ACTA Acta Sci. Pol., Hortorum Cultus 10(3) 2011, 3-13

INFLUENCE OF SOIL APPLICATION OF IODINE AND SUCROSE ON MINERAL COMPOSITION OF SPINACH PLANTS

Sylwester Smoleń, Włodzimierz Sady
University of Agriculture in Kraków

Abstract. Iodine is not an essential nutrient for plants. Side-effects of its application on mineral nutrition of plants have not yet been thoroughly documented. The aim of the study was to evaluate the influence of soil application of iodine and sucrose on mineral composition of spinach plants. In 2009–2010, a pot experiment with spinach *Spinacia oleracea* L. 'Olbrzym zimowy' cv. cultivation on mineral soil was carried out in the plastic tunnel. The research included diverse combinations with pre-sowing iodine fertilization (in the form of KI) and soil application of sucrose: 1) – control (without iodine fertilization and sucrose application), 2) – 1 mg I dm^{-3} of soil, 3) – 2 mg I dm^{-3} of soil, 4) – 1 mg I + 1 g sucrose dm^{-3} of soil and 5) – 2 mg I + 1 g sucrose dm^{-3} of soil. In spinach samples as well as soil after cultivation the content of: P, K, Mg, Ca, S, Na, B, Cu, Fe, Mn, Mo, Zn, Al, Ba, Cd, Ce, Co, Cr and La was determined using ICP-OES technique, while Cl – using nephelometric method. Iodine synergistically improved the uptake of Mg, Na and Ce as well as Fe (for Fe only in the case of higher iodine doses) while antagonistically affected Cr uptake by spinach plants. After application of iodine in a dose of 2 mg I dm^{-3} soil, higher accumulation of Na, Fe, Zn and Al was observed along with reduced concentration of P, S, Cu and Ba in spinach plants when compared to the control. Simultaneous application of iodine and sucrose (in comparison to the control or plants fertilized only with iodine) contributed to a significant increase in the accumulation of K, S and Mo as well decreased content of Mg, Fe, Ba, Co and La in spinach plants.

Key words: iodine, sucrose, mineral composition, heavy metals, trace elements, spinach

INTRODUCTION

In the last few years, iodine biofortification of crop plants (particularly vegetables) has been postulated as an alternative way – to salt iodization – of introducing this element into human diet [Strzetelski 2005, White and Broadley 2005, 2009, Yang et al.

Corresponding author – Adres do korespondencji: Sylwester Smoleń, Department of Soil Cultivation and Fertilization of Horticultural Plants, University of Agriculture in Kraków, Al. 29 Listopada 54, 31-425 Kraków, Poland, e-mail: ssmolen@ogr.ar.krakow.pl

2007, Zhao and McGrath 2009]. Development of agronomic principles concerning iodine application requires thorough research documenting wide aspects of iodine influence on plants. It is especially important as iodine is not included to the group of mineral nutrients for plants. In such as case, an assessment of iodine interaction on yield as well as physiological and biochemical processes taking place in plants, including mineral nutrition, is needed.

Previous studies on iodine biofortification of: cabbage [Weng et al. 2008], lettuce [Bai et al. 2007, Blasco et al. 2008], tomato and spinach [Gonda et al. 2007], alfalfa [Altmok et al. 2003], pakchoi, celery, pepper and radish [Hong et al. 2009] as well as radish [Strzetelski et al. 2010] have generally been focused on the optimization of plant enrichment in this element. In most cases, no information was given concerning side-effects occurring due to iodine application. Recognition of iodine influence on plant mineral nutrition is particularly significant as our preliminary studies revealed that depending on applied form (I^- or IO_3^-) and dose, this element can act antagonistically or synergistically on the uptake of other minerals by plants.

Plant uptake of iodine is dependent on its availability, which in turn is governed by the adsorption–desorption characteristics of soils [Dai et al. 2009]. Three days after iodine introduction to soil, approximately 95% of this element is strongly adsorbed by Fe and Al sesquioxides [Muramatsu et al. 1990, Yoshida et al. 1992]. Processes of iodine desorption to soil solution are slow and therefore limiting its uptake from soil by plant roots [Fuge and Johnson, 1986, Muramatsu et al. 1996, Yamaguchi et al. 2005]. It is described as one of the major causes of low effectiveness of iodine biofortification of crop plants through soil fertilization with this element. Iodine desorption takes place more effectively in soils with negative values of redox potential (Eh) which occur in anaerobic conditions, resulting e.g. from long-lasting excessive soil moisture. Studies conducted by Muramatsu et al. [1996] indicated that in soil incubated with sucrose, a decrease of Eh values was observed correlating with enhanced iodine desorption form soil.

In such a case, soil application of sucrose along with iodine fertilization would most probably improve the effectiveness of iodine biofortification of plants. On the other hand, lower values of Eh affect the level of available forms of mineral nutrients and heavy metals in soil [Calmano et al. 1993, Chuan 1996]. This, in turn, can significantly influence plant growth as well as the yield quantity and quality, e.g. through increased accumulation of heavy metals in edible parts of plants.

The aim of the study was to evaluate the influence of iodine fertilization and soil application of sucrose on mineral composition of spinach plants.

MATERIAL AND METHODS

Spinach (*Spinacia oleracea* L.) 'Olbrzym zimowy' c.v. was cultivated in the 2009–2010 in open-work containers sized 60 × 40 × 20 cm, placed in the plastic tunnel. The containers were filled with silt loam (35% sand, 28% silt and 37% clay) with mean content of organic matter 2.76% and the following concentrations of the available nutrient forms soluble in 0.03 M acetic acid: N ($N\text{-}NO_3$+$N\text{-}NH_4$) 58.7 mg, P 39.3 mg, K 73.3 mg, Mg 151.5 mg, Ca 1245.2, S 17.2, Na 6.8 and Cl 0.0 mg in 1 dm^{-3} soil. Soil $pH_{(H2O)}$ was 6.97, the oxidation-reduction (redox) potential of the soil (Eh): -326.7 mV, while soil salinity (electrical conductivity – EC) 0.31 mS cm^{-1}. The contents of assimilable forms of nitrogen, phosphorus and potassium were supplemented before the cultivation to the following levels: 100 mg N, 60 mg P and 160 mg K dm^{-3} of soil with the use of calcium nitrate, potassium phosphate and potassium sulfate. Plants in containers were irrigated with the same amount of tap water.

In the study, various combinations with pre-sowing fertilization with iodine (in the form of KI) and soil application of sucrose were applied including: 1) – control (without iodine and sucrose application), 2) – 1 mg I dm^{-3} of soil, 3) – 2 mg I dm^{-3} of soil, 4) – 1 mg I + 1 g sucrose dm^{-3} of soil and 5) – 2 mg I + 1 g sucrose dm^{-3} of soil. Iodine and sucrose were applied pre-sowing in the form of water solutions using 1 dm^{-3} of solution per 1 container.

The experiment was carried out according to randomized method in three replications. Each replicate (one container) consisted of 4 rows with 10 plants per row. Seeds sowing were performed on 20th and 23rd March in the subsequent years with 20 seeds in a row. After germination the plants were singled out leaving 10 seedlings in one row (40 plants per one container). Spinach was harvested on 28th April 2009 and 4th May 2010.

Each year, shredded plant material (spinach leaves) was dried at 70°C and mineralized in 65% super pure HNO_3 (Merck no. 100443.2500) in a CEM MARS-5 Xpress microwave oven [Pasławski and Migaszewski 2006]. In mineralized plant material concentration of P, K, Mg, Ca, S, Na, B, Cu, Fe, Mn, Mo, Zn, Al, Ba, Cd, Ce, Co, Cr and La was determined using ICP-OES technique with the use of a Prodigy Teledyne Leeman Labs USA spectrometer. Chloride content (Cl^-) in spinach was assessed using nephelometric method after extraction with 2% CH_3COOH [Nowosielski 1988].

In both years of the study concentration of P, K, Mg, Ca, S, Na (after extraction with 0.03 mol CH_3COOH) and B, Cu, Fe, Mn, Mo, Zn, Al, Ba, Cd, Ce, Co, Cr and La (after extraction with 1 mol HCl) in soil after the harvest was determined by ICP-OES method. Concentration of Cl in soil prior to seed sowing as well as after cultivation (in 0,03 mol CH_3COOH extracts) was assayed according to nephelometric method. Soil $pH_{(H2O)}$ and Eh were assessed by potentiometer, while salinity (EC) – conductometrically.

Prior to the experiment, organic matter concentration in soil was determined using Tiurin method modified by Oleksynowa. The content of N-mineral (N-NH_4, N-NO_3), P, K, Mg, Ca, S, and Na was determined after extraction with 0.03 mol CH_3COOH [Nowosielski 1988]. Nitrogen level was estimated by FIA technique [PN-EN ISO 13395:2001, PN-EN ISO 11732:2005 (U)], while P, K, Mg, Ca, S, and Na were assessed by ICP-OES method.

Obtained results were statistically verified by ANOVA module of Statistica 8.0 PL program for significance level $P < 0.05$. Changes of any significance were assessed with the use of variance analysis. In case of significant changes homogenous groups were determined on the basis of Duncan test.

RESULTS AND DISCUSSION

Meteorological data. During spinach cultivation (in 2009 and 2010) the course of mean daily temperature and relative humidity remained at a comparable level (fig. 1). Mean daily temperature and air humidity throughout spinach cultivation were respectively: 13.7°C and 67.4% RH in 2009 while 15.5°C and 68.8% RH in 2010.

