THE EFFECT OF FOLIAR NUTRITION WITH NITROGEN, MOLYBDENUM, SUCROSE AND BENZYLADENINE ON THE CONTENTS OF DRY WEIGHT, Cd, Cu AND Zn IN CARROT

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Summary

Carrot Kazan F₁ cv. was grown in containers 60×40×20 cm in size, placed on the open site under shadow fabric. The loam clay was used as the substrate, supplemented with the assimilable components to the following levels: 100 mg N, 80 mg P, 120 mg K, 80 mg Mg, 2000 mg Ca·dm⁻³ of the soil. In the treatments triple foliar nutrition with the following solutions: 1-control (no foliar nutrition), 2-urea, 3-urea+Mo, 4-urea+Mo+BA (benzyladenine), 5-urea+Mo+BA+sucrose, 6-BA 5 and 7-BA 10 was applied. The concentrations of 20 g·dm⁻³ (urea and sucrose), 1 mg·dm⁻³ (Mo) and 5 mg·dm⁻³ (benzyladenine) were applied in combined solutions, while BA alone was used either as 5 or 10 mg·dm⁻³. Foliar nutrition significantly affected dry weight content, Cu and Zn but had no influence on Cd concentration in carrot. The highest content of dry weight was assessed in carrot sprayed with Urea+Mo+Ba+sucrose solution and BA 10. The greatest amounts of Cu were found in storage roots of crops sprayed with Urea+Mo solution, whereas the highest contents of Zn were detected in plants receiving only urea foliar nutrition. A marked effect of interaction of foliar nutrition with the years of research were observed only for Zn concentrations in carrot. Soil of the individual experimental treatments after carrot cultivation differed significantly with respect to its pH reaction and concentrations of readily soluble forms Cd, Cu and Zn.

key words: carrot, foliar nutrition, cadmium, benzyladenine, urea, sucrose

INTRODUCTION

Foliar nutrition with nutrients influences on the larger yield and contents of dry weight in plants (Marschner 1995), but at the same time the effectiveness of this treatment depends among others on the degree of plant feeding and soil

abundance in nutrients (Komosa 1990). Plants may be also fed by foliarly applied sugars. Studies of Kováčik (1999) revealed that foliar nutrition of garden radish with sucrose caused an increase in the level of yielding and diminishing nitrate content in storage organs of this plant.

Benzyladenine (BA) is a synthetic cytokinin. Physiological role of this group of plant hormones is connected with stimulating cell divisions, delaying ageing processes, stimulating seed germination, shortening the bud rest period and regulation of biochemical processes - regulation of enzymes activity (Borkowska 1997). Few papers point to the fact that exogenous cytokinines may affect the nutrient uptake by plants. Studies conducted by Wang *et al.* (2003) revealed that foliar spraying of BA (in concentration 10^{-8} M) of the NH_4^+ - fed tobacco plants enhanced K^+ uptake (by 88%) and xylem transport (by 26%), and stimulated net deposition of K^+ in the upper and middle leaves and in the stem. Phloem retranslocation of K^+ from shoots to roots amounted up to 53% of the xylem transport of K^+ , while K^+ mobilization from the lower leaves and roots was reduced. The effect of this phytohormone combined with foliar nutrition on microcomponent and heavy metal uptake by plants has not been finally properly diagnosed.

The research aimed at determining the effect of urea, sucrose, molybdenum and benzyladenine foliar nutrition on dry mass and Cd, Cu and Zn content in carrot storage roots.

MATERIAL AND METHODS

In years 2004-2005 carrot Kazan F₁ was cultivated in $60 \times 40 \times 20$ cm latticed containers, placed in the open field under a shadow fabric. The containers were filled in with medium silt loam (3% sand, 28% silt and 37% clay) with mean content of organic substance 3.25%, and the following content of the available nutrient forms soluble in 0.03 M acetic acid: N ($\text{N-NO}_3 + \text{N-NH}_4$) 28.0 mg, P 4.3 mg, K 28.8 mg, Mg 137.4 mg and Ca - 1424.7 mg in 1 dm³ of soil, and average total contents of Cd 1.04 mg, Cu 45.0 mg and Zn 202.1 mg per 1 kg of soil. The total sorption capacity of the soil used for the experiment was $11.2 \text{ cmol}^+ \cdot \text{kg}^{-1}$ at 89.8% base saturation ratio. The soil reaction $\text{pH}_{\text{H}_2\text{O}}$ was 7.29, pH_{KCl} 6.70 while total salt content (EC) was on the level of $0.45 \text{ mS} \cdot \text{cm}^{-1}$.

Seeds were sown on 20.04.2004 and 27.04.2005. The content of the available nutrient forms during vegetation period was maintained on the following levels: P 80 mg, K 120 mg, Mg 80 mg, Ca 2000 mg·dm⁻³ of soil by means of fertilization (based on the results of the soil chemical analysis) conducted on 8.04. and 5.07. 2004 and 25.04. and 1.07. 2005. Nutrients were supplied to the soil in KH_2PO_4 , K_2SO_4 , CaCO_3 and $\text{MgSO}_4 \cdot 7 \text{ H}_2\text{O}$ with microelements (contained: 0.35% Mn, 0.3% Cu, 0.2% Zn, 0.05% B and 0.01% Mo). The soil was fertilized with nitrogen three times during the vegetation period (i.e. on 20.04., 5.07. and 23.08. 2004, and on 25.04., 1.07. and 22.08.2005) basing on the results of the soil chemical analysis to supplement the N-mineral content to the level of 100 mg N·dm⁻³ of soil.

The experimental objects included foliar sprays of plants with the solutions of following compounds: 1-control (no foliar nutrition), 2-urea, 3-urea+Mo, 4-urea+Mo+BA, 5-urea+Mo+BA+sucrose, 6-BA and 7-BA 10. The plants in individual objects were sprayed thrice (on 30.06., 6.08. and 24.08.2004 and on 28.06., 1.08. and 23.08.2005) with solutions containing: 20 g·dm⁻³ of urea and sucrose, 1 mg·dm⁻³ of Mo and 5 mg·dm⁻³ BA (benzyladenine). In BA 10 object the 10 mg·dm⁻³ benzyladenine concentration was used.

Carrot was harvested and its yield was assessed on 15.09.2004 and 27.09.2005, at the same time the soil was sampled for analyses. The soil reaction pH_{H₂O} was assessed by potentiometer and organic matter with Tiurin method modified by Oleksynowa. Base saturation ratio was determined with AAS method after soil extraction with 1 M NH₄Cl. Total content of Cd, Cu and Zn content in soil were assessed using *Aqua Regia* method, readily soluble forms of Cd, Cu and Zn in soil were assessed after extraction with 0.01 M CaCl₂. Analysis of carrot storage roots were conducted at harvest on fresh plant material. The content of dry matter was assessed at 105°C, Cd, Cu and Zn concentrations in carrot storage roots were determined after mineralization in a mixture of HNO₃ : HClO₄ : H₂SO₄ in the 6 : 2 : 0.25 ratio. The assessments of Cd, Cu and Zn in soil and plant material samples were conducted with AAS method.

Statistical analyses of the obtained results were conducted using ANOVA module of Statistica 6.1 PL programme for P=0.05. The significance of differences was calculated with Tukey's test. The second experimental factor, i.e. the influence of climatic conditions on content of dry matter, Cd, Cu and Zn concentrations in carrot storage roots, was shown in the statistical calculations.

The year 2005 was characterized by a higher daily temperature in May, July and September, but lower temperature in August as compared with 2004 (Table 1).

Table 1. Meteorological data for the region where experiments were localized (Kraków-Balice) for the period of experiments in years 2004-2005

Month	Year 2004			Year 2005		
	Average air temperature (°C)	Rainfall (mm)	Sunshine (h)	Average air temperature (°C)	Rainfall (mm)	Sunshine (h)
May	12.7	42.6	193.7	14.5	61.3	241.5
June	16.8	56.4	180.1	17.0	40.6	249.3
July	18.4	97.4	200.9	19.9	134.4	220.4
August	18.7	77.2	229.0	17.3	102.6	182.3
September	13.3	36.1	188.3	14.0	27.2	190.9
Mean	16.0	61.9	198.4	16.5	73.2	216.9
Sum	-	309.7	992.0	-	366.1	1084.4

In both years of investigations mean daily temperatures in June were approximate. The year 2005 had slightly higher total rainfall in May, July and August but lower in June and September than 2004. A relatively high monthly number of sunshine hours were observed in May, June and July 2005 and in August 2004. On the other hand in both years of the experiment September was characterized by an approximate number of sunshine hours. Generally the year 2005 was characterized by a higher number of rainfall total and greater number of sunshine hours during carrot vegetation than the year 2004.

RESULTS

The experiment results revealed that the applied foliar nutrition with various combinations of solutions significantly affected dry mass content in carrot storage roots (Table 2). The highest content of dry weight was characteristic for carrot sprayed with Urea+Mo+BA+sucrose solution and BA in 10 mg·dm⁻³ concentration, and the lowest was detected in carrot fed by foliarly applied mixture of Urea+Mo+BA. No significant influence in the interaction of foliar nutrition and years of investigations on dry mass content in carrot was demonstrated (Fig.1). In both years of the experiment dry weight content in carrot remained on a similar level (Table 2).

Table 2. Dry weight (d.w.), cadmium, copper and zinc contents in carrot storage roots depending on foliar nutrition – means for 2004-2005

Mean for objects with foliar nutrition	% d.w.	(mg·kg ⁻¹ fresh weight)		
		Cd	Cu	Zn
Control	10.95	0.065	0.421	4.732
Urea	10.91	0.066	0.781	5.002
Urea+Mo	11.35	0.069	1.243	4.801
Urea+Mo+BA	10.79	0.065	0.545	4.456
Urea+Mo+BA+sucrose	12.47	0.080	0.633	4.737
BA	11.75	0.055	0.373	4.689
BA 10	12.35	0.069	0.347	4.265
LSD _{0.05}	1.270	n.s.	0.8253	0.4606
Mean for year of research				
Year 2004	11.66	0.061	0.591	2.520
Year 2005	11.36	0.072	0.649	6.817
LSD _{0.05}	n.s.	n.s.	n.s.	0.2462

n.s.- not significant.

Foliar nutrition with individual solutions had no marked effect upon Cd concentrations in carrot (Table 2). In both years of the investigations carrot was characterized by a similar content of this element. No significant influence of interaction of foliar nutrition and the years of experiment on Cd concentrations

in carrot was noted, either (Fig.1). However, it should be mentioned that in both years of the investigations Cd content in carrot receiving foliar nutrition with Urea+Mo+BA+sucrose solution was on a similar level. On the other treatments (except object No. 6 – BA) slightly higher Cd concentrations were found in carrot in 2005 as compared with 2004.

Fig. 1. Dry weight (A), cadmium (B), copper (C) and zinc (D) contents in carrot storage roots concerning foliar nutrition and year of research.

Objects: 1- Without of foliar nutrition, 2- Urea, 3- Urea+Mo, 4- Urea+Mo+BA, 5- Urea+Mo+BA+sucrose, 6- BA, 7- BