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AFTER EFFECT OF IRON CHELATES ON THE YIELDING AND IRON CONTENT IN GREENHOUSE LETTUCE

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Abstract. In the years 2005 and 2006, spring and autumn experiments were carried out with greenhouse lettuce 'Michalina' cultivar, which was fertilized with three iron chelates, i.e.: Fe-DTPA, Fe-EDTA+DTPA, Fe-AM-4 in the following doses (mg Fe·dm^{-3}): 20 (control), 50, 75, 100 and 125. The objective of the work were the after effect of the mentioned chelates investigated in the autumnal experiments. Containers with peat that were used in spring experiments were stored in the greenhouse until autumn. In mid--September, lettuce seedlings were planted into the stored peat-filled containers after supplementation of the macro- and micro-elements with the exception of iron. No negative action of chelates was found. Plants yielded well without any symptoms of chelate excess which were observed in spring. After the application of the studied chelates, independent of the levels of Fe, the lettuce yields were similar. Increasing Fe levels, independent of chelates, were accompanied by a similar Fe content in leaves, by an increasing content of copper and decreasing contents of manganese and zinc.

Key words: lettuce, iron chelates, Fe-DTPA, Fe-EDTA+DTPA, Fe-AM-4 (NH_4-EDTA), yielding, after effect

INTRODUCTION

For the production of microfertilizer chelates, the following carriers are used: EDTA, HEEDTA, DTPA, EDDHA, EDDHHA, NTA and citric acid [Hoffmann and Górecki 2000]. They are used among others for the production of iron chelates. One of them is Fe EDDHA which was used in hydroponic cultivation of spinach [Assimakopoulou 2006]. Other examples are also iron chelates applied in the work of Tyksiński and Komosa [2007]. Hoffmann et al. [2004] studied the chelation degree of fertilizer microelements. The latter authors found very good complexation properties of EDTA and DTPA. The chelation degree of microelements depended on the pH value of the

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solution, the presence of fertilizer salts as well as on the application of complexing salt. In the studies of Borowik et al. [2003], carried out in the Institute of Artificial Fertilizers in Puławy, it was found that the most durable bonds with iron were created by the anions of DTPA and EDTA acids, while the weakest ones were produced by the anion of citric acid.

Tyksiński and Komosa [2007] found that some iron chelates applied in lettuce fertilization, i.e. Fe EDTA+DTPA and Fe-AM-4 significantly decreased the yields and evoked the occurrence of chelate excess symptoms. Therefore, it has been decided to investigate the after effect of the above mentioned chelates.

The objective of the presented work was the investigation of the after effects of iron chelates, i.e. Fe-EDTA+DTPA, Fe-DTPA and Fe-AM-4 in the autumnal cultivation of greenhouse lettuce.

MATERIAL AND METHODS

After the harvest of lettuce in spring 2005 and 2006, the containers where lettuce was grown were stored in the greenhouse until autumn and the cultivation moisture was maintained in them.

The autumnal experiment carried out in 2006 was a repetition of the experiment of 2005. In autumn 2005, seeds of 'Michalina' cultivar were sown on the 21st of August into pallets. One week later, the pallets were filled with raised peat limed with 5.0 g $CaCO_3 \cdot dm^{-3}$ and enriched with l.5 g Azofoska$\cdot dm^{-3}$. The dose of $CaCO_3$ was determined on the basis of neutralization curve.

On the 12th of September, the substrates which remained after the spring experiment were enriched with microelements supplementing them to the levels of $mg \cdot dm^{-3}$: N-180, P-140, K-220, Mn-20, Zn-20, Cu-5, B-1, Mo-1. There was no need to supplement the contents of Ca (2045), Mg (160) and $S\text{-}SO_4$ (250).

