight of lettuce heads. The greatest weight of lettuce heads was produced using B content in the nutrient solution within the range of 0.40–1.60 mg dm^{-3} [96].

Sampling place	B-I	B-II	B-III	B-IV	B-I	B-II	B-III	B-IV
	Experiment I				Experiment II			
Dripper	0.11 a	0.41 d	0.80 f	1.57 h	0.11 a	0.41 c	0.82 f	1.63 h
Alboney	0.21 b	0.58 e	0.93 g	1.87 i	0.27 b	0.59 d	0.99 g	1.92 i
Emotion	0.26 c	0.58 e	0.96 g	2.00 j	0.32 b	0.67 e	1.01 g	2.11 j

Notes: Results were subjected to analysis of variance, independently for each experiment; nutrient solution collected from slabs of cv.: [1]'Alboney F_1'; [2] 'Emotion F_1'; values described with identical letters do not differ significantly at α = 0.05.

Table 5. The effect of increasing B concentration in nutrient solution (mg•dm^{-3}) on contents of that microelement in cultivation slabs.

2.2.5.3. Chemical composition of leaves

An increase in B contents in the nutrient solution applied in fertigation had a significant effect on the content of this micronutrient in indicator parts of tomato (**Table 6**). In combinations of B-II and B-III, an increase in B contents in the nutrient solution caused an increase in B content by ±100%. Significantly, the greatest mean B content was assayed using the nutrient solution of 1.60 (207.07 mg·kg^{-1}). Significant differences in the mean B content in leaves were observed between cultivars. According to the studies conducted by other authors, an increase in the content of B in the nutrient solution has a significant effect on contents of this micronutrient in tomato leaves [93]. [79] when growing tomato at a toxic level of boron in the nu-

trient solution assayed 155 mg B·kg^{-1} in tomato leaves. Results in this study for B contents in indicator parts of tomato at 0.80 and 1.60 indicate a toxic state of nutrition of plants in the case of the investigated micronutrient. According to Kabata-Pendias and Pendias [71], an admissible B content for tomato plants is 100 mg·kg^{-1} B in d.m. In turn, according to De Kreij et al. [97], an optimal content of B in tomato leaves should be 54.0–75.6 mg·kg^{-1} B d.m. When analyzing the state of nutrition of plants in the case of boron, we need to state that in this study (Experiment I) plants of cv. Alboney F_1 yielded best at B contents in indicator parts of 33.24–78.58 mg·kg^{-1}, whereas for cv. Emotion F_1 it was at 79.44 mg·kg^{-1}. In analyses with the use of boric acid (Experiment II), cv. Alboney F_1 yielded best at B contents in indicator parts of 32.80–80.62 mg·kg^{-1}, whereas for cv. Emotion F_1 at 83.89 mg·kg^{-1}. Recorded B contents were lower than those reported by Komosa et al. [23] in their studies on yielding of cv. Emotion F_1 in closed systems with recirculation and without recirculation of the nutrient solution.

Variety	B-I	B-II	B-III	B-IV	Mean
			Experiment I		
			B content in leaves		
Alboney F_1	33.24 a	78.58 b	167.46 d	207.02 f	121.57 B
Emotion F_1	37.94 a	79.44 b	139.83 c	188.68 e	111.47 A
Mean	35.59 A	79.01 B	153.65 C	197.85 D	
			Experiment II		
			B content in leaves		
Alboney F_1	32.80 a	80.62 c	173.56 e	218.30 g	126.32 B
Emotion F_1	45.17 b	83.89 c	148.61 d	195.83 f	118.37 A
Mean	38.98 A	82.25 B	161.09 C	207.07 D	

Notes: Means in rows marked with various big letters differ significantly; means in columns marked with various big letters differ significantly; means in rows and columns marked with various small letters differ significantly.

Table 6. The influence of boron nutrition on content of B in leaves (in mg kg^{-1} d.m.).