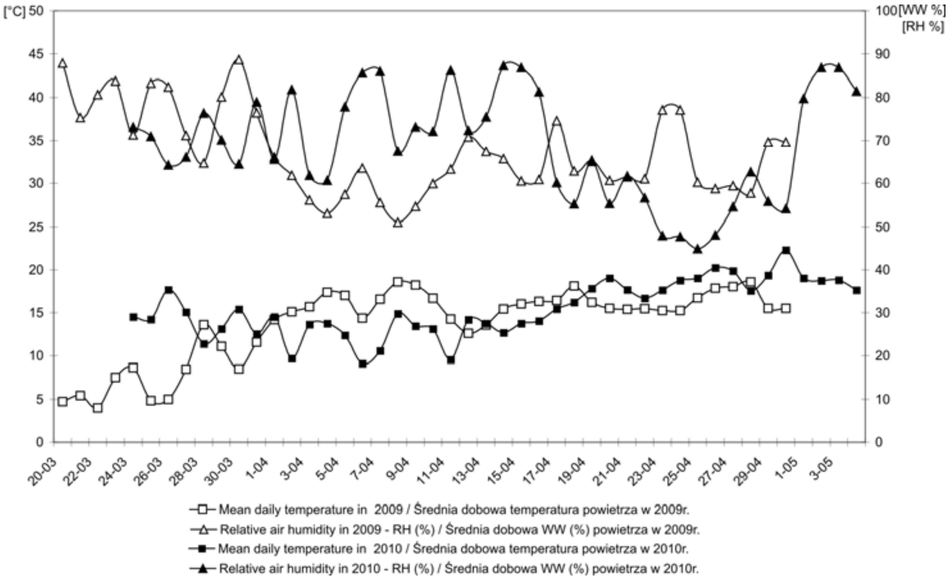

Fig 1. Mean daily temperature and relative air humidity during spinach cultivation in a foil tunnel in both years of the study

Ryc. 1. Średnia dobowa temperatura i wilgotność względna powietrza w okresie uprawy szpinaku w tunelu foliowym

Mineral content of spinach and soil. In the present study, iodine fertilization together with soil application of sucrose had a statistically significant effect on spinach content of: P, K, Mg, Ca, S, Na, Cu, Fe, Mn, Mo, Zn, Al, Ba, Ce, Co, Cr and La while no relevant changes was observed in relation to the level of Cl, B and Cd in spinach plants (table 1–3). It should be underlined however that the range of mentioned influence was specific for both iodine fertilization as well as for interaction between soil application of iodine and sucrose.

Taking into consideration the effect of iodine fertilization (in both doses, irrespective to sucrose application), it was observed that introduction of this element contributed to increased concentration of Mg, Na, Ce (synergistic interaction) as well as reduced accumulation of Cr (antagonistic interaction) in spinach plants in comparison to the control (table 1–3).

Table 1. Content of P, K, Mg, Ca, S, Na and Cl in spinach leaves and in soil after spinach cultivation (means for 2009–2010)
Tabela 1. Zawartość P, K, Mg, Ca, S, Na i Cl w liściach szpinaku oraz w glebie po uprawie szpinaku (średnie z lat 2009–2010)

	Iodine and sucrose doses per 1 dm^3 of soil Dawki jodu i sacharozy na dm^3 gleby	P	K	Mg	Ca	S	Na	Cl
Spinach % d.w. Szpinak % s.m.	Control – Kontrola	0.75 ab	9.72 ab	1.04 b	1.52 bc	0.42 b	0.16 a	1.09
	1 mg I	0.78 c	9.96 bc	1.07 bc	1.54 c	0.42 b	0.20 b	1.17
	2 mg I	0.73 a	9.64 a	1.08 c	1.50 abc	0.40 a	0.21 c	1.36
	1 mg I + 1 g sucrose – sacharoza	0.76 bc	10.83 d	0.99 a	1.48 ab	0.46 c	0.16 a	1.16
	2 mg I + 1 g sucrose – sacharoza	0.75 ab	10.09 c	0.96 a	1.46 a	0.46 c	0.16 a	1.42
	Test *F* for mineral content in spinach Test *F* dla zawartości pierwiastków w szpinaku	*	*	*	*	*	*	n.s. n.i.
Soil $mg \cdot dm^{-3}$ Gleba $mg \cdot dm^{-3}$	Control – Kontrola	61.7 a	72.8 a	106.6	1017.0	76.7 ab	14.5 abc	5.5
	1 mg I	70.0 b	90.6 b	112.0	1147.7	91.4 c	15.2 c	6.0
	2 mg I	58.5 a	75.4 a	113.4	1097.9	79.3 abc	12.6 a	6.0
	1 mg I + 1 g sucrose – sacharoza	56.7 a	76.6 a	113.3	1088.8	68.8 a	13.0 ab	4.5
	2 mg I + 1 g sucrose – sacharoza	70.4 b	96.2 b	119.5	1159.7	86.5 bc	15.0 bc	3.8
	Test *F* for mineral content in soil Test *F* dla zawartości pierwiastków w glebie	*	*	n.s. n.i.	n.s. n.i.	*	*	n.s. n.i.