In spring, iron was applied in the form of:

1. Fe-DTPA (6.3% Fe),
2. Fe-EDTA+DTPA (8% Fe),
3. Fe-AM-4 (NH_4 EDTA) (11% Fe)

Levels of iron Fe ($mg \cdot dm^{-3}$) established in spring: 20 (control), 50, 75, 100 and 125. In autumn, iron was not supplemented. Lettuce seedlings were planted into containers (6 dm^3) on the 15th of September. The content of Fe in raised peat were 12.6 $mg \cdot dm^{-3}$ (control combination); pH in H_2O = 5.93. During vegetation, plants were irrigated to 70% water capacity of peat determined on the basis of Wahnschaff's cylinders. Each combination consisted of five replications; one replication was represented by one container with four lettuce plants. There was a joint control for the whole experiment. On the 3rd of November, lettuce was cut, weighed, dried in extractor drier and homogenized. Mean samples were taken for chemical analyses. The following chemical analyses were carried out after the termination of the autumnal analyses in the years 2005 and 2006:

1) analyses of substrates: in mean samples of peat, the content of macrocomponents and iron, pH in H_2O were determined and EC was measured by conductometric method.

2) analyses of plant material: contents of iron, copper, manganese and zinc by ASA method after wet mineralization in a mixture of HNO_3 and $HClO_4$ acids in 3:1 proportion.

RESULTS

Lettuce yielding. The mean yield of lettuce grown in autumn 2005 and 2006 is shown in table 1. The chelates and iron levels used in the experiments had a differentiated effect on yielding. Lettuce yields obtained after the application of all four Fe levels were higher than in the control. Lettuce yields at the levels of 50, 75 and 100 mg Fe·dm^{-3} were similar. On the level 125 mg Fe·dm^{-3} were significantly higher than those obtained with the remaining Fe levels.

Table 1. The effect of iron chelates on the yield of lettuce fresh master (g·container^{-1}; mean values for autumn experiments 2005 and 2006).
Tabela 1. Wpływ chelatów na plon świeżej masy sałaty (g·pojemnik^{-1}; średnie dla doświadczeń jesiennych 2005 i 2006 r.).

Fe level Poziom Fe mg·dm-3 (A)	Chelate – Chelat (B)			$\bar{x}$ for Fe levels $\bar{x}$ dla poziomów Fe
	Fe-DTPA	Fe-EDTA+DTPA	Fe-AM-4	
Control 20 – Kontrola 20	316.2	316.2	316.2	316.2
50	373.7	342.4	379.8	365.3
75	358.7	411.1	349.4	373.1
100	352.5	405.2	390.4	382.7
125	386.5	446.4	437.2	423.4
$\bar{x}$ for chelates $\bar{x}$ dla chelatów	357.5	384.3	374.6	

$LSD_{0.05}$ for Fe levels (A); $NIR_{0,05}$ dla poziomów Fe (A) = 25.5
$LSD_{0.05}$ for chelates Fe (B); $NIR_{0,05}$ dla chelatów Fe (B) = 19.7
$LSD_{0.05}$ for A×B; $NIR_{0,05}$ dla A×B = 44.1

Comparing the yielding of lettuce under the effect of the studied chelates, independent of the Fe levels, it was found that the highest yield was significantly higher after the application of Fe EDTA+DTPA than after Fe-DTPA.

Iron content in lettuce leaves. The content of iron in lettuce leaves is shown in table 2. Comparison of Fe content in lettuce leaves grown with increasing Fe levels, independent of chelate, indicated that the lowest Fe content was in the control combination. The mean values for Fe levels: 50, 100 and 125 mg Fe·dm^{-3} were significantly higher than in control combination.

The effect of chelates, (analysed independently from Fe levels), on iron content in leaves has shown to be significant. Iron content after the application of Fe-DTPA was higher than after the application of Fe-AM-4. Also when Fe-EDTA+DTPA was applied, the Fe content was higher than after Fe-AM-4.

