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EFFECT OF MANGANESE NUTRITION ON CONTENT OF NUTRIENT AND YIELD OF LETTUCE (*Lactuca sativa* L.) IN HYDROPONIC

WPŁYW ŻYWIENIA MANGANEM NA ZAWARTOŚĆ SKŁADNIKÓW I PLONOWANIE SAŁATY (*Lactuca sativa* L.) W HYDROPONICE

Abstract: The aim of conducted studies was estimation of increase manganese nutrition on content of nutrient and yielding of lettuce (*Lactuca sativa* L.) in hydroponic cultivation. Plants were grown in rockwool using closed system fertigation with recirculation of nutrient solution. In experiment were used nutrient solution with following nutrient contents [mg·dm^{-3}]: N-NH_4 < 10, N-NO_3 150, P-PO_4 50, K 150, Ca 150, Mg 50, Fe 3.00, Zn 0.44, Cu 0.03, B 0.011, pH 5.50, EC 1.8 mS·cm^{-1}. It was studied the following manganese concentrations in nutrient solution (in [mg·dm^{-3}]): 0.5, 4.8, 9.6, 19.2 (described as Mn-I, Mn-II, Mn-III and Mn-IV). It was found a significant influence of increasing manganese concentration applied in fertigation on the content of: N, K (for Mn-IV); P, Fe, Cu (for Mn-III and Mn-IV); Mg, Zn (for Mn-II to Mn-IV) in aboveground parts of lettuce. It was no differences in case of calcium and sodium content. Increasing concentration of manganese used to fertigation significantly influenced the content of Mn in plants. Manganese also affected on the SPAD measurement (decreasing at Mn-IV) and yielding of the plants (decreasing for Mn-II to Mn-IV comparing with Mn-I).

Keywords: lettuce, manganese, macroelements, microelements

Introduction

Important factor influence on plant performance in modern plant production is water quality [1, 2]. Most of the groundwater to a depth of 100 meters contain no more than 0.5 mg Mn·dm^{-3} [3], however sometimes water may contain up to 10 mg Mn·dm^{-3} [4]. It is known, that about 5% of water used to prepare of nutrient solution contain from 1 to 4.5 mg Mn·dm^{-3}. Real huge problem in environment cause of nutrient losses from open fertigation systems under cover, both tunnels or greenhouses [5, 6]. One of the factor influences on contamination of groundwater in manganese are nutrient discharge from open fertigation systems. Estimated ranges of manganese discharges depended on species and range from 0.01-0.02 kg·ha^{-1} (in case of anthurium) to 0.05-1.20 kg·ha^{-1} (in case of tomato) [5, 6]. Important problem is also salinity of groundwater and deterioration of their quality. Mentioned fact was a one of reason to conducted studies concentrated on the influence of

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salinity in plant production. In case of lettuce a lot of studies have focused on this problem [7-12].

Manganese causes a significant oxidative stress for plants [13]. This microelement also significantly influence on the uptake of other nutrients like phosphorus, potassium, calcium, magnesium, iron, zinc, copper [14-20]. The aim of conducted studies was effect of increase manganese in the nutrient solution on content of nutrient and yielding of lettuce (*Lactuca sativa* L.) in hydroponic cultivation.

Material and methods

Vegetation experiments were carried out from March to May in 2012-2013 year in a greenhouse located in the area of the Experimental Station of Departments of the Faculty of Horticulture and Landscape Architecture University of Life Sciences in Poznan. The aim of conducted studies was effect of increase manganese in the nutrient solution on content of nutrient, growth and yield of lettuce (*Lactuca sativa* L.) in hydroponic cultivation.

The experiments were established using the randomized complete block design in 3 replications with used of butterhead lettuce (*Lactuca sativa* L.) cv. 'Sunny'. One replication consisted of 3 plants. Studies were conducted on 36 plants (4 combinations × 3 replications × 3 plants per replication).

3 weeks before vegetation experiment seedlings were prepared. The seeds were sowed individually to rockwool fingers, which 48h before fill up the nutrient solution. Seedlings (in 3-4 leaves phase) were put in the fill of nutrient solution rockwool blocks (10 x 10 x 10 cm). After 1 week seedling were placed in a special hydroponic model with closed fertigation system (ATAMI Wilma). Nutrient solutions were dose 6 times daily per 5 minutes in each cycle. Nutrient solution leaching from the root zone were collected to tank located bellow the plants and used again to their nutrition.