2.2.5.4. Chemical composition of fruits

In this study, the content of B in tomato fruits was dependent on B content in the nutrient solution used in fertigation (**Table 7**). The greatest B content in fruits of tomato cv. Alboney F_1 was recorded in combinations B-III (16.30 mg·kg^{-1}) and B-IV (16.43 mg·kg^{-1}), while for cv. Emotion F_1 in combination B-IV (17.30 mg·kg^{-1}). Differences in B contents in fruits were shown only in the B-II combination (Experiment I). In all the combinations, significant differences were observed between cultivars in terms of B contents (Experiment II). Significantly greater B contents were assayed in fruits of cv. Emotion F_1. The greatest mean B content in fruits was recorded in combination B-IV (26.50 mg·kg^{-1}). According to other authors, the content of B in tomato fruits is significantly lower in comparison with those recorded in leaves [98,99]. Results obtained in studies on the application of borax for B contents in fruits were lower than those

reported by Komosa et al. [24]. Using boric acid, greater boron levels were found in fruits, while differences were found between cultivars in the mean B content in tomato fruits.

Variety	B-I	B-II	B-III	B-IV	Mean
			Experiment I		
			B content in fruits		
Alboney F_1	11.66 a	13.10 b	16.30 de	16.43 de	14.60 A
Emotion F_1	11.56 a	14.26 c	15.30 cd	17.30 e	14.37 A
Mean	11.61 A	13.68 B	15.80 C	16,86 D	
			Experiment II		
			B content in fruits		
Alboney F_1	11.66 a	16.70 b	19.90 c	24.26 d	18.13 A
Emotion F_1	15.33 b	19.56 c	24.10 d	28.73 e	21.93 B
Mean	13.49 A	18.31 B	22.00 C	26.50 D	

Notes: Means in rows marked with various big letters differ significantly; means in columns marked with various big letters differ significantly; means in rows and columns marked with various small letters differ significantly.

Table 7. The influence of boron nutrition on content of B in fruits (in mg kg^{-1} d.m.).

3. Conclusions

1. When analyzing the produced marketable yield, it needs to be stressed that the optimal level of B in the nutrient solution for cv. Alboney F_1 amounts to 0.011–0.40 mg dm^{-3}, while for cv. Emotion F_1 0.40 mg B dm^{-3}. Increased B content in the nutrient solution caused a significant reduction of the marketable yield in both cultivars. Cultivar Emotion F_1 responded with a decrease in the marketable yield both to a deficit and excess B in the nutrient solution.
2. It needs to be stated that B content in growing mats exceeding 0.93 mg dm^{-3} (Experiment I) causes a significant reduction of plant yielding. However, a further increase in the content of B in nutrient solutions in the rhizosphere up to 1.87 mg dm^{-3} does not cause a significant reduction of the marketable yield between these combinations. The conducted Experiment II using boric acid as a source of B in the nutrient solution showed identical dependencies in the case of the greatest marketable yield; however, the content of B in mats close to 2.00 mg dm^{-3} caused a significant reduction of yielding in comparison with combination B-III (±1.00 mg·dm^{-3}).
3. An increase in B contents in the nutrient solution applied in fertigation had a significant effect on the content of this micronutrient in indicator parts of tomato. Results in this study for B contents in indicator parts of tomato at 0.80 and 1.60 indicate a toxic state of nutrition of plants in the case of the investigated micronutrient.

4. In this study, the content of B in tomato fruits was dependent on B content in the nutrient solution used in fertigation. Using boric acid, greater boron levels were found in fruits, while differences were found between cultivars in the mean B content in tomato fruits.

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References

[1] Piróg J. Growing plants in greenhouses on various substrates. National sympodium. Poznań; 1994. (In Polish).

[2] Komosa A. Inert media – progress or inertia?. Advances of Agricultural Sciences Problem 2002: 485 147–167. (In Polish).

[3] Komosa A., Kleiber T., Markiewicz B. The effect of nutrient solutions on yield and macronutrient status of greenhouse tomato (*Lycopersicon esculentum* Mill.) grown in aeroponic and rockwool culture with or without recirculation of nutrient solution. Acta Sci. Pol. Hortorum. Cultus 2014; 13 (2), 163–177.

[4] Pudelski T. Tomatoes under glass and foil. Warszawa: PWRiL; 1998. (In Polish).

