APARATURA
BADAWCZA I DYDAKTYCZNA

The effect of choline-stabilized orthosilicic acid application under Mn excessive nutrition on yielding of hydroponically grown lettuce (*Lactuca sativa* L.)

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Keywords: manganese, choline-stabilized orthosilicic acid, lettuce, nutrient status, yielding

ABSTRACT

The aim of the study was the evaluation of different concentrations of silicon effect and high levels of manganese in the nutrient medium on the yielding and nutrient status of hydroponically grown lettuce cv. 'Sunny'. Plants were grown in rockwool in closed fertigation system with nutrient solution recirculation. The following levels of silicon were studied: 0.21, 0.42 and 0.63 $mg \cdot dm^{-3}$. The source of silicon was fertilizer contain choline-stabilized orthosilicic acid (ch-OSA) (0.6% Si). Control combination was plants without Si nutrition. Silicon nutrition significantly influenced on content of macroelements in aboveground parts of plant: decreasing of nitrogen (for 0.21 and 0.63 mg $Si \cdot dm^{-3}$), increasing of: phosphorus (for 0.42 and 0.63 mg $Si \cdot dm^{-3}$), potassium (for 0.21 and 0.42 mg $Si \cdot dm^{-3}$), calcium (for all the Si-treatment) and magnesium (only for 0.21 mg $Si \cdot dm^{-3}$) comparing with control. In case of microelements Si significantly reduced zinc content (only in case 0.63 mg $Si \cdot dm^{-3}$) and iron (for all the Si-treatment), with lack of significantly influence in case of manganese, copper and sodium. Increasing silicon nutrition significantly and positively influenced on plant yielding.

Wpływ stosowania stabilizowanego choliną kwasu ortokrzemowego w warunkach nadmiernego żywienia manganem na plonowanie uprawianej hydroponicznie sałaty (*Lactuca sativa* L.)

Słowa kluczowe: mangan, stabilizowany choliną kwas ortokrzemowy, sałata, stan odżywienia, plonowanie

STRESZCZENIE

Celem badań była ocena wpływu zróżnicowanych stężeń krzemu i wysokiego poziomu manganu w pożywce na plonowanie i stan odżywienia uprawianej hydroponicznie sałaty odm. 'Sunny'. Rośliny uprawiano w wełnie mineralnej z zastosowaniem fertygacji w systemie zamkniętym z recyrkulacją pożywki. Badano następujące poziomy krzemu: 0,21, 0,42 i 0,63 mg·dm^{-3}. Źródłem krzemu był nawóz zawierający stabilizowany choliną kwas ortokrzemowy (ch-OSA) (0,6% Si). Kombinacją kontrolną były rośliny nie żywione krzemem. Żywienie krzemem wpływało istotnie na zawartość makroskładników w nadziemnych częściach roślin: obniżenie azotu (0,21 i 0,63 mg Si·dm^{-3}), wzrost zawartości: fosforu (0,42 i 0,63 mg Si·dm^{-3}), potasu (0,21 i 0,42 mg Si·dm^{-3}), wapnia (wszystkie kombinacje z Si) i magnezu (tylko 0,21 mg Si·dm^{-3}) w porównaniu z kontrolą. W przypadku mikroskładników Si istotnie obniżał zawartość cynku (tylko dla 0,63 mg Si·dm^{-3}) i żelaza (wszystkie badane kombinacje), przy braku istotnego wpływu na zawartość manganu, miedzi i sodu. Wzrastające żywienie krzemem istotnie i pozytywnie wpływało na plonowanie roślin.

1. INTRODUCTION

Mn phytotoxicity is observed in a reduction of biomass and photosynthesis, and biochemical disorders like oxidative stress [1]. Previous studies have shown that silicon increases the tolerance of plants to manganese stress, and not on the reduction of uptake. Silicon (Si) was classified as an essential for some plant or very often beneficial element [2], which may also influence positively on plant growth and yielding [3-7], especially under different stress conditions [2, 8] f.e. cause by heavy metal phytotoxicity [9, 10]. Silicon enhances also resistance of plants to diseases caused by both fungi and bacteria [11, 12]. So far, research into the use of silicon as a mitigating stress manganese ion in the case of: beans [13], barley [14], cucumber [15, 16], rice [17, 18] or horsegram serpentine [19, 20].

Silicon nutrition may significantly influence on nutrient uptake by plants [2, 7, 9, 21], but earliest studies there were conducted on different species than lettuce grown under Mn stress. The aim of present studies was the effect of Si application under Mn excessive nutrition on content of macro- and microelements in leaves and yielding of hydroponically grown head lettuce (*Lactuca sativa* L.).

2. MATERIAL AND METHODS

Vegetation experiment was carried out from March to May in a specialist culture greenhouse equipped with the modern climate control system and energy-saving curtain systems, 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 study was response of hydroponically grown head lettuce (*Lactuca sativa* L. cv. 'Sunny') on silicon application under excessive Mn nutrition. There were studies 4 combinations: control + 3 levels of silicon nutrition. The experiments were established using the randomized complete block design in 8 replications (replication was one single plant).

Seedlings were prepared 3 weeks before the vegetation experiment. The seeds were sown individually to rockwool fingers, which 48h before fill up the nutrient solution (NS). Seedlings (in 3-4 leaves phase) were put in the rockwool blocks (10 x 10 x 10 cm) which were full of NS. After 1 week seedlings were placed in a special hydroponic model with a closed fertigation system (ATAMI Wilma). A model growing system consists of a covered tank which is filled with 70 liters of NS prior to planting. NS were dosed 6 times daily per 5 minutes in each cycle. Solution leaching from the root zone were collected in a tank located bellow the plants and used again for their nutrition. For plant fertigation was used NS with the following chemical composition (mg·dm^{-3}): N-NH_4<10, N-NO_3 150, P-PO_4 50, K 150, Ca 150, Mg 50, Fe 3.00, Mn 19.2, Zn 0.44, Cu 0.03, B 0.01, pH 5.50, EC 1.8 mS·cm^{-1}. The following levels of silicon nutrition were studied: 0.21, 0.42 and 0.63 mg·dm^{-3} of NS (denotes as Si-I, Si-II and Si-III). Control combination was cultivation without Si nutrition. The source of silicon was fertilizer contain choline-stabilized orthosilicic acid (ch-OSA) (0.6% Si; Actisil, Yara). During the whole period of the experiment a medium temperature of 17-18°C was maintained.

For chemical analyses the aboveground parts from all the plants grown within each combination were collected. The plant material was dried at 45-50°C and then ground. In order to assay the total forms of nitrogen, phosphorus, potassium, calcium, magnesium and sodium the 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) [22]. 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 (FAAS, on a Carl Zeiss Jena apparatus). Results of chemical analyses and plant yielding were carried out by Anova and Duncan test (α = 0.05).

3. RESULTS AND DISCUSSION

3.1 Macroelements

Silicon applied in nutrient solution under excessive manganese nutrition significantly modified chemical composition of plants with macroelements (Fig. 1). At level of Si-I and Si-III were recorded significantly decreasing of nitrogen content while in case of Si-II increasing above control level. Against did not find a silicon influence of nitrogen content in cucumber leaves [7]. Si fertilization may significantly influence on phosphorus status of plants [2, 21]. In described studies at level Si-II and Si-III was found significantly increased the content of phosphorus comparing with control and Si-I combination. Plant treatment of silicon (for Si-I and Si-II) caused significantly increasing content of potassium in leaves comparing with control and Si-III combination. Opposite trend of potassium content was found by Jarosz [7]. In conducted studies there was found a significantly increasing of calcium content caused by Si nutrition. The highest content of that nutrient, similar like in case potassium, was determined for Si-I. Other authors [2, 7, 23] found an opposite trend of calcium content under silicon nutrition. Only in case of Si-I were recorded significant influence of Si on magnesium content. A significant influence of silicon nutrition was found early in case of cucumber [7].