Plants were grown in rockwool using closed system fertigation with recirculation of nutrient solution. Water, on the basis of which the nutrient solution was prepared, contained [$mg \cdot dm^{-3}$]: $N\text{-}NH_4$ - tr. (traces), $N\text{-}NO_3$ - 3.7, $P\text{-}PO_4$ - 0.3, K - 1.8, Ca - 57.3, Mg - 13.4, $S\text{-}SO_4$ - 58.3, Fe - 0.08, Mn - 0.08, Zn - 0,44, B - 0.01, Cu - tr., Mo - tr., HCO_3 - 277.5, pH - 7.00, EC - 0.74 $mS \cdot cm^{-1}$. In experiment were used a nutrient solution with following nutrient contents [$mg \cdot dm^{-3}$]: $N\text{-}NH_4 < 10$, $N\text{-}NO_3$ 150, $P\text{-}PO_4$ 50, K 150, Ca 150, Mg 50, Fe 3.00, Zn 0.44, Cu 0.03, B 0.011, pH 5.50, EC 1.8 $mS \cdot cm^{-1}$. It was studied the following manganese concentration in nutrient solution (in [$mg \cdot dm^{-3}$]): 0.5, 4.8, 9.6, 19.2 (described as: Mn-I, Mn-II, Mn-III and Mn-IV).

To prepare nutrient solutions there were used following fertilizers: potassium nitrate (13% $N\text{-}NO_3$, 38.2% K), calcium nitrate (14.7% $N\text{-}NO_3$, 18.5% Ca), monopotassium phosphate (22.3% P, 28.2% K), potassium sulphure (44.8% K, 17% S), magnesium sulphure (9.9% Mg, 13% S), Librel FeDP7 (7% Fe), manganese sulphate (32.3% Mn), copper sulphate (25.6% Cu), borax (11.3% B) and sodium molibdate (39.6% Mo). To regulated pH values there were used nitric acid (38%). Using N-Tester apparatus by Yara the Chlorophyll index (SPAD) was determined in case of the highest leaves on the plants.

To chemical analyses were collected the aboveground parts of plants. Collected material dried at 45-50ºC and then ground. In order to assay total forms of nitrogen, phosphorus, potassium, calcium, magnesium and sodium plant material was mineralized in concentrated sulfuric acid, while for analyses of total iron, manganese, zinc and copper - in a mixture of nitric and perchloric acids (3:1, v/v) [21]. After mineralization of plant material the following determinations were performed: N-total using the distillation method according to Kjeldahl in a Parnas-Wagner apparatus; P, colorimetrically with ammonia molybdate; K, Ca, Mg, Na, Fe, Mn, Zn, Cu using atomic absorption spectroscopy (ASA, on a Carl Zeiss Jena apparatus). Results of chemical analyses of plants were analyzed statistically using the Duncan test ($\alpha = 0.05$).

Results and discussion

Macroelement and sodium content. It was found a stable content of **nitrogen** and **potassium** (without significant differences) within range from Mn-I to Mn-III (Fig. 1). Significantly decreasing of mentioned nutrient were recorded only in case of Mn-IV. According with increasing of manganese nutrition was found decreasing trend of **phosphorus** content in lettuce leaves. Increasing manganese nutrition did not influence significantly in **calcium** (it was decreasing trend, but no significant) and **sodium** content. Higher than optimal concentration of manganese applied in nutrient solution (Mn-II to Mn-IV) significantly decreased the magnesium content in leaves.

Microelement content. Decreasing trend of metallic microelement content (except Mn) was found (Fig. 2). In case of **iron** and **copper** nutrition of lettuce at level of Mn-III and Mn-IV significantly decreased the content of mentioned ion comparing with Mn-I and Mn-II (for Fe) and Mn-I (for Cu). Increasing content of manganese significantly decreased the **zinc** content in leaves. In conducted studies was found significant and positive plants reaction on increasing nutrition of **manganese**. Increasing manganese nutrition significantly decreasing **chlorophyll content** (express in result of SPAD reading) in leaves. Excessive nutrition with manganese significantly reduced the plants yielding (in case from Mn-II to Mn-IV, comparing with Mn-I).