Means followed by the same letters are not significantly different for $P < 0.05$. Test *F*: * – means are significantly different, n.s. – not significant.
Średnie oznaczone tymi samymi literami nie różnią się istotnie dla P < 0,05. Test F: * – średnie różnią się istotnie, n.i. – brak istotnego zróżnicowania.

Conducted studies revealed a significant influence of diverse iodine doses (combinations no. 2 and 3) on the content of P, S, Na, Cu, Fe, Zn, Al and Ba in spinach. Application of higher iodine dose, in comparison to 1 mg I dm^{-3}, resulted in greater concentration of Na, Fe, Zn and Al as well as reduced the accumulation of P, S, Cu and Ba in spinach plants (table 1–3). Significantly enough, iron concentration after fertilization with 2 mg I dm^{-3} was even higher than in the control combination. At the same time, soil concentration of Fe remained at a comparable level in those three tested combinations. Thus, obtained results show that higher doses of iodine (applied without sucrose) can stimulate Fe uptake by spinach plants. It is worth adding that sulfur content in spinach plants fertilized with 2 mg I dm^{-3} was lower when compared to the control. In case of this element, revealed changes in S concentration in plants were not directly reflected by detected diversity of soil content of S forms easily soluble in 0.03 M acetic acid. Spinach plants grown in the presence of lower iodine dose (1 mg I dm^{-3} of soil) contained the highest amount of P in leaves. This observation can be related with determined greater concentration of this element in soil from this combination. Similarly, revealed diversity of Al accumulation in spinach could have been reflected by respective concentrations of this element in soil from particular combinations. No such relations were found for Na, Cu, Zn and Ba.

In both tested combinations with simultaneous application of iodine and sucrose (in comparison to fertilization with iodine only), increase in the content of K, S and Mo as well as Zn (for Zn in the case of 1 mg I dm^{-3} dose) along with reduced accumulation of Mg, Na, Fe Ba, Ce, Co and La were observed in spinach plants (table 1–3). In the case of Ca and Mn, decrease in the content of these elements was caused solely by application of sucrose in 1 mg I dm^{-3} dose. In respect of Al and Cr, a similar reaction was found after pre-sowing application of sucrose and iodine in the dose of 2 mg I dm^{-3} of soil.

Table 2. Content of B, Cu, Fe, Mn, Mo and Zn in spinach leaves and in soil after spinach cultivation (means for 2009–2010)
Tabela 2. Zawartość B, Cu, Fe, Mn, Mo i Zn w liściach szpinaku oraz w glebie po uprawie szpinaku (średnie z lat 2009–2010)

	Iodine and sucrose doses per 1 dm^3 of soil Dawki jodu i sacharozy na dm^3 gleby	B	Cu	Fe	Mn	Mo	Zn
Spinach $mg \cdot kg^{-1}$ d.w. Szpinak $mg \cdot kg^{-1}$ s.m.	Control – Kontrola	23.2	9.54 ab[1]	326.6 c	42.2 b	0.25 ab	137.2 bc
	1 mg I	23.6	9.66 b	336.2 c	42.5 b	0.24 ab	127.6 a
	2 mg I	23.0	9.28 a	347.2 d	43.3 b	0.22 a	138.8 bc
	1 mg I + 1 g sucrose – sacharoza	23.2	9.58 b	299.4 b	40.6 a	0.30 c	135.4 b
	2 mg I + 1 g sucrose – sacharoza	22.8	9.37 ab	268.4 a	42.7 b	0.27 bc	139.7 c
	Test *F* for mineral content in spinach Test *F* dla zawartości pierwiastków w szpinaku	n.s. n.i.	*	*	*	*	*
Soil $mg \cdot kg^{-1}$ Gleba $mg \cdot kg^{-1}$	Control – Kontrola	1.24	5.28 c	1731.4 b	250.3	0.11	53.2 c
	1 mg I	1.20	5.08 abc	1612.2 ab	237.1	0.10	48.6 b
	2 mg I	1.20	5.11 bc	1621.4 ab	248.1	0.11	48.1 b
	1 mg I + 1 g sucrose – sacharoza	1.16	4.89 ab	1536.2 a	236.5	0.10	45.5 ab
	2 mg I + 1 g sucrose – sacharoza	1.21	4.74 a	1488.6 a	227.0	0.09	44.5 a
	Test *F* for mineral content in soil Test *F* dla zawartości pierwiastków w glebie	n.s. n.i.	*	*	n.s. n.i.	n.s. n.i.	*

1 – See table 1 – Opis jak w tabeli 1.

