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A COMPARISON OF THE EFFICIENCY OF ORGANIC AND MINERAL IRON COMPOUNDS IN THE GREENHOUSE CULTIVATION OF LETTUCE

Elżbieta Kozik, Wojciech Tyksiński, Maciej Bosiacki

Chair of Horticultural Plant Nutrition
Poznań University of Life Sciences

Abstract

In 2007-2008, pot experiments were conducted on cv. Michalina head lettuce grown in an unheated greenhouse in spring. The aim of the study was to compare organic and mineral iron compounds as well as their rates in terms of the efficiency of their effect on yield of lettuce and iron content in lettuce leaves. The experimental factors included: 1) sources of iron, i.e. 2 mineral – iron(II) sulfate and iron (III) sulfate, and 3 organic – iron (III) citrate, iron (II) gluconate and iron chelate Fe (III) DTPA, 2) level of iron, i.e. 6 levels – 20 (control), 45, 70, 95, 120 and 220 mg Fe dm^{-3} substrate.

Lettuce was grown in 6 dm^3 containers. Limed highmoor peat, enriched with macro- and micronutrients to meet requirements of lettuce, was used as a substrate. Each experiment included 26 combinations comprising 4 replications each. A container with 4 lettuce plants constituted one replication. Lettuce was harvested at the consumption stage. Concentrations of iron, copper, manganese and zinc were determined in plant material by ASA after wet mineralization in a mixture of acids HNO_3 and $HClO_4$ at a 3:1 ratio (v:v).

The application of iron(III) sulfate, iron(II) sulfate, iron citrate or iron gluconate ranging from 45 to 220 mg Fe dm^{-3} and Librel Fe-DTPA chelate ranging from 45 to 120 mg Fe dm^{-3} did not have any significant effect on the yield of lettuce. Librel Fe-DTPA applied at a rate of 220 mg Fe dm^{-3} resulted in a reduction of yield. The highest Fe content (irrespectively of the applied Fe rates) in lettuce leaves was recorded after the application of Librel Fe DTPA, while the lowest one – after iron gluconate was used. When analyzing the effect of Fe levels, irrespectively of the used iron compounds, the lowest Fe content in leaves was observed in the control, growing at the levels of 45 and 70 mg Fe dm^{-3}, as well as at 90 and 120 mg Fe dm^{-3} and reaching its peak after the application of 220 mg Fe dm^{-3}.

Key words: iron compounds, lettuce, yielding, micronutrients.

dr hab. Elżbieta Kozik, Chair of Horticultural Plant Nutrition, Poznań University of Life Sciences, Zgorzelecka 4, 60-196 Poznań, e-mail: knaw@up.poznan.pl

PORÓWNANIE SKUTECZNOŚCI ORGANICZNYCH I MINERALNYCH ZWIĄZKÓW ŻELAZA W UPRAWIE SAŁATY W SZKLARNI

Abstrakt

W latach 2007-2008 wiosną w nieogrzewanej szklarni przeprowadzono doświadczenia wazonowe z sałatą głowiastą odmiany Michalina. Celem pracy było porównanie organicznych i mineralnych związków żelaza, a także ich dawek pod kątem skuteczności działania na plon sałaty oraz zawartość żelaza w jej liściach. Czynnikami doświadczeń były: 1) źródło żelaza, tj. 2 mineralne – siarczan żelaza (II) i siarczan żelaza (III) oraz 3 organiczne – cytrynian żelaza (III), glukonian żelaza (II) i chelat żelaza Fe (III) DTPA; 2) poziom żelaza, tj. 6 poziomów – 20 (kontrola), 45, 70, 95, 120, 220 mg Fe dm^{-3} podłoża.

Sałatę uprawiano w pojemnikach o objętości 6 dm^3. Jako podłoże zastosowano torf wysoki zwapnowany i wzbogacony w makro- i mikroskładniki zgodnie z wymaganiami sałaty.