Generally determined content of **nitrogen** in leaves were similar like cited in literature [7, 22-24] (Table 1).

Table 1

The content of macroelements [%] in lettuce leaves according other authors

Source	N	P	K	Ca	Mg
Abou-Hadid et al [7]	3.54-4.21	0.97-0.98	7.24-8.20	-	-
Markiewicz and Kleiber [10]	3.18-3.54	0.37-0.63	4.4-9.04	1.39-1.52	0.62-0.69
Gül et al [22]	3.72-4.16	0.29-0.38	4.58-7.10	1.73-2.07	0.27-0.40
Karimaei et al [23]	1.57-4.23	0.18-0.39	4.6-8.9	-	-
Kleiber et al [24]	4.04-5.21	0.74-1.07	8.15-9.16	1.37-1.39	0.75
Jarosz and Dzida [25]	4.97-5.84	0.38-0.43	6.54-7.70	1.00-1.21	0.33-0.39
Matraszek et al [26]	-	0.93-4.08	1.74-2.58	0.30-0.44	0.50-0.63

Lower content of that ion was also found [10] - were authors studied the EC level of nutrient solution in lettuce cultivation. Higher content of nitrogen was determined in case of lettuce cultivation in organic medium [25] - authors found a significant and positive effect on potassium nutrition on the nitrogen content in lettuce. On the content of N, P, K in lettuce tissue significant influence the nutrition level [24].