[5] Kleiber T., Markiewicz B., Niewiadomska A. Organic substrates for intensive horticultural cultures: Yield and nutrient status of plants, microbiological parameters of substrates. Pol. J. Environ. Stud. 2012; 21 (5), 1261–1271.

[6] Pawlińska A., Komosa A. The effect of substrates and nutrient solutions on yield of greenhouse tomato. Rocz. AR Pozn. CCCL VI Ogrodn. 2004; 37, 173–180 (in Polish).

[7] ANTHURA. Cultivation Guide Anthurium. Anthura; 1998, 43.

[8] Jarosz Z., Horodko K. The yielding and mineral composition of greenhouse tomato grown in inert media. Rocz. AR Pozn. CCCLIV Ogrodn. 2004; 37, 81–86.

[9] Jarosz Z., Horodko K. The yielding and mineral composition of greenhouse tomato grown in inert media. Rocz. AR Pozn. CCCLIV Ogrodn. 2004; 37, 81– 86.

[10] RuniaW.TH., Amsing JJ. Disinfection of recirculation water from closed cultivation systems by heat treatment. Acta Hort. 2001; 548, 215–222.

[11] Van Os EA. Heat treatment for disinfecting draincoater technological and economic aspects. Proc. 7th Int. Congr. Soilless Culture, Flevohof, 1988, 353–359.

[12] Van Os EA. New developments in recircualtion systems and disinfection methods for greenhouse crops. Hort. Eng. 2001; 16 (2), 2–5.

[13] Wohlanka W. Water disinfection. Taspo Praxis 1990; 18, 73–81.

[14] Benoit F., Ceustermans N. Horticultural aspects ecobiological soilless growing methods. Acta Hort. 1995; 396, 11–19.

[15] Runia WTH., Amsing JJ. Disinfestation of nematode infested recirculation water by ozone and activated hydrogen peroxide. Proceedings of 9th International Congress on Soilless Culture, St. Helier, Jersey, 12–19 April 1996.

[16] Nurzyński J. Fertilization of horticultural plants. Lublin: Wyd. AR; 2003, 1–153 (in Polish).

[17] Baran S. Possibilities of the use of GRODAN mineral wool to form water properties insoils and grounds. Advances of Agricultural Sciences Problem 2008; 535, 15 (in Polish).

[18] Dubsky M., Šramek F. The effect of rockwool on physical properties of growing substrates for perennial. Hort. Sci. (Prague) 2009; 36 (1), 38.

[19] Breś W., Kleiber T., Trelka T. Quality of water used for drip irrigation and fertigation of horticultural plants. Folia Hort. 2010; 22 (2), 67–74.

[20] Kleiber T. Pollution of the natural environment in intensive cultures under greenhouses. Archiv. Environ. Protect. 2012; 38 (2), 45–53.

[21] Gajc-Wolska J., Bujalski D., Chrzanowska A. Effect of substrate on yielding and quality of greenhouse cucumber fruits. J. Elementol. 2008; 13 (2), 205–210.

[22] Komosa A., Piróg J., Kleiber T. Changes of macro and micronutrients in the root environment of greenhouse tomato grown in fiber wood. Veg. Crps. Res. Bull. 2009; 70, 71–80.

[23] Komosa A., Kleiber T., Piróg J. Contents of macro- and microelements in root environment of greenhouse tomato grown in rockwool and wood fiber depending on nitrogen levels in nutrient solutions. Acta Sci. Pol. Hortorum. Cultus 2010; 9 (3), 59–68.

[24] Komosa A.,Piróg J., Weber Z., Markiewicz B. Comparison of yield, nutrient solution changes and nutritional status of greenhouse tomato (*Lycopersicon esculentum* Mill.) grown in recirculating and non-recirculating nutrient solution systems. J. Plant Nutr. 2011; 34, 1473–1488. DOI:10.1080/01904167.2011.585204.

[25] Kozłowska M., Bandurska H., Floryszak-Wieczorek J., Politycka B. Plant physiology PWRiL; 2007. (In Polish).