Każde doświadczenie obejmowało 26 kombinacji składających się z 4 powtórzeń. Powtórzenie stanowił pojemnik z 4 roślinami sałaty. Zbiór sałaty przeprowadzono w fazie dojrzałości konsumpcyjnej. W materiale roślinnym oznaczono zawartość żelaza, miedzi, manganu i cynku metodą ASA po mineralizacji na mokro w mieszaninie kwasów HNO_3 i $HClO_4$ w stosunku 3:1 (v:v).

Zastosowanie siarczanu żelaza (III), siarczanu żelaza (II), cytrynianu żelaza lub glukonianu żelaza w zakresie 45-220 mg Fe dm^{-3} oraz chelatu Librel Fe-DTPA w zakresie 45-120 mg Fe dm^{-3} nie miało istotnego wpływu na plon sałaty. Librel Fe-DTPA zastosowany na poziomie 220 mg Fe dm^{-3} spowodował zmniejszenie plonu. Największą zawartość Fe (niezależnie od dawki Fe) w liściach sałaty stwierdzono po zastosowaniu Librel Fe DTPA, a najmniejszą po zastosowaniu glukonianu żelaza. Analizując wpływ poziomów Fe, niezależnie od związków żelaza, stwierdzono najmniejszą zawartość Fe w liściach w próbie kontrolnej, większą po zastosowaniu 45 i 70 mg Fe dm^{-3}, jeszcze większą w przypadku 90 i 120 mg Fe dm^{-3} i największą po zastosowaniu 220 mg Fe dm^{-3}.

Słowa kluczowe: związki żelaza, sałata, plonowanie, mikroskładniki.

INTRODUCTION

Iron deficiency is associated with the incidence of anaemia, which affects approx. 500 million people worldwide. Groups at the highest risk include children and women at the child-bearing age (THOMPSON 2007). Iron deficits in food occur despite the fact that its total content in soils is generally quite high (on average 2%). Plant chlorosis caused by deficit of available iron is common worldwide, particularly on calcareous soils and in arid and semi-arid regions (RUSZKOWSKA, WOJCIESKA-WYSKUPAJTYS 1996, LUCENA 2003).

The iron requirements in Europe and Poland are satisfied much more often than in the Third World countries. However, the amount of iron consumed with typical diets by different population groups in Poland is frequently lower that the recommended level. GOLCZ and DŁUBAK (1998) as well as BOSIACKI and TYKSIŃSKI (2009) indicated low content of iron in vegetables sold in the city of Poznań. Studies on a variety of suitable sources of iron for plants and their rates need to be conducted.

The aim of the study has been to compare organic and mineral iron compounds as well as their rates in terms of their efficiency on the yield of lettuce and on the iron content in its leaves.

MATERIAL AND METHODS

In 2007-2008, pot experiments were conducted on cv. Michalina head lettuce grown in an unheated greenhouse in spring. The experimental factors included:

A) iron compounds:
- mineral – iron (III) sulfate $Fe_2(SO_4)_3 \cdot H_2O$ and iron (II) sulfate $FeSO_4 \cdot 7H_2O$;
- organic – iron (III) citrate $C_6H_5O_7Fe \cdot H_2O$, iron (II) gluconate $C_{12}H_{22}FeO_{24}$ and iron (III) chelate Librel Fe-DTPA,

B) level of iron:
- 6 levels – the control (20), 45, 70, 95, 120 and 220 mg Fe dm^{-3} substrate.

Each year of the experiment, on 21 March, lettuce seeds were sown in a single-seed system to multiple trays with cups size of 4x4 cm filled with highmoor peat (Lithuania), limed at 5 g dm^{-3} $CaCO_3$ and enriched with Azofoska at 1.5 g dm^{-3}. Lettuce seedlings were transplanted to containers of 6 dm^{-3} filled with appropriately prepared substrate (11 April). Each combination included 4 replications, with a container with four lettuce plants constituting one replication. The control was the same for the entire experiment, i.e. fertilization with macro- and micronutrients except iron.