3.2 Microelements

Silicon nutrition significantly reduced the iron content in leaves (Fig. 2). Level of Fe was lower in case of Si-I and Si-III comparing with Si-II. In cucumber leaves the content of iron was changeable and depended on the level of Si [7] – but in spite of that determined contents did not differed significantly. In conducted studies plants were grown under excessive manganese nutrition (19.2 mg Mn·dm^{-3} of NS) which significantly decreasing yielding of lettuce [24] but without visual symptoms on the plants. Silicon nutrition did not influence significantly on the manganese plants status. In cucumber cultivation there was found a positive effect in case the smallest dose of Si – the highest did not differed significantly manganese status [7]. Decreasing trend of manganese in cucumber tissues caused by Si nutrition was also found by Maksimović et al. [25]. The most intensive Si nutrition (at Si-III) significantly reduced the zinc content. Similar decreasing trend of zinc content in plants under Si nutrition was also found [7]. Silicon nutrition did not influence on copper content. These results positive corresponded with Jarosz [7] which didn't found a significant differences in copper content in cucumber leaves under increasing silicon nutrition.

In spite of decreasing of yielding cause by excessive Mn nutrition (19.2 mg·dm^{-3}) [24] on the plants were not observed toxic symptoms on the leaves. The content of silicon in nutrient solution recommended to commercial plant cultivation in case of fertilizer contain orthosilic acid is 0.3 mg Si·dm^{-3}. In conducted studies there were studies wider ranges of that nutrient (0.21-0.63 mg Si·dm^{-3}). Silicon nutrition significantly improved plant yielding – for every Si-combination yielding was higher than in control (Fig. 3). In case of the most intensive silicon nutrition yielding of plants

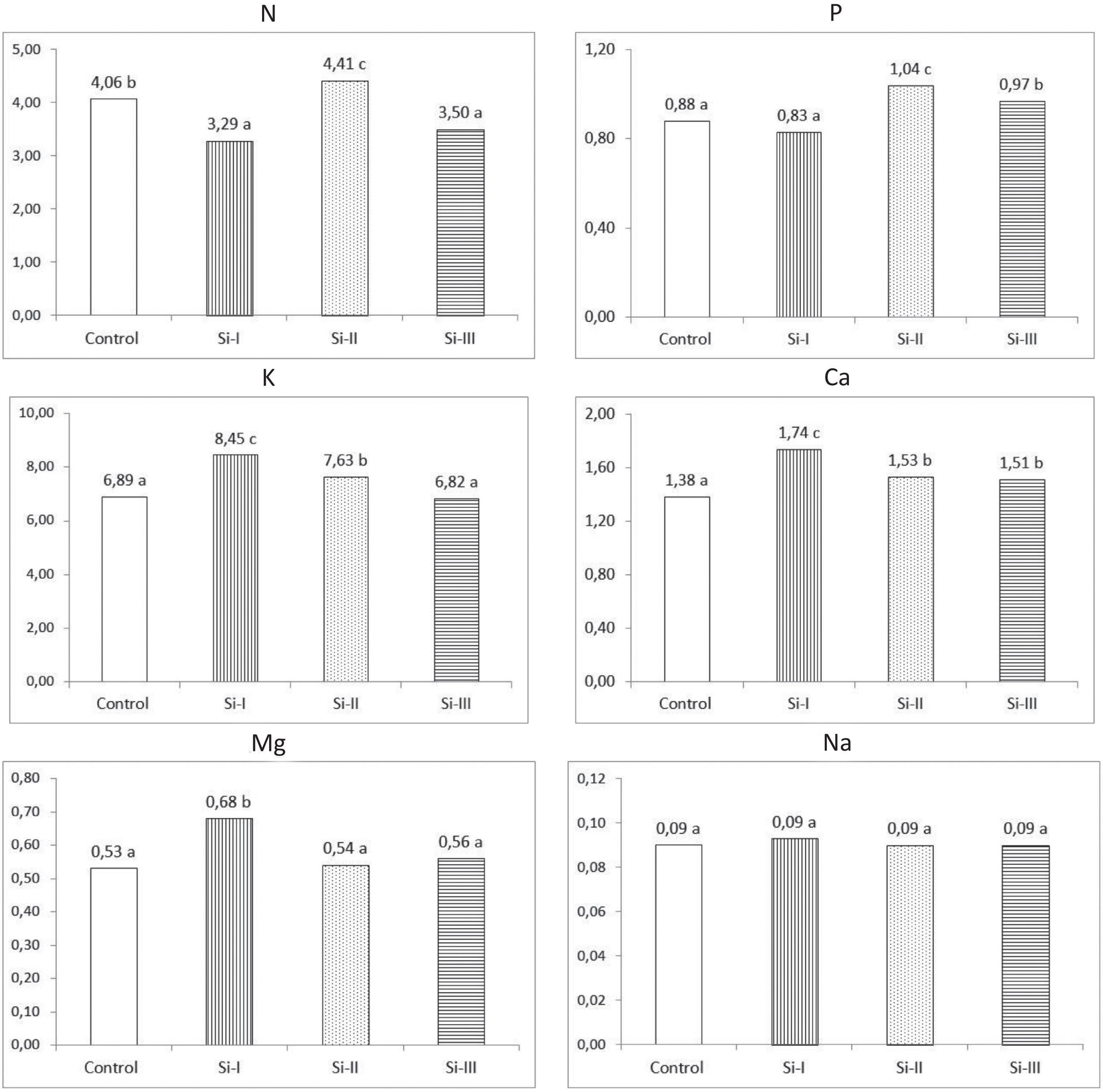

Figure 1 The effect of Si nutrition on macroelements and sodium content of in lettuce (% in d.m. of leaves)
Rysunek 1 Wpływ żywienia krzemem na zawartość makroskładników i sodu w sałacie (% w s.m. liści)

For Figs. 1-3: Values described with identical letters do not differ significantly at α = 0.05;
Wartości opisane tymi samymi literami nie różnią się od siebie istotnie przy α=0,05

was higher about 19.4% comparing with control combination. Positive effect of silicon nutrition (the same source of Si like in described studies) on plant yielding under manganese stress was found by author in preliminary studies in case of tomato – plants response depend on cultivar and Mn concentration in NS and in case of lettuce use silica sol as a source of Si (unpublished data). Positive effect of silicon nutrition was early found also by other authors [3, 5, 15, 18, 26]. The key mechanisms of Si-mediated alleviation of abiotic stresses in higher plants is very complicated [8] and includes inter alia: stimulation of antioxidant systems in plants or complexation or co-precipitation of toxic metal ions with Si.

In conducted studies in lettuce cultivation was found significantly alleviate of excessive manganese nutrition after increasing ch-OSA concentration applied in form of fertigation. Similar phenomenon was found also in other studies. One

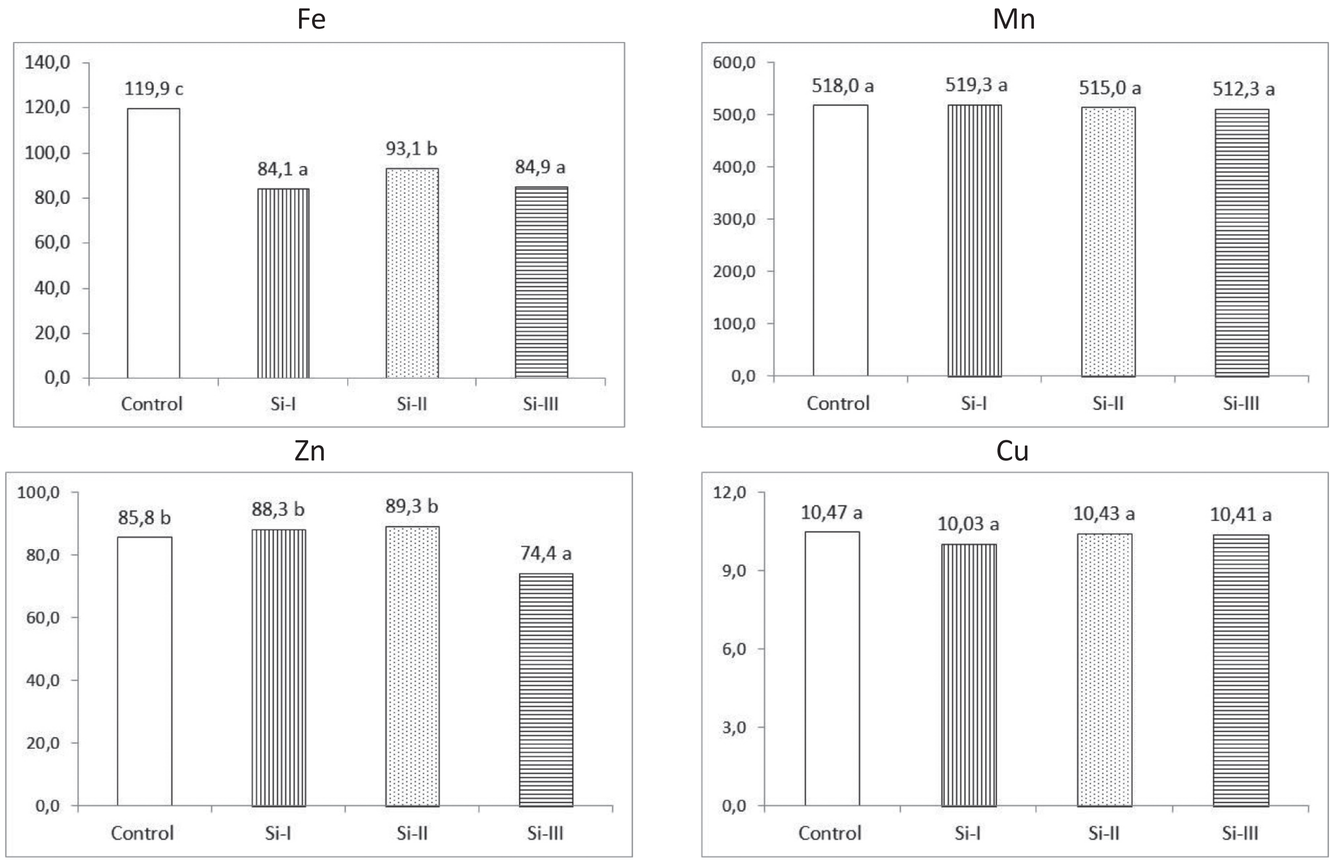

Figure 2 The effect of Si nutrition on microelements content in lettuce (in mg·kg^{-1} d.m. of leaves)

Rysunek 2 Wpływ żywienia krzemem na zawartość mikroskładników w sałacie (w mg·kg^{-1} s.m. liści)

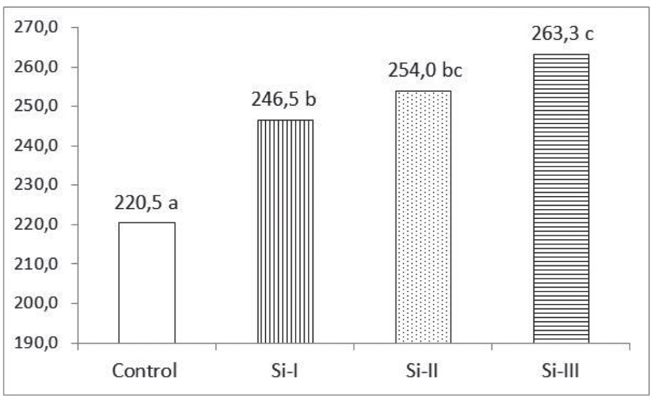

Figure 3 The effect of silicon nutrition on plant yielding (in g·plant^{-1})