[26] Kozik E., Komosa A. The influence of macro- and micronutrients on yield quantity and quality.In: Komosa A., Breś W., Golcz A., Kozik E. (Red.), Horticultural plants nutrition. Fundamentals and prospects. PWRiL; 2012, 204–205. (In Polish).

[27] Maksimović DJ., Bogdanović J., Maksimović V., Nikolić M. Silicon modulates the metabolism and utilization of phenolic compounds in cucumber (*Cucumis sativus* L.) grown at excess manganese. J. Plant Nutr. Soil Sci. 2007; 170, 739–744.

[28] Savvas D., Papastavrou D., Ntatsi G., Ropokis A., Olympios C. Interactive effects of grafting and manganese supply on growth, yield, and nutrient uptake by tomato. HortScience 2009; 44 (7), 1978–1982.

[29] Shenker M., Plessner OE., Tel-Or E. Manganese nutrition effects on tomato growth, chlorophyll concentration, and superoxide dismutase activity. J. Plant Physiol. 2004; 161, 197–202.

[30] Aschner JL., Aschner M. Nutritional aspects of manganese homeostasis. Mol. Aspects Med. 2005; 26 (4), 353–362.

[31] Dri. Dietary references intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium and zinc. 2002. www.nap.edu/books/0309072794/html.

[32] Nutrition Working Group of International Life Sciences Institute Europe. Recommended daily amounts of vitamins and minerals in Europe. Nutr. Abstracts Rev. A 1990; 60, 827–842.

[33] Marzec Z., Marzec A., Zaręba S. Survive daily food rations source of iron and manganese 16 for adults. Roczniki PZH. 2004, 29–34. (In Polish).

[34] Kłos A., Bertrandt J., Stężycka E., Szymańska W. Copper, zinc, magnesium and manganese content in daily food rations used for alimentation of students of the main school of fire service in Warsaw. Bromat. Chem. Toksykol. 2011; XLIV (3), 336–340 (in Polish).

[35] Roth AJ., Garrick MD. Iron interactions and biological interactions mediating the physiological ant toxic actions of manganese. Biochem. Pharmocol. 2003; 66, 1–13.

[36] Dobson AW., Erikson KM., Aschner M. Manganese neurotoxicity. Ann. N.Y. Acad. Sci. 2004; 1012, 115–128.

[37] Kleiber T. Studies on increasing manganese nutrition effect of tomato (*Lycopersicon esculentum* Mill.) on differentiation of rhizosphere chemical composition. Scientific and Didactic Equipment 2014a; 2, 119–126.

[38] Kleiber T., Borowiak K., Budka A., Kayzer D. Relations between Mn concentration and yield, nutrient, water status, and gas exchange parameters of tomato. Acta Biol. Cracoviens. Series Bot. 2014a; 56 (2), 98–106.

[39] Kleiber T. Effect of manganese on nutrient content in tomato (*Lycopersicon esculentum* Mill.) leaves. J. Elementol. 2015; 20 (1), 115–126. DOI:10.5601/jelem.2014.19.2.580.

[40] Kleiber T., Szablewski T., Stuper-Szablewska K., Cegielska-Radziejewska R. Determination of correlations between content of manganese in nutrient solution and concentration of trace elements in tomato fruits (*Lycopersicon esculentum* Mill.). Food. Science. Technology. Quality 2014b; 6 (97), 81–91 (in Polish).

[41] Kleiber T., Szablewski T., Stuper-Szablewska K., Cegielska-Radziejewska R. Determination of manganese stress influence on content of trace elements in leaves of

tomatoes (*Lycopersicon esculentum* Mill.) Bromat. Chem. Toksykol. 2014c; XLVII (I), 89–95 (in Polish).

[42] Kleiber T., Grajek M. Tomato reaction on excessive manganese nutrition. Bulgarian J. Agric. Sci. 2015; 21 (1), 124–131.

[43] Kleiber T. Influence of manganese on yielding of tomato (*Lycopersicon esculentum* Mill.) cultivated in rockwool. Nauka Przyroda Technol. 2014b; 8 (2), 14.

[44] Kleiber T. Changes of nutrient contents in tomato fruits under the influence of increasing intensity of manganese nutrition. Ecol. Chem. Eng. S 2014c; 21 (2), 297–307.

[45] Kleiber T., Bosiacki M., Breś W. The effect of ch-OSA application on tomato grown under increasing manganese stress. J. Elementol. 2015a; 20 (4), 897–910. DOI:10.5601/jelem. 2015.20.1.820.

[46] Kleiber T., Calomme M., Borowiak K. The effect of choline-stabilized orthosilicic acid on microelements and silicon concentration, photosynthesis activity and yield of tomato grown under Mn stress. Plant Physiol. Biochem. 2015b; 96, 180–188.

[47] Horiguchi T. Mechanism of manganese toxicity and tolerance of plants IV. Effects of silicon on alleviation of manganese toxicity of rice plants. Soil Sci. Plant Nutr. 1988; 34 (1), 65–73.

[48] Iwasaki K., Maier P., Fecht M., Horst WJ. Effects of silicon supply on apoplastic manganese concentrations in leaves and their relation to manganese tolerance in cowpea (*Vigna unguiculata* (L.) Walp.). Plant Soil 2002; 238, 281–288.

[49] Liang Y., Wanchun S., Yong-Guan Z., Christie P. Mechanisms of silicon-mediated alleviation of abiotic stresses in higher plants: A review. Environ. Pollut. 2007; 147 (2), 422–428.

[50] Zanão Júnior LA., Ferreira Fontes RL., Lima Neves JC., Korndörfer GH., Vinícius Tavares de Ávila V. Rice grown in nutrient solution with doses of manganese and silicon. R. Bras. Ci Solo. 2010; 34, 1629–1639.

[51] Spector TD., Calomme MR., Anderson SH., Clement G., Bevan L., Demeester N., Swaminathan R., Jugdaohsingh R., Vanden Berghe DA., Powell JJ. Choline-stabilized orthosilicic acid supplementation as an adjunct to calcium/vitamin D3 stimulates markers of bone formation in osteopenic females: A randomized, placebo-controlled trial. BMC Musculoskelet. Disord. 2008; 9, 85.

[52] Tomaszewska B. Boron in groundwater and landfill leachate. Exploration Technology Geothermal Energy, Sustainable development nr 1–2/2010. 161 – 171.

[53] Brown P.H., Bellalui N., Wimmer M.A., Bassil E.S., Ruiz J., Hu H., Pffefer H., Dannel F., Romheld V. (2002): Boron in plant biology. Plant Biology 4/2: 205 – 223.

[54] Lityński T., Jurkowska H. Soil fertility and plant nutrition. Warszawa: PWN; 1982. (In Polish).

[55] Shol'nik MY. The Physiological Role of B in Plants. London, UK: Borax Consolidated Limited; 1965.

[56] Fotyma M., Mercik S. Agricultural Chemistry II. Warszawa: Wyd PWN; 1995 (in Polish).

[57] Ruiz JM., Bretones G., Baghour M., Ragala L., Belakbir A., Romero L. Relationship between boron and phenolic metabolism in tobacco leaves. Phytochemistry 1998b; 48, 269–272.

[58] O'Neill MA., Ishii T., Albersheim P., Darvill AG. Rhamnogalacturonan II: Structure and function of a borate cross-linked cell wall pectic polysaccharide. Annu. Rev. Plant Biol. 2004; 55, 109–139.

[59] Biernat J., Pieczyńska J. The role of boron in the metabolism and in human nutrition. Bromatologia chemistry and toxicology. 2000; 33 (4), 289–294. (In Polish).

[60] Hu H., Brown PH. Localisation of boron in cell walls ofsquash and tobacco and its association with pectin. Plant Physiol. 1994; 105, 681–689.

[61] Goldbach HE., Rerkasem B., Wimmer MA., Brown PH., Thellier M., Bell RW. Boron in Plant and Animals Nutrition. New York: Kluwer Academic/Plenum Publishers; 2002.

[62] Kobayashi M., Matoh T., Azuma J. Two chains of rhamnogalacturonan II are cross-linked by borate-diol ester bonds in higher plant cell walls. Plant Physiol. 1996; 110, 1017–1020.