The substrate was prepared from highmoor peat, which was limed based on the neutralization curve to pH in H_2O = 6.3. After liming, sufficient concentrations of Ca – 2045, Mg – 160, S-SO_4 – 25 mg dm^{-3} were found in the substrate, therefore they were not supplemented. The other nutrients in the substrate were supplemented to the following levels (in mg dm^{-3}): N – 180, P – 140, K – 220, Zn – 20, Mn – 20, Cu – 5, B – 1 and Mo – 1. Iron was applied according to the assumptions adopted for the experiment, considering its initial content in limed peat of 20 mg Fe dm^{-3}.

While growing, plants were watered to 70% water capacity, which was measured using Wahnschaffe cylinders. On 16 May 2007 and 13 May 2008, lettuce was harvested. Plants were cut, weighed, dried in a convection dryer and homogenized. Concentrations of iron, manganese, zinc and copper were determined in the plant material by ASA after wet mineralization in a mixture of acids HNO_3 and $HClO_4$ at a 3:1 ratio (v:v). The results of fresh weight of lettuce heads and content of micronutrients in plants were analyzed statistically. After significant differences had been identified, means were clustered according to the Newman Keuls test at the significance level α=0.05.

RESULTS AND DISCUSSION

Mean results from the 2-year experiment indicate that the average weight of lettuce heads did not differ significantly after the application of iron in the form of $Fe_2(SO_4)_3 \cdot H_2O$, $FeSO_4 \cdot 7H_2O$, $C_6H_5O_7Fe \cdot H_2O$ or $C_{12}H_{22}FeO_{24}$ at rates ranging from 45 to 220 mg Fe dm^{-3} and in the form of Librel Fe-DTPA at rates ranging from 45 to 120 mgFe dm^{-3} (Table 1). It was only the highest level of the Librel Fe-DTPA chelate (220 mg Fe dm^{-3}) that resulted in a significant reduction of lettuce yield. At this rate of the chelate, the yield of lettuce was lower, also in comparison to the yield harvested in the control combination. TYKSIŃSKI (1992), when growing lettuce on peat, observed that yields of lettuce did not differ at iron rates ranging from 0 to 900 mg Fe dm^{-3} applied in the form of iron (II) sulfate. In turn, TYKSIŃSKI and KOMOSA (2007), after an application of 125 mg Fe dm^{-3} in the form of chelate Fe-DTPA, stated a significant reduction of lettuce yield in relation to a rate of 75 mg Fe dm^{-3}. Moreover, in combinations of 100 and 125 mg Fe dm^{-3}, brown necrotic spots appeared on leaves. These authors suggested that such a response of plants was not an effect of excess iron, but rather of the carrier used in the production of the chelate.

Table 1

The effect of iron compounds on the yield of lettuce fresh matter (g container^{-1}). Mean values for the experiments in 2007 and 2008

Fe compounds	Fe level (mg dm^{-3} substrate)						$\overline{x}$
	20 (control)	45	70	95	120	220	
$Fe_2(SO_4)_3 \cdot H_2O$	496.5 *b*	517.4 *b*	495.1 *b*	491.5 *b*	500.5 *b*	468.9 *b*	495.0 *b*
$FeSO_4 \cdot 7H_2O$	496.5 *b*	498.5 *b*	492.6 *b*	488.8 *b*	536.4 *b*	516.9 b	504.9 *b*
$C_6H_5O_7$ Fe$\cdot H_2O$	496.5 *b*	523.4 *b*	536.8 *b*	536.9 *b*	511.9 *b*	517.0 *b*	520.4 *b*
$C_{12}H_{22}FeO_{24}$	496.5 *b*	522.1 *b*	517.3 *b*	546.6 *b*	539.4 *b*	491.3 *b*	518.9 *b*
Librel Fe-DTPA	496.5 *b*	523.9 *b*	515.6 *b*	458.3 *b*	459.5 *b*	237.0 *a*	448.5 *a*
$\overline{x}$	496.5 *b*	517.1 *b*	511.5 *b*	504.4 *b*	509.5 *b*	446.2 *a*	

Means followed by same letters are not significantly different at $\alpha = 0.05$.