Table 2. The iron content in lettuce leaves (mg·kg^{-1} d.m.; mean values for autumn experiments 2005 and 2006)
Tabela 2. Zawartość żelaza w liściach sałaty (mg·kg^{-1} s.m.; wartości średnie dla doświadczeń jesiennych 2005 i 2006 r.)

Fe level Poziom Fe mg·dm^{-3} (A)	Chelate – Chelat (B)			$\bar{x}$ for Fe levels $\bar{x}$ dla poziomów Fe
	Fe-DTPA	Fe-EDTA+DTPA	Fe-AM-4	
Control 20 – Kontrola 20	76.9	76.9	76.9	76.9
50	102.4	94.1	73.3	89.9
75	86.0	89.4	64.2	79.9
100	87.3	83.2	80.7	83.7
125	101.1	90.4	96.4	96.0
$\bar{x}$ for chelates $\bar{x}$ dla chelatów	90.7	86.8	78.3	

$LSD_{0.05}$ for Fe levels (A); $NIR_{0,05}$ dla poziomów Fe (A) = 6.4
$LSD_{0.05}$ for chelates Fe (B); $NIR_{0,05}$ dla chelatów Fe (B) = 5.0
$LSD_{0.05}$ for A×B; $NIR_{0,05}$ dla A×B = 11.1

Contents of copper, manganese and zinc in lettuce leaves. A supplementary objective of the presented work was the investigation of the interdependence between the increasing iron levels in the form of chelates and the contents of copper, manganese and zinc in lettuce (table 3).

Copper. With the increase of Fe levels, there increased also the content of copper. In lettuce fertilized with iron (4 levels), the copper content was higher than in the control combination.

Comparing copper content after the application of chelates, independently of Fe levels, it was found that it was similar, significantly higher after the application of Fe-DTPA and Fe-AM-4 than after the use of Fe-EDTA+DTPA.

Manganese. With the increase of Fe levels, the content of manganese decreased. The Fe content was the highest in the control combination. Comparing manganese content after the application of chelates, independent of Fe levels, it was found that it was the highest after the use of Fe-AM-4, i.e. significantly higher than after the application of the remaining two chelates.

Zinc. Increasing levels of iron were accompanied by a decreasing content of zinc. Zinc content was the highest in the control combination.

Comparison of zinc content after the application of Fe chelates, independent of their level, indicated that it was the highest after the application of Fe-AM-4, i.e. significantly higher than after the use of the remaining chelates.

DISCUSSION

Results of studies with the application of Fe chelates presented in the subjective literature differ. In the work of Tyksiński and Komosa [2007], it was shown that the best source of iron for lettuce grown in peat is the Fe-DTPA chelate in the doses of 50 and

75 mg Fe·dm^{-3} . In the work of Chohura et al. [2007] it was shown that tomatoes grown in peat substrate fertilized with Fe 8 Forte yielded significantly better than in case of the remaining chelates, i.e. Fe 13 Top and Librel Fe DP 7.

Table 3. The copper, manganese and zinc in lettuce leaves (mg·kg^{-1} d.m.; mean values for experiments 2005 and 2006)
Tabela 3. Zawartość miedzi, manganu i cynku w sałacie (mg·kg^{-1} s.m.; średnie dla doświadczeń jesiennych 2005 i 2006 r.)

Fe level Poziom Fe mg·dm^{-3} (A)	Chelate – Chelat (B)			$\bar{x}$ for Fe levels $\bar{x}$ dla poziomów Fe
	Fe-DTPA	Fe-EDTA+DTPA	Fe-AM-4	
		Copper – Miedź *		
Control 20 – Kontrola 20	5.33	5.33	5.33	5.33
50	6.50	5.80	5.85	6.05
75	6.05	6.48	6.45	6.33
100	7.28	6.60	7.05	6.98
125	8.18	7.55	9.05	8.26
$\bar{x}$ for chelates $\bar{x}$ dla chelatów	6.67	6.35	6.75	
		Manganese – Mangan**		
Control 20 – Kontrola 20	43.68	43.68	43.68	43.68
50	15.23	15.43	31.28	20.64
75	14.60	14.08	25.58	18.08
100	12.70	14.03	16.00	14.24
125	13.05	12.13	17.13	14.10
$\bar{x}$ for chelates $\bar{x}$ dla chelatów	19.85	19.87	26.73	
		Zinc – Cynk***		
Control 20 – Kontrola 20	120.2	120.2	120.2	120.2
50	77.6	80.5	125.1	94.4
75	75.3	75.9	105.2	85.5
100	72.5	77.3	100.1	83.3
125	68.1	73.3	80.3	73.9
$\bar{x}$ for chelates $\bar{x}$ dla chelatów	82.7	85.4	106.2	