What should be underlined is that application of iodine and sucrose (in both tested combinations) contributed to a significant increase in the level of K, S and Mo in spinach when compared not only to plants fertilized with iodine alone but also to the control. Adversely, fertilization with I and sucrose (in both doses) reduced accumulation of Mg, Fe, Ba, Co and La in spinach below its concentration detected for the control plants as well as plants treated with iodine only. Only in the case of K, Fe and Ba did iodine dose influence observed relation. Increased accumulation of K was more distinctly observed for lower iodine dose application (1 mg I + 1 g sucrose dm^{-3}). As for Fe and Ba, higher iodine dose applied together with sucrose (2 mg I + 1 g sucrose dm^{-3}) more strongly reduced the uptake and accumulation of mentioned elements in spinach plants.

Generally, little information is available concerning iodine effect on plant nutrition with mineral nutrients what makes it particularly difficult to discuss the results obtained in our study. In their pioneer studies, Hageman et al. [1942] revealed a significant influence of iodine on Ca, Cu, Fe, Mg and Mn content in tomato plants. However, applied iodine doses over 2 ppm contributed to numerous plant damages and those exceeding 16 ppm caused plant death. Tomato plants fertilized with 2 ppm of iodine contained relatively more Mn, Cu as well as Fe than control plants. It is worthy to mention that in plants from this particular combination 1.29% more ash was determined when compared to the control, which supports the hypothesis of iodine fertilization affecting the level of plant mineral nutrition. In the studies on field cultivation of lettuce [Smoleń et al. 2011 a], both foliar and soil application of iodine contributed to increased concentration of Mg, Ca, Mn and Cd as well reduced accumulation of P, Cu and Zn in lettuce leaves. Diverse influence of iodine dose, form and method of application was however observed in reference to the content of K, S, Na, B, Fe, Mo, Al and Pb in lettuce. Conducted experiment with field cultivation of carrot [Smoleń et al. 2011 b] revealed that soil fertilization with iodine resulted in higher concentration of P, Zn Cd and Pb (synergistic effect) as well decreased Cu content in carrot storage roots.

Table 3. Content of Al, Ba, Cd, Ce, Co, Cr and La in spinach leaves and in soil after spinach cultivation (means for 2009–2010)
Tabela 3. Zawartość Al, Ba, Cd, Ce, Co, Cr i La w liściach szpinaku oraz w glebie po uprawie szpinaku (średnie z lat 2009–2010)

	Iodine and sucrose doses per 1 dm^3 of soil Dawki jodu i sacharozy na dm^3 gleby	Al	Ba	Cd	Ce	Co	Cr	La
Spinach $mg \cdot kg^{-1}$ d.w. Szpinak $mg \cdot kg^{-1}$ s.m.	Control – Kontrola	363.0 c[1]	6.7 c	1.9	1.1 a	0.152 b	0.96 d	0.43 b
	1 mg I	329.9 b	7.0 d	1.9	1.3 b	0.151 b	0.88 bc	0.43 b
	2 mg I	354.0 c	6.7 c	2.0	1.2 b	0.152 b	0.90 cd	0.44 b
	1 mg I + 1 g sucrose – sacharoza	316.4 b	6.3 b	2.0	1.0 a	0.137 ab	0.82 b	0.39 a
	2 mg I + 1 g sucrose – sacharoza	287.8 a	6.0 a	2.0	1.1 a	0.130 a	0.71 a	0.36 a
	Test *F* for mineral content in spinach Test *F* dla zawartości pierwiastków w szpinaku	*	*	n.s. n.i.	*	*	*	*
Soil $mg \cdot kg^{-1}$ Gleba $mg \cdot kg^{-1}$	Control – Kontrola	1381.8 c	54.5	0.98	11.97 c	1.50	1.32	5.83 c
	1 mg I	1300.9 abc	53.2	0.94	11.42 abc	1.45	1.27	5.60 abc
	2 mg I	1312.3 bc	53.4	0.95	11.66 bc	1.52	1.28	5.70 bc
	1 mg I + 1 g sucrose – sacharoza	1227.6 ab	50.9	0.92	11.02 ab	1.47	1.21	5.39 ab
	2 mg I + 1 g sucrose – sacharoza	1189.7 a	50.2	0.90	10.72 a	1.40	1.17	5.25 a
	Test *F* for mineral content in soil Test *F* dla zawartości pierwiastków w glebie	*	n.s. n.i.	n.s. n.i.	*	n.s. n.i.	n.s. n.i.	*

1 – See table 1 – Opis jak w tabeli 1.