When analyzing the iron content in lettuce, it was found to be dependent on the applied compound and the level of iron (Table 2). The biggest amounts of iron were found in plants fertilized with Librel Fe-DTPA, while the lowest amounts were found in the case of iron gluconate. In turn, when iron was supplied in the form of iron (III) sulfate, lettuce had a significantly higher content of iron in comparison to that fertilized with iron (II) sulfate and iron citrate. Irrespective of the source of iron, over the entire range

Table 2

The iron content in lettuce leaves (mg kg^{-1} d. m.).
Mean values for the in experiments 2007 and 2008

Fe compounds	Fe level (mg dm^{-3} substrate)						$\overline{x}$
	20 (control)	45	70	95	120	220	
$Fe_2(SO_4)_3 \cdot H_2O$	149.9 *ab*	179.9 *b-e*	184.8 *b-e*	207.5 *de*	203.0 *c-e*	216.6 *e*	190.3 *c*
$FeSO_4 \cdot 7H_2O$	149.9 *ab*	159.7 *a-d*	152.2 *ab*	176.0 *b-e*	172.0 *a-d*	170.5 *a-d*	163.4 *b*
$C_6H_5O_7\ Fe \cdot H_2O$	149.9 *ab*	164.1 *a-d*	162.0 *a-d*	162.7 *a-d*	151.9 *ab*	166.9 *a-d*	159.6 *b*
$C_{12}H_{22}FeO_{24}$	149.9 *ab*	146.3 *ab*	147.2 *ab*	154.1 *a-c*	122.2 *a*	136.7 *ab*	142.8 *a*
Librel Fe-DTPA	149.9 *ab*	169.1 *a-d*	181.3 *b-e*	262.6 *f*	283.9 *f*	391.2 *g*	239.6 *d*
$\overline{x}$	149.9 *a*	163.8 *b*	165.5 *b*	192.6 *c*	186.6 *c*	216.4 *d*	

Means followed by same letters are not significantly different at $\alpha = 0.05$.

of fertilization treatments, the content of iron in lettuce was significantly higher than in the control combination. Its highest content was recorded after the introduction of 220 mg Fe dm^{-3} to the substrate. Lettuce grown in a substrate with 45 and 70 mg Fe dm^{-3} contained similar levels of iron and significantly lower ones than in a substrate with 95 and 120 mg Fe dm^{-3}. It needs to be stressed that after the application of Librel Fe-DTPA chelate within the range of 95-220 mg Fe dm^{-3}, a significantly higher content of iron appeared in lettuce in comparison with the other experimental objects. The efficiency of Fe chelation by DTPA and citric acid was investigated by HOFFMAN et al. (2004). Very good chelation efficiency was observed for DTPA. In a study by TYKSIŃSKI and KOMOSA (2007), after the application of Fe-DTPA chelate at rates of 100-125 mg Fe dm^{-3}, lettuce showed symptoms of iron excess in the form of brown necrotic spots on leaves or marbled chlorosis. Such plant response was not found in this study.

Iron has a significant effect on the volume and quality of yield; however, it creates considerable problems due to it being readily transformed into forms hardly available to plants (GARCIA-MINA et al. 2003, CHOHURA et al. 2007). WREESMAN (1996) stated that the application of chelate forms is of primary importance in the limitation of iron immobilization, as they are characterized by good water solubility and low dissociation constant.