[63] O'Neill MA. Warrenfeltz D, Kates K, Pellerin P Doco T Darvill AG, Albersheim P. Rhamnogalacturona – II, a pectic polysaccharide in the walls of growing plant cell, forms a dimer that is covalently cross-linked by a borate ester – In vitro conditions for the formation and hydrolysis of the dimer. J. Biol. Chem. 1996; 271,22923–22930.

[64] O'Neill MA., Eberhard S., Albersheim P., Darvill AG. Requirement of borate cross-linking of cell wall rhamnogalacturonan II for *Arabidopsis* growth. Science 2001; 294, 846–849.

[65] Ishii T., Matsunaga T., Hayashi N. Formation of rhamnogalacturonan II-borate dimer in pectin determines cell wall thickness of pumpkin tissue. Plant Physiol. 2001; 126, 1698–1705.

[66] Kaneko S., Ishii T., Matsunaga T. A boron-rhamngalcturonan-II complex from bamboo shoot cell walls. Phytochemistry 1997; 44, 243–248.

[67] Murray F.J. A human health risk assessment of boron (boric acid and borax) in drinking water. Regul. Toxicol. Pharmacol. 1995; 22 (3), 221–230.

[68] Nielsen F.H. The emergence of boron as nutritionally import ant throughout the life cycle. Nutrition 2000; 16, 512–514.

[69] Kurtoğlu V., Kurtoğlu F., Coşkun B. Effects of boron supplementation of adequate and inadequate vitamin D_3-containing diet on performance and serum biochemical characters of broiler chickens. Res. Vet. Sci. 2001; 71, 183–187.

[70] Li Q., Zhang T. A novel method of the determination of boron in the presence of a little metanol by discoloring spectrophotometry in pharmaceutitcal an biological samales. Talanta 2007; 71, 296–302.

[71] Kabata-Pendias A., Pendias H. Biogeochemistry of trace elements. Warszawa: Wyd. Nauk, PWN; 1999. (In Polish).

[72] Moore JA., Expert Scientific Committee. An assessment of boric acid and borax using the IEHR evaluative process for assessing human developmental and reproductive toxicity of agents. Reprod. Toxicol. 1997; 11 (1), 123–160.

[73] Rainey CJ., Nyquist LA., Christensen RE. Daily boron intake from the American diet. J. Am. Dietet. Assoc. 1998; 99, 335–340.

[74] Biego GH., Joyeux M., Hartemann P., Derby G. Daily intake of essentials minerals and metalic micropollutants from foods in France. Sci. Total Environ. 1998; 217, 27–36.

[75] Castillo J.R., Mir J.M., Bendicho C., Martinez C. Determination of boron in waters by using methyl borate generation and flame atomic-emission spektrometry. Atomic Spectroscopy. 1985. 6. 152 – 155.

[76] Kabata-Pendias A., Pendias H. Trace Elements in Soli and Plants. Boca-Raton, FL: CRC Press; 2001.

[77] ItakuraT., SasaiR., ItohH. Precipitation recovery of boron from wastewater by hydrothermal mineralization. Water Res. 2005; 39 (12), 2543–2548.

[78] Melnyk L., Goncharuk V., Butnyk I., Eugene Tsapiuk E. Boron removal from natural and wastewaters using combined sorption/membrane process. Desalination 2005; 185, 147–157.

[79] RMS. J. Laws 2008; 143, item 896.

[80] Kowalczyk W., Dyśko J., Felczyńska A. Evaluation of the nutrient elements polution level of the groundwater intakes on the concentrated areas of greenhouse production. Vegetable News. 2010.51. 29 – 34. (In Polish).

[81] Jarosz Z., Dzida K. Effect of substratum and nutrient solution upon yielding and chemical composition of leaves and fruits of glasshouse tomato grown in prolonged cycle. Acta Sci. Pol. Hortorum. Cultus 2011; 10 (3), 247–258.

[82] Jarosz Z., Dzida K., Nurzyńska-Wierdak R. Possibility of reusing expanded clay in greenhouse tomato cultivation. Part i. Yield and chemical composition of fruits. Acta Sci. Pol. Hortorum Cultus 2012; 11 (6), 119–130.