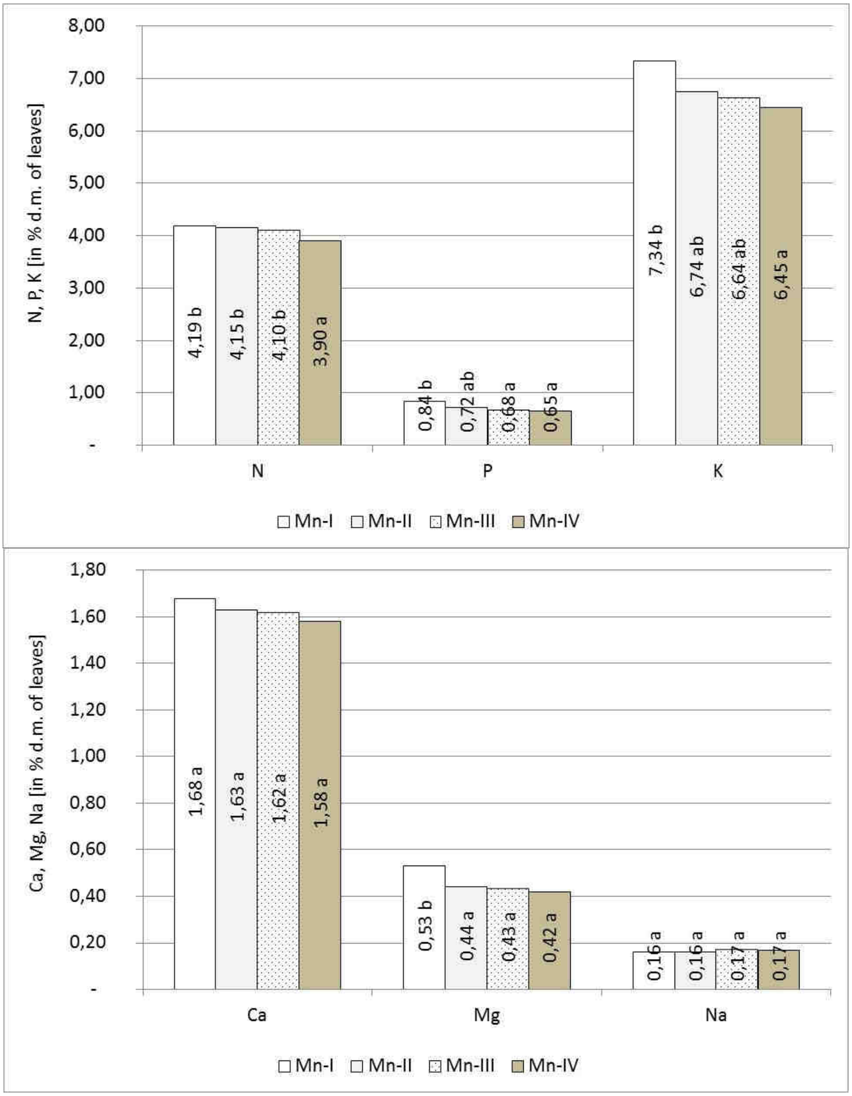

Fig. 1. The influence of manganese nutrition on nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) content (in % d.m. of leaves; means from 2 years). Description for Figures 1, 2: Values marked with the same letter do not differ statistically at $\alpha = 0.05$

Determined content on **phosphorus** in lettuce tissues were varied. In my studied it was found range between 0.65-0.82% P. Most of authors found lower content of that macroelement [10, 22, 23]. Higher content of phosphorus was found by authors studied the EC effect [7] and nickel nutrition [26] in lettuce cultivation. Content of **potassium** in leaves of lettuce were similar to described by many authors [7, 22-24]. Lower content of that ion was found by in case of Ni nutrition [26] while higher in case of lettuce cultivation under the light stress [24]. Wider range of potassium content was recorded in studies concentrated on the effect of salinity in lettuce growing [10].

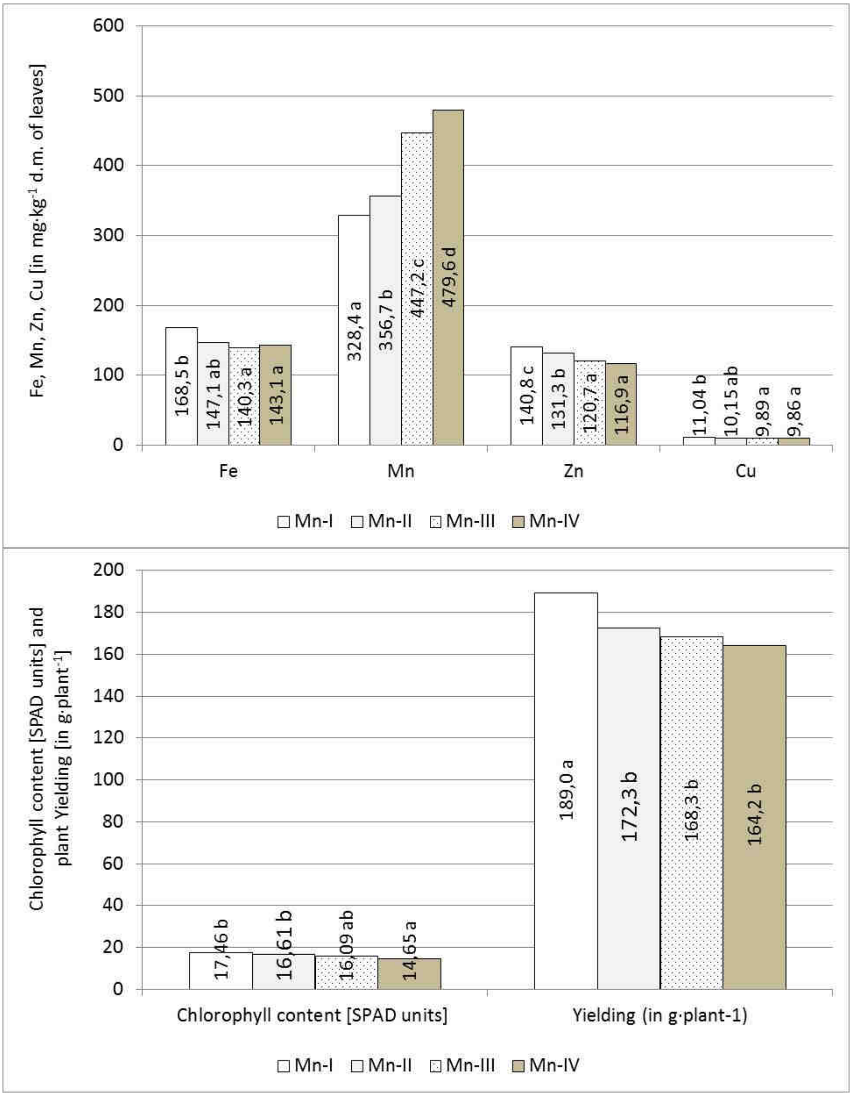

Fig. 2. The influence of manganese nutrition on iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) content (in mg·kg^{-1} d.m. of leaves; mean from 2 years) also SPAD measurement (SPAD units) and yielding of lettuce (in g·plant^{-1})

Content of **calcium** cited in literature are different than in my studies. Higher content of that ion was described in paper of scientists [22] tested the effect of growing media. Most of cited source [10, 23, 24, 26] cited lower content of calcium in leaves of lettuce. Calcium is an important nutrient protects plants against tip-burn. It is known that the reduction of the content of calcium below the above optimal value (1% Ca) may have influence on the appearance of physiological perturbation on plants [27-29]. Significant factor influence on the content of calcium in lettuce is potassium nutrition [25]. **Magnesium** is an essential component of chlorophyll, and the correct nutrient status of plant in Mg affected by, inter alia, on the rate of photosynthesis [30]. Determined by other authors content of Mg in lettuce are varied. Some researchers found lower [22, 25], while some of scientist higher [10, 24, 26].

In conducted studies was found a significant effect on manganese nutrition on **iron** content. In earliest studies prove a significant influence of nickel nutrition on the content of Fe in lettuce [26]. In case of cultivation in organic medium the significant factor influenced on the content of iron is form of that ion (mineral or organic) [31]. It was found that Increasing doses of manganese did not exert any effect on the content of iron in the lettuce cultivation in organic medium [32]. Determined content of that microelement were similar to those cited in literature [9, 33]. Lower content of iron was also determined [22, 26, 34]. Higher content of Fe was also found too [7].

Table 2

The content of microelements [mg·kg^{-1}] and sodium [%] in lettuce according other authors

Source	**Fe**	**Mn**	**Zn**	**Cu**	**Na**
Abou-Hadid et al [7]	821.0-838.8	115.1-119.8	60.8-83.0	23.6-32.5	-
Gül et al [22]	91.2-126.5	42.92-66.22	60.86-75.57	4.44-8.33	-
Hakerlerler et al [34]	55.9	22.0	30	5	-
Kleiber and Markiewicz [9]	133.8-244.8	34.9-100.2	146.7-218	5.90-10.53	0.24-0.57
Kleiber et al [24]	-	-	-	-	0.24-0.59
Kozik et al [31]	149.1-193.4	174.4-346.8	110.7-187.3	14.3-27.9	-
Kozik et al [32]	185.7-193.3	233.3-342.2	148.5-162.7	12.42-13.49	
Matraszek et al [26]	76.9-96.0	14.1-43.7	73.9-120.2	5.33-8.26	-
Winsor and Adams [33]	50-200	-	-	5-15	-

Determined content of **manganese** (even in case of Mn-I) were higher than cited by other authors [7, 22, 26, 31, 32, 34]. Cited content of **zinc** in lettuce leaves are varied. Lower content of that metal was found in many studies [7, 22, 26, 34] also higher content too [32, 33]. Assay of this nutrient are in the range given by Kozik et al [31]. Determined content of **copper** are lower that recorded by other authors [7, 31, 32]. Lower content of Cu was also found [22, 26, 34]. Assay of this nutrient are in the range given earlier [33]. There are few sources cited the content of **sodium** in lettuce. Determined content of that ion were lower that found by others [9, 24].

With the increase in the content of chlorophyll in leaves is increased by the absorption of light [35]. The use of the absorption bands of light is not destructive method to estimate leaf chlorophyll content [36, 37]. The relationship between measurements and SPAD chlorophyll is extracted characteristic and specific for different plant species [37]. There is a significant and positive correlation (R^2 0.85-0.92) between SPAD value and the content of total chlorophyll and chlorophyll a and chlorophyll b in case of lettuce [38]. In conducted studies increasing manganese nutrition significantly decreasing chlorophyll content (SPAD values). It was also found a lowering trend of SPAD under the salinity stress [7]. Opposite, increasing trend of SPAD was found in other studies [12]. The relationship between the SPAD and the leaf chlorophyll content was found in the case of other species [39-41].

In case on philodendron nutrient status with macroelements significantly influence on SPAD value [37]. In lettuce cultivation was found a significant influence of salinity [10] also the light condition [42] on the chlorophyll content. In the literature, examples are given increase in the content of chlorophyll in plants grown under stress conditions such as aqueous [43]. It was also shown a negative correlation between SPAD index and the rate of photosynthesis - which suggests that no amount of chlorophyll, but its photosynthetic activity determines the intensity of the process. Chlorophyll in plants can serve other functions such as protection - in the case of stress caused by adverse external factors [43].

Manganese is antagonistic ion in relation to iron and calcium [44] and potassium, magnesium, zinc and copper [16, 20, 45, 46]. This microelement reduced also content other metallic microelements in plants [19]. Conducted studies confirm decreasing content in case of mentioned nutrient except of calcium where found no significantly differences under the increasing manganese nutrition. Excess manganese may reduce magnesium uptake by as much as 50% [14]. In conducted studies content of magnesium was lower about 20.7% (comparing Mn-I do Mn-IV). Manganese may have a negative effect on the uptake of potassium and phosphorus [15] what was found in my studies. In spite of significant changes of macro-, microelements and sodium content on the plants were no visual symptoms of manganese toxicity.

Conclusions

Based on conducted studies one can say the increasing manganese concentration applied in fertigation may significantly influence on plant nutrient status, both macro- like micronutrients. It was found that within studied Mn range of nutrition decreasing content in leaves of: N, K (significant only for Mn-IV); P, Fe, Cu (significant for Mn-III and Mn-IV); Mg, Zn (significant from Mn-II to Mn-IV). Content of calcium (in spite of decreasing tendency) and sodium in leaves was stable. Increasing concentration of manganese used to fertigation significantly changed the Mn status of plants. Manganese significantly decreased the SPAD measurement (at Mn-IV) and plants yielding (Mn-II to Mn-IV comparing with Mn-I). In spite of significant decreasing of plant yielding there were no visual symptoms of manganese toxicity present on the leaves.

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WPŁYW ŻYWIENIA MANGANEM NA ZAWARTOŚĆ SKŁADNIKÓW I PLONOWANIE SAŁATY (*Lactuca sativa* L.) W HYDROPONICE

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Abstrakt: Celem przeprowadzonych badań była ocena wpływu wzrastającego żywienia manganem na zawartość składników pokarmowych i plonowanie sałaty (*Lactuca sativa* L.) w uprawie hydroponicznej. Rośliny uprawiano w wełnie mineralnej z zastosowaniem układu zamkniętego z recyrkulacją pożywki. W doświadczeniach stosowano pożywkę o następującej zawartości składników pokarmowych [$mg \cdot dm^{-3}$]: N-NH_4 < 10, N-NO_3 150, P-PO_4 50, K 150, Ca 150, Mg 50, Fe 3,00, Zn 0,44, Cu 0,03, B 0,011, pH 5,50, EC 1,8 $mS \cdot cm^{-1}$. Badano następujące poziomy żywienia manganem w pożywce [$mg \cdot dm^{-3}$]: 0,5, 4,8, 9,6, 19,2 (opisane jako Mn-I, Mn-II, Mn-III i Mn-IV). Wykazano istotny wpływ wzrastających stężeń manganu stosowanego w fertygacji na zawartość w częściach nadziemnych sałaty: N, K (dla Mn-IV); P, Fe, Cu (dla Mn-III i Mn-IV); Mg, Zn (dla Mn-II do Mn-IV). Nie stwierdzono różnic w przypadku zawartości wapnia i sodu. Wzrastające stężenia manganu stosowanego w formie fertygacji silnie wpływały na zawartość tego składnika w roślinach. Mangan oddziaływał także na odczyt SPAD (obniżenie dla Mn-IV) i plonowanie roślin (obniżenie dla Mn-II - Mn-IV w porównaniu z Mn-I).

Słowa kluczowe: sałata, mangan, makroskładniki, mikroskładniki