*Copper – Miedź
$LSD_{0.05}$ for Fe levels (A); $NIR_{0,05}$ dla poziomów Fe (A) = 0.34
$LSD_{0.05}$ for chelates Fe (B); $NIR_{0,05}$ dla chelatów Fe (B) = 0.26
$LSD_{0.05}$ for A×B; $NIR_{0,05}$ dla A×B = 0.58

**Manganese – Mangan
$LSD_{0.05}$ for Fe levels (A); $NIR_{0,05}$ dla poziomów Fe (A) = 2.16
$LSD_{0.05}$ for chelates Fe (B); $NIR_{0,05}$ dla chelatów Fe (B) = 1.67
$LSD_{0.05}$ for A×B; $NIR_{0,05}$ dla A×B = 3.74

***Zinc – Cynk
$LSD_{0.05}$ for Fe levels (A); $NIR_{0,05}$ dla poziomów Fe (A) = 3.57
$LSD_{0.05}$ for chelates Fe (B); $NIR_{0,05}$ dla chelatów Fe (B) = 2.76
$LSD_{0.05}$ for A×B; $NIR_{0,05}$ dla A×B = 6.18

In the work of Komosa et al. [2002], no differences were shown in the yielding of greenhouse tomato grown in mineral wool fertilized with different sources of Fe, i.e. with Fe 13 Top, Fe 8 Forte and Librel Fe-DP 7. It must be stressed that it was a cultivation in mineral wool, while Fe concentrations in the traditional nutrients and substrates are quite different. Also in mineral wool, studies were carried out on the effect of ferric chelates Librel – DP 7, Pionier Fe 13 and Top 12 [Kołota et al. 2006] on the yielding of greenhouse tomato. The mentioned chelates used as the source of iron have shown a similar usefulness.

Tyksiński and Komosa [2007] who were growing lettuce in spring experiments in 2005 and 2006, found that the doses of 75, 100 and 125 mg $Fe \cdot dm^{-3}$ in the form of chelates Fe EDTA+DTPA and Fe-AM-4 caused a significant yield decrease in relation to the control. Furthermore, there occurred necrotic spots on the plants. The smallest dose of chelates, i.e. 50 mg $Fe \cdot dm^{-3}$ caused a yield decrease in relation to the control, although the plants were healthy. Only the chelate Fe-DTPA in the doses of 50-100 mg $Fe \cdot dm^{-3}$ insured good yielding and healthy plants. The described results induced the authors to keep the containers with peat (after lettuce harvest) until autumn.

In autumn, into the substrates, after their supplementation with microelements, lettuce seedling were planted. This permitted the observation of the after effect of iron chelates. In the control, the lowest yield was obtained (tab. 1). Three studied chelates and differentiated Fe levels insured good yielding and healthy plants. Differences in yielding were small. Iron could not have been the reason of low lettuce yields and of the symptoms of chelate excess in the spring experiments. In experiments carried out for many years with lettuce grown in peat, Tyksiński [1992] showed that plants tolerated the dose of 900 mg $Fe \cdot dm^{-3}$ .The only reason could have been the Fe chelate carriers EDTA+DTPA and Fe-AM-4 which in the period of incubation (between the spring and the autumn experiments) were possibly decomposed or immobilized.

Analysis of iron content in lettuce fertilized with chelates (in the discussed work), indicated that in the control combination, it was smaller than after the application of the doses of 50, 100 and 125 mg $Fe \cdot dm^{-3}$, independent of chelates. Differences in Fe content between chelates, independent of Fe levels, were not great. In spring experiments [Tyksiński and Komosa 2007], iron content after the application of Fe-EDTA+DTPA and Fe-AM-4 was significantly higher than after the application of Fe-DTPA. Iron chelates studied by Kołota et al. [2006] also exerted a significant effect on the iron content in tomato leaves.

Iron content in lettuce fertilized with chelates (independent of chelate) within the levels of Fe (control) to 100 mg $Fe \cdot dm^{-3}$ oscillated between 77 and 84 $mg \cdot kg^{-1}$. Tyksiński [1992] reported that iron content in lettuce fertilized with $FeSO_4 \cdot 7H_2O$ in the dose range of: 0–100 mg $Fe \cdot dm^{-3}$ oscillated between 230 and 260 mg $Fe \cdot kg^{-1}$ (autumn experiment). The difference resulted from the application of different iron forms (chelated and mineral) in the years 2005 and 2006 (results published in 1992).

CONCLUSIONS

1. No toxic action of chelates were found to be exerted on the growth and yielding of lettuce as after effects.

2. Lettuce yield after the application of all four Fe levels, independent of chelate, were higher than in the control combination. The highest yield was obtained at the level of 125 mg Fe·dm^{-3}. Comparison of lettuce yielding after the application of three chelates (independent of Fe doses) indicated that the yields were similar and plants were healthy.

3. Increasing iron levels in substrates independent of chelate were accompanied by Fe content in lettuce in the interval of 80–96 mg·kg^{-1} d.m. Difference in the content of iron between the chelates, independent of Fe level, was not high, it was contained in the range from 78.3–90.7 mg·kg^{-1}.

4. Increasing doses of iron in the form of chelates were accompanied by an increase of copper content in and decreasing contents of manganese and zinc in the lettuce.

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NASTĘPCZE DZIAŁANIE CHELATÓW ŻELAZA NA PLONOWANIE I ZAWARTOŚĆ ŻELAZA W SAŁACIE SZKLARNIOWEJ

Streszczenie. W latach 2005 i 2006 prowadzono doświadczenia wiosenne i jesienne z sałatą szklarniową odm. 'Michalina', którą nawożono trzema chelatami żelaza, tj. Fe-DTPA, Fe-EDTA+DTPA i Fe-AM-4 w dawkach: (mg Fe·dm^{-3}): 20 (kontrola), 50, 75, 100 i 125. Wyniki doświadczeń wiosennych opublikowano. Przedmiotem niniejszej pracy jest działanie następcze chelatów badane w doświadczeniach jesiennych. Doświadczenie 2006 było powtórzeniem doświadczenia 2005 r. Po ścięciu sałaty wiosną pojemniki z torfem przechowano w szklarni do jesieni i w połowie września wysadzono rozsadę sałaty do tych pojemników po uprzednim uzupełnieniu makro- i mikroskładnikami z wyjątkiem żelaza. Działanie następcze chelatów żelaza można ocenić pozytywnie. Nie stwierdzono ujemnego wpływu chelatów na plonowanie sałaty i jej wygląd. Największy plon uzyskano na poziomie 125 mg Fe·dm^{-3}. Po zastosowaniu badanych chelatów plony były zbliżone, rośliny były zdrowe. Rosnącym poziomom żelaza, niezależnie od chelatu, odpowiadała zbliżona zawartość żelaza w liściach sałaty, rosnąca zawartość miedzi i obniżająca się zawartość manganu i cynku.

Słowa kluczowe: sałata, chelaty żelaza, Fe-DTPA, Fe-EDTA+DTPA, Fe-AM-4 (NH4-EDTA), plonowanie, działanie następcze

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