The content of manganese in lettuce depending on the source and level of iron in the substrate is given in Table 3. Lettuce fertilized with iron (III) sulfate contained significantly more manganese than that fertilized with the other iron compounds. The lowest manganese content was recorded in lettuce grown on a substrate with chelate Librel Fe-DTPA. Manganese content in plants decreased with the increasing levels of iron in the substrate, although the reduction was significant (except for 45 mg Fe dm^{-3}) only in

Table 3

The manganese content in lettuce leaves (mg kg^{-1} d. m.).
Mean values for the experiments in 2007 and 2008

Fe compounds	Fe level (mg dm^{-3} substrate)						$\bar{x}$
	20 (control)	45	70	95	120	220	
$Fe_2(SO_4)_3 \cdot H_2O$	308.4 *b-d*	326.9 *cd*	330.3 *cd*	339.8 *cd*	306.4 *b-d*	351.6 *d*	327.2 *c*
$FeSO_4 \cdot 7H_2O$	308.4 *b-d*	313.4 *b-d*	289.8 *b-d*	275.6 *b-d*	281.9 *b-d*	285.2 *b-d*	292.4 *b*
$C_6H_5O_7\,Fe \cdot H_2O$	308.4 *b-d*	329.9 *cd*	288.4 *b-d*	291.6 *b-d*	266.3 *b-d*	257.9 *b-d*	290.4 *b*
$C_{12}H_{22}FeO_{24}$	308.4 *b-d*	327.9 *cd*	292.9 *b-d*	270.8 *b-d*	246.0 *bc*	228.5 *b*	279.1 *b*
Librel Fe-DTPA	308.4 *b-d*	155.5 *a*	152.5 *a*	137.4 *a*	139.3 *a*	101.8 *a*	165.8 *a*
$\bar{x}$	308.4 *c*	290.7 *bc*	270.8 *ab*	263.1 *ab*	247.9 *a*	244.9 *a*	

Means followed by same letters are not significantly different at $\alpha = 0.05$.

comparison to the control combination. A similar dependence between manganese and iron in studies on lettuce was reported by Tyksiński (1993).

The content of zinc, similarly to manganese, was the highest in lettuce fertilized with iron (III) sulfate, while the lowest one was found in lettuce fertilized with chelate Librel Fe-DTPA (Table 4). Plants fertilized with iron (II) sulfate were better nourished with zinc than those fertilized with iron citrate or iron gluconate. The level of iron ranging from 70 to 220 mg Fe dm^{-3} substrate in relation to the level of 45 mg Fe dm^{-3}, as well as the control combination (20 mg Fe dm^{-3}) caused a significant reduction of the zinc content in plants. The content of zinc in lettuce grown after the application of 70 mg Fe dm^{-3} was significantly bigger only in relation to the treatment including 120 mg Fe dm^{-3}. The determined zinc content fell within the range considered by Tyksiński (1992) as optimal for lettuce.

Different iron fertilization rates had an effect on the nutritional status of lettuce in copper (Table 5). Irrespectively of the level of iron in the substrate, the mean copper content in plants was the highest when iron was applied in the form of Librel Fe-DTPA chelate. Lettuce fertilized with iron (II) sulfate, iron citrate or iron gluconate contained less copper than that fertilized with iron (III) sulfate. With the iron content in the substrate ranging from 70 to 95 mg Fe dm^{-3}, the content of copper in plants was similar to that recorded in the control. After the application of 45 mg Fe dm^{-3} substrate, the content of copper in lettuce was significantly lower, while at 120 and 220 mg Fe dm^{-3} it was significantly higher. A similar increase in the content of copper under the influence of increasing levels of iron in the substrate was found in investigations on lettuce conducted by Tyksiński and Komosa (2008), while Anchondo et al. (2001) showed an opposite dependence in leaves and fruits of chili pepper grown in a hydroponic system.