Rysunek 3 Wpływ żywienia krzemem na plonowanie roślin (w g·roślina^{-1})

of positive symptoms of Si nutrition under Mn-stress is increasing the biomass production [16]. Horiguchi [17] reported that in a result of silicon application increasing the internal tolerance to an excessive amount of Mn in the tissues with simultaneous decreasing content of that microelement in plant. Si-treated plants contain less Mn located in the symplast (<10%) and more Mn bounded to the cell wall (>90%) compared with non-Si-treated plants (about 50% in each compartment) [15]. In a result manganese present in Si-treated plants was less available and for this reason less toxic than in plants no Si-treated. Alleviation of Mn toxicity by silicon in cucumber was attributed to a significant reduction in membrane lipid peroxidation which reason was excess Mn and to a significant increase in enzymatic (e.g. SOD, APX, DHAR and GR) and non-enzymatic antioxidants (e.g. ascorbate and glutathione) [27]. Gunes et al. [28] proved that Si alleviates B toxicity of wheat by preventing oxidative membrane damage and also translocation of B from root to shoot and/or soil to plant. Si alleviation of Cd toxicity by attributed to the decrease in Cd concentration in shoot and stimulation of antioxidants systems [10]. Si nutrition of melon influenced positively on the content of chlorophyll and reduced transpiration rates compared with untreated plants [29].

Similarly like in described study application of Si under manganese stress did not influence on the content of Mn aboveground parts of cucumber [16], with significantly decreasing content of that microelement in roots. Source and concentration of silicon significantly influenced on plant yielding [30]. In described studies the source of silicon was choline-stabilized orthosilicic acid. Si is taken up by the roots in the form of silicic acid an uncharged monomeric molecule (pH of solution <9) [4, 31]. Rogalla and Römheld [15] claimed that supplied sodium silicate decreased symptoms of manganese toxicity in *Cucumis sativus* L. grown in hydroponic. Górecki and Danielski-Busch [6] claimed that slow-release Ca- and NH_4-silicates contributed to increased yield and elevated Si content in cucumber leaves and fruits. Positive effect of silicon application in form of potassium silicate on the content of chlorophyll in cucumber leaves was also found [32]. Silicon fertilizers are one of the effective sources in increase of growth and yield in rice farms [27]. Henriet et al. [33] claimed that content of Si in plant tissue increasing with concentration of that ion with nutrient solution. Mentioned authors found a significantly influence of Si on uptake of potassium and calcium by banana.

Application of silicon may be one approach to improve growth of maize increase its production in arid or semi-arid areas but would not fully substitute for an adequate water supply [34]. Water stress reduced content of: calcium and potassium of maize (*Zea mays* L.) leaves, but addition of Si increased these nutrient levels. Positive influence of silicon nutrition on the content of that nutrient in plant was confirmed.

The analysis of the results obtained in the present study showed increasing content of potassium (for Si-I and Si-II) and calcium (for all the Si treatment) comparing with control. Fruits of cucumber Si-treated contained lower content of zinc and copper, with simultaneous higher content of dry matter [7]. Leaves of Si treated plants were characterized by lower calcium level comparing with control combination. In case of lettuce was significantly decreasing of zinc (for Si-III) with no differences in case of copper content. In rice was found decreasing content of nitrogen, potassium, iron and manganese with simultaneously increasing content of calcium and magnesium after Si nutrition [21]. Decreasing content of P in aboveground parts of plant Si-treated could be explaining that trend by the ion competition [4].

4. CONCLUSIONS

1. Application of choline-stabilized orthosilicic acid in nutrient solution modified significantly content of macroelements in aboveground parts of plants.
2. Silicon nutrition significantly reduced zinc content (only in case 0.6 mg Si·dm^{-3}) and iron (for all the Si-treatment) in leaves comparing with control with simultaneous lack of influence in case of manganese, copper and sodium.
3. Silicon in form of choline-stabilized orthosilicic acid applied in nutrient solution significantly improved yielding of plants grown under manganese stress.

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