On the basis of the present and previous studies conducted by Smoleń et al. [2011 a, b] it can be stated that iodine applied into soil (in the form of KI) synergistically influences the uptake of magnesium but antagonistically affects copper absorption – these relations were confirmed for spinach as well as lettuce and carrot cultivation [Smoleń et al. 2011 a, b]. KI form of iodine can lower P content in leafy vegetables such as spinach and lettuce (Table 1 and [Smoleń et al. 2011 a]) while increase its accumulation in carrot storage roots [Smoleń et al. 2011 b, c]. To sum up the results obtained both in the present and previous studies [Smoleń et al. 2011 a, b, c] it should be underlined that iodine interaction on uptake and accumulation of other tested mineral nutrients (apart from discussed P, Mg and Cu) along with heavy metals and trace elements in plants can be influenced by numerous factors. Among the most important ones, the following should be included: iodine form, dose and method of its application; conditions of plant cultivation as well as genotypic variation in efficiency of nutrient uptake by plants.

The level of easily available forms of iodine, mineral nutrients, heavy metals and trace elements in soil is strongly affected by soil pH and redox potential [Fuge and Johnson, 1986, Calmano et al. 1993, Chuan 1996]. In the present study, fertilization with iodine only had no significant influence on pH and electrical conductivity (EC) of soil after spinach cultivation when compared to the control (table 4). It was observed, however, that soil application of higher dose of iodine (also together with sucrose) resulted in a relatively small but statistically significant increase in soil Eh when compared to the control and fertilization with 1 mg I dm^{-3}. In this particular case, change in redox potential of soil did not, however, significantly affected soil content of tested elements in comparison to other combinations (table 1–3). It is worth to mention that simultaneous application of iodine and sucrose (especially in the dose of 1 mg I + 1 g sucrose dm^{-3}) contributed to relatively insignificant increase in soil reaction (pH) as well as lowered value of EC and Eh. Still, it did not directly affected the level of easily soluble forms of mineral nutrients, heavy metals and trace elements in soil after spinach cultivation.

Table 4. Soil $pH_{(H_2O)}$, salinity (electrical conductivity – EC) and oxidation-reduction (redox) potential (Eh) – (means for 2009–2010)

Tabela 4. Odczyn (pH_{H_2O}), koncentracja soli ogółem (EC) oraz potencjał oksydo-redukcyjny (Eh) gleby po uprawie szpinaku – (średnie z lat 2009–2010)

Iodine and sucrose doses per 1 dm^3 of soil Dawki jodu i sacharozy na dm^3 gleby	$pH_{(H_2O)}$	EC (mS cm^{-1})	Eh (mV)
	6.78 a[1]	0.37 b	336.7 b
Control – Kontrola	6.79 a	0.40 b	338.3 b
1 mg I	6.75 a	0.39 b	341.8 c
2 mg I	7.05 c	0.27 a	330.1 a
1 mg I + 1 g sucrose – sacharoza	6.94 b	0.38 b	337.2 b
Test *F* for a particular soil property Test *F* dla właściwości gleby	*	*	*

1 – See table 1 – Opis jak w tabeli 1.

Studies conducted by Muramatsu et al. [1996] revealed that after 60-day soil incubation with 5 g dm^{-3} soil dose of sucrose (laboratory test), a decrease in soil Eh from positive (app. +580 mV) to negative values (app. -200 mV) was noted. This observation was highly correlated with enhanced iodine desorption form soil. In the present work, the range of Eh reduction in soil after sucrose application was relatively small (table 4). A possible explanation could be the application of fivefold lower concentration of sucrose than used by Muramatsu et al. [1996]. Additionally, in our work sucrose was introduced to soil during spinach cultivation. Prior to the study, a trial 13-day laboratory incubation with 5 g dm^3 of soil dose of sucrose and glucose was carried out on soil subsequently used for spinach cultivation. Sucrose application contributed to a decrease in Eh values from +238.5 to -116.3 mV, while glucose – to the level of -66.7 mV.

In soil samples collected before spinach cultivation no chlorides was determined (Material and Methods chapter). Hence, a particular attention should be given on the fact that a significant amount of chloride ions was detected in spinach plants (table 1) even though no mineral fertilizer containing Cl^- was used throughout the cultivation. Consequently, tap water used for irrigation was a major source of chlorides for plants as well as soil after spinach cultivation. The assessed chloride content in tap water was equal to 14.6 mg dm^{-3}.

CONCLUSIONS

Analysis of mineral composition of spinach leaves revealed that iodine synergistically improved the uptake of Mg, Na, Ce and Fe (for Fe – only in the case of higher I dose) as well as negatively affected Cr uptake by spinach.