Table 4

The zinc content in lettuce leaves (mg kg^{-1} d. m.).
Mean values for the experiments in 2007 and 2008

Fe compounds	Fe level (mg dm^{-3} substrate)						$\overline{x}$
	20 (control)	45	70	95	120	220	
$Fe_2(SO_4)_3 \cdot H_2O$	150.3 *f-h*	188.8 *i*	188.8 *i*	185.9 *i*	162.2 *g-i*	190.2 *i*	177.7 *e*
$FeSO_4 \cdot 7H_2O$	150.3 *f-h*	178.8 *h-i*	160.1 *g-i*	161.2 *g-h*	149.9 *f-h*	152.6 *f-h*	158.8 *d*
$C_6H_5O_7\ Fe \cdot H_2O$	150.3 *f-h*	167.4 *g-i*	149.9 *f-h*	141.6 *e-g*	127.6 *d-f*	123.5 *d-f*	143.4 *c*
$C_{12}H_{22}FeO_{24}$	150.3 *f-h*	161.0 *g-i*	122.7 *d-f*	124.9 *d-f*	113.9 *c-e*	104.6 *b-d*	129.6 *b*
Librel Fe-DTPA	150.3 *f-h*	94.5 *a-c*	80.1 *ab*	75.9 *a*	89.7 *a-c*	110.8 *cd*	100.2 *a*
$\overline{x}$	150.3 *c*	158.1 *c*	140.3 *b*	137.9 *ab*	128.7 *a*	136.3 *ab*	

Means followed by same letters are not significantly different at $\alpha = 0.05$.

Table 5

The copper content in lettuce leaves (mg kg^{-1} d. m.).
Mean values for the experiments in 2007 and 2008

Fe compounds	Fe level (mg dm^{-3} substrate)						$\overline{x}$
	20 (control)	45	70	95	120	220	
$Fe_2(SO_4)_3 \cdot H_2O$	9.9 *a-e*	9.5 *a-e*	9.6 *a-e*	12.8 *e-i*	12.7 *e-i*	14.2 *hi*	11.4 *b*
$FeSO_4 \cdot 7H_2O$	9.9 *a-e*	7.5 *a-c*	9.5 *a-e*	10.7 *a-h*	10.9 *b-h*	11.3 *c-i*	9.9 *a*
$C_6H_5O_7\ Fe \cdot H_2O$	9.9 *a-e*	7.3 *a-c*	10.1 *a-f*	6.7 *a*	10.1 *a-f*	10. 4 *a-h*	9.1 *a*
$C_{12}H_{22}FeO_{24}$	9.9 *a-e*	7.3 *a-c*	8.5 *a-d*	6.9 *ab*	10.3 *a-g*	10.1 *a-f*	8.9 *a*
Librel Fe-DTPA	9.9 *a-e*	11.9 *d-i*	11.7 *d-i*	14.1 *g-i*	14.0 *f-i*	14.8 *i*	12.8 *c*
$\overline{x}$	9.9 *b*	8.7 *a*	9.9 *b*	10.2 *b*	11.6 *c*	12.17 *c*	

Means followed by same letters are not significantly different at $\alpha = 0.05$.

Differences in the content of iron as well as manganese, zinc and copper under the influence of fertilization with $FeSO_4$ and Librel Fe-DTPA chelate are confirmed in a study by YLIVAINIO et al. (2004) with $FeSO_4$ and the chelates Fe-ETPA, Fe-EDDS and Fe-EDDHA.

In view of the iron nutrition status of lettuce, fertilization with Librel Fe-DTPA chelate at 45-120 mg Fe dm^{-3} is recommendable. This level provides the highest iron content in lettuce, similar yields and an optimal copper content. Reduced concentrations of zinc and manganese may be increased by fertilization with these microelements.

CONCLUSIONS

1. Application of iron (III) sulfate, iron (II) sulfate, iron citrate or iron gluconate ranging from 45 to 220 mg Fe dm^{-3}, or Librel Fe-DTPA chelate within the range from 45 to 120 mg Fe dm^{-3} did not have any significant effect on yields of lettuce. Librel Fe-DTPA applied at 220 mg Fe dm^{-3} resulted in reduced yields.

2. The highest Fe content (irrespectively of Fe rates) was found after the application of Librel Fe-DTPA chelate, while the lowest one – after the application of iron gluconate.

3. Irrespectively of the applied iron compounds, the highest increase in the content of iron in lettuce in relation to the control was found at 220 mg Fe dm^{-3} substrate.

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