[83] Kowalczyk K., Gajc-Wolska J. Effect of the kind of growing medium and transplant grafting on the cherry tomato yielding. Acta Sci. Pol. Hortorum Cultus 2011; 10 (1), 61–70.

[84] Wysocka-Owczarek M. Tomatoes under Cover. The Cultivation of Conventional and Modern. Warszawa: Hortpress Sp. z o.o; 1998, 166–187 (in Polish).

[85] Adams P., Nutrition of greenhouse vegetables in NFT and hydroponics systems. Acta Hort. 1994; 361, 245–257.

[86] Borowski E., Nurzyński J. Effect of different growing substrates on the photosynthesis parameters and fruit yield of greenhouse-grown tomato. Acta Sci. Pol. Hortorum. Cultus 2012; 11 (6), 95–105.

[87] Hochmuth GJ., Hochmuth RC. Nutrient Solution Formulation for Hydroponic (Perlite, Rockwool, NFT) Tomatoes. Florida: University of Florida, HS796; 2012.

[88] Kleiber T., Markiewicz B. Application of 'Tytanit' in grenhouse tomato growning. Acta Sci. Pol. Hortorum. Cultus 2013; 12 (3), 117–126.

[89] Komosa A., Górniak T. The effect of chloride on nutrie nt contents in fruits of greenhouse tomato (*Lycopersicon esculentum* Mill.) Grown in rockwool. Acta Sci. Pol. Hortorum. Cultus 2012; 11 (5), 43–53.

[90] Markiewicz B., Kleiber T. The effect of Tytanit application on the content of selected microelements and the biological value of tomato fruits. J. Elem. 2014; 19 (4), 1065–1072. DOI:10.5601/jelem.2014.19.3.486.

[91] Zekki H., Gauthier L., Gosselin A. Growth, productivity and mineral composition of hydroponically cultivated greenhouse tomatoes, with or without nutrient solution recycling. J. Am. Soc. Hort. Sci. 1996; 121 (6), 1082–1088.

[92] Adamicki F., Dyśko J., Nawrocka B., Ślusarski C., Wysocka-Owczarek M. Methodology of Integrated Production of Tomatoes under Cover. Warszawa: PIORIN; 2005 (in Polish).

[93] Oyinlola EY. Distribution of boron and its uptake in the plants parts of two tomato varietes. Chem. Class J. 2005; 2, 77–80.

[94] Piróg J., Komosa A. Influence of substrate and cultivar on quantity and quality of greenhouse tomato yield. Acta Agrophys. 2006; 7 (3), 699–707 (in Polish).

[95] Breś W., Golcz A., Komosa A., Kozik E., Tyksiński W. Horticulture plant nutrition. Wydawnictwo UP; 2009. Poznań. (In Polish).

[96] Markiewicz B., Bosiacki M., Kleiber T. Effect of boron fertigation on yield and nutrientcontent of lettuce grown (*Lactuca sativa* L.) in the closed fertigation system with recirculation of the nutrient solution. ABiD 2013; 4: 318 – 322, 2013.

[97] De KreijC., SonneveldC., WarmenhovenM.G., StraverN. Guide values for nutrient element contents of vegetables and flowers under glass. Voedingsoplossingen Glastuinbouw 1990; 23.

[98] Garate A.J., Carpena-Ruiz R.O., Ramon A.M. Influence of boron on manganese and other nutrients in tissues sets of conductors . Annals of Soil Science and Agricultural Biology1984, 43: 1467–1477.

[99] Gupta UC. Boron nutrition of crops. Adv. Agron. 1979; 31, 273–305.

[100] Roth AJ., Garrick MD. Iron interactions and biological interactions mediating the physiological ant toxic actions of manganese. Biochem. Pharmocol. 2003; 66, 1–13.

[101] TomaszewskaB. Boron in Groundwater and Waste Dump Leachates. Technika Poszukiwań Geologicznych Geotermia, Zrównoważony Rozwój; 2010, 161–171 (in Polish).

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