After application of 2 mg I dm^{-3} of soil, in comparison to fertilization with lower dose of iodine, higher concentration of Na, Fe, Zn and Al as well as reduced content of P, S, Cu and Ba were observed in spinach plants.

Simultaneous application of iodine and sucrose, when compared to the control and fertilization with iodine only, contributed to: a significant increase in the accumulation of K, S and Mo as well lowered level of Mg, Fe, Ba, Co and La in spinach plants.

Increasing iodine dose from 1 to 2 mg I dm^{-3} of soil applied with the same amount of sucrose resulted in a significantly higher content of K as well as reduced uptake of Fe and Ba by spinach plants.

Among all determined elements, only in the case of Al could obtained variation in its content in spinach plants have been directly related to the interaction of tested factors on Al level in soil.

A relatively weak influence of iodine and simultaneous application of I and sucrose was noted in reference to soil pH and redox potential. It did not, however, directly affect the level of easily soluble forms of tested elements in soil after spinach cultivation.

REFERENCES

Altmok S., Sozudogru-Ok S., Halilova H., 2003. Effect of iodine treatments on forage yields of alfalfa. Com. Soil Sci. Plant Anal. 34 (1–2), 55–64.

Bai G., Nakahara T., Murase H., Ueno D., Akao S., Someya T., Inoue K., 2007. Marking by introducing iodine into lettuce grown in hydroponics to certify the provenance. J. Sci. High Techn. Agric. 19 (3), 137–140.

Blasco B., Rios J.J., Cervilla L.M., Sanchez-Rodriguez E., Ruiz J.M., Romero L., 2008. Iodine biofortification and antioxidant capacity of lettuce: potential benefits for cultivation and human heath. Ann. Appl. Biol. 152, 289–2999.

Calmano W., Hong J., Förstner U., 1993. Binding and mobilization of heavy metals in contaminated sediments affected by pH and redox potential. Wat. Sci Tech. 28 (8–9), 223–235.

Chuan M.C., Shu G.Y., Liu J.C., 1996. Solubility of heavy metals in a contaminated soil: Effects of redox potential and pH.. Water, Air, Soil Poll. 90 (3–4), 543–556.

Fuge R., Johnson C.J., 1986. The geochemistry of iodine–a review. Environ. Geochem. Health 8 (2), 31–54.

Dai J.L., Zhang M., Hu Q.H., Huang Y.Z., Wang R.Q., Zhu Y.G., 2009. Adsorption and desorption of iodine by various Chinese soils: II. Iodide and iodate. Geoderma 153, 130–135.

Gonda K., Yamaguchi H., Maruo T., Shinohara Y., 2007. Effects of iodine on growth and iodine absorption of hydroponically grown tomato and spinach. Hort. Res. Japan. 6 (2), 223–227.

Hageman R.H., Hodge E.S., McHargue J.S., 1942. Effect of potassium iodide on the ascorbic acid content and growth of tomato plants. Plant Physiol. 17 (3), 465–72.

Hong C.-L., Weng H.-X., Yan A.-L., 2009. The fate of exogenous iodine in pot soil cultivated with vegetables. Environ. Geochem. Heath., 31 (1), 99–108.

Muramatsu Y., Yoshida S., Uchida S., 1996. Iodine Desorption From Rice Paddy Soil. Water, Air Soil Poll. 86, 359–371.

Muramatsu, Y., Uchida, S., Sriyotha, P., Sriyotha, K., 1990. Some considerations on the sorption and desorption phenomena of iodide and iodate on soil. Water Air Soil Pollut. 49, 125–138.

Nowosielski, O., 1988. The rules in development of fertilizing strategies in horticulture. PWRiL Publisher, Warsaw (In Polish).

Pasławski P., Migaszewski Z.M., 2006. The quality of element determinations in plant materials by instrumental methods. Polish J. Environ. Stud. 15(2a), Part I, 154–164.

PN-EN ISO 11732:2005 (U). Water quality. Determination of ammonium nitrogen. Method by flow analysis (CFA and FIA) and spectrometric detection. (In Polish).

PN-EN ISO 13395:2001. Water quality – Determination of nitrite nitrogen and nitrate and the sum of both by flow analysis (CFA and FIA) and spectrometric detection. (In Polish).

Smoleń S., Rożek S., Ledwożyw-Smoleń I., Strzetelski P., 2011a. Preliminary evaluation of the influence of soil fertilization and foliar nutrition with iodine on the efficiency of iodine biofortification and chemical composition of lettuce. J. Element. *In print.*

Smoleń S., Rożek S., Strzetelski P., Ledwożyw-Smoleń I., 2011b. Preliminary evaluation of the influence of soil fertilization and foliar nutrition with iodine on the effectiveness of iodine biofortification and mineral composition of carrot. J. Element. 16 (1), 103–114.

Smoleń S., Sady W., Rożek S., Ledwożyw-Smoleń I., Strzetelski P., 2011c. Preliminary evaluation of the influence of iodine and nitrogen fertilization on the effectiveness of iodine biofortification and mineral composition of carrot storage roots. J. Element. *In print.*

Strzetelski P., 2005. Występowanie i przemieszczanie jodu w systemie gleba-roślina. Post. Nauk Roln. 6, 85–100.

Strzetelski P., Smoleń S., Rożek S., Sady W., 2010. The effect of differentiated fertilization and foliar application of iodine on yielding and antioxidant properties in radish (*Raphanus sativus* L.) plants. Ecol. Chem. Eng. 17 (9), 1189–1195.

Weng H.-X., Hong C.-L., Yan A.-L., Pan L.-H., Qin Y.-C., Bao L.-T., Xie L.-Li., 2008. Mechanism of iodine uptake by cabbage: Effects of iodine species and where it is stored. Biol. Trace Elem. Res. 125 (1), 59–71.

White P.J., Broadley M.R., 2005. Biofortifying crops with essential mineral elements. Trends Plant Sci. 10 (12), 586–593.

White P.J., Broadley MR., 2009. Biofortification of crops with seven mineral elements often lacking in human diets – iron, zinc, copper, calcium, magnesium, selenium and iodine. New Phytol., 182 (1), 49–84.

Yamaguchi N., Nakano M., Tanida H., 2005. Transformation of iodine species in soil under upland field and submerged paddy field conditions. SPring-8 Res Front 2005. http://www.spring8.or.jp/pdf/en/res_fro/05/112–113.pdf.

Yang X.-E., Chen W.-R., Feng Y., 2007. Improving human micronutrient nutrition through biofortification in the soil-plant system: China as a case study. Environ. Geochem. Heath. 29 (5), 413–28.

Yoshida S., Muramatsu Y., Uchida S., 1992. Studies on the sorption of I^- (iodide) and IO_3^- (iodate) onto andosols. Water Air Soil Pollut. 63, 321–329.

Zhao F.-J., McGrath S.P., 2009. Biofortification and phytoremediation. Curr. Opin. Plant Biol. 12, 373–380.

WPŁYW JODU I SACHAROZY STOSOWANYCH DOGLEBOWO NA SKŁAD MINERALNY SZPINAKU

Streszczenie. Jod nie jest składnikiem pokarmowym roślin. Jego uboczny wpływ na gospodarkę mineralną roślin nie został dobrze udokumentowany. Celem badań było określenie oddziaływania jodu oraz doglebowego wnoszenia sacharozy na skład mineralny roślin szpinaku. W latach 2009–2010 w tunelu foliowym przeprowadzono doświadczenie wazonowe z uprawą szpinaku *Spinacia oleracea* L. ‘Olbrzym zimowy’ na glebie mineralnej. Badaniami objęto zróżnicowane kombinacje z przedsiewnym doglebowym stosowaniem jodu (w formie KI) i sacharozy: 1) – kontrola (nienawożona jodem i bez aplikacji sacharozy), 2) – 1 mg I dm^{-3} gleby, 3) – 2 mg I dm^{-3} gleby, 4) – 1 mg I + 1 g sacharozy dm^{-3} gleby i 5) – 2 mg I + 1 g sacharozy dm^{-3} gleby. W szpinaku oraz w glebie po uprawie oznaczono zawartość P, K, Mg, Ca, S, Na, B, Cu, Fe, Mn, Mo, Zn, Al, Ba, Cd, Ce, Co, Cr i La techniką ICP-OES oraz zawartość Cl metodą nefelometryczną. Jod oddziaływał synergistycznie na pobieranie Mg, Na i Ce oraz Fe (dla Fe tylko wyższa dawka jodu) oraz antagonistycznie na pobieranie Cr przez rośliny szpinaku. Po zastosowaniu jodu w dawce 2 mg I dm^{-3} gleby, w porównaniu do nawożenia jodem w niższej dawce, odnotowano zwiększenie zawartości Na, Fe, Zn i Al oraz obniżenie zawartości P, S, Cu i Ba w szpinaku. Łączne użycie jodu i sacharozy (w porównaniu do nawożenia roślin samym jodem oraz w odniesieniu do kontroli) powodowała istotny wzrost zawartości K, S i Mo oraz obniżenie zawartości Mg, Fe, Ba, Co i La w szpinaku.

Słowa kluczowe: jod, sacharoza, skład mineralny, metale ciężkie, pierwiastki śladowe, szpinak

Accepted for print – Zaakceptowano do druku: 8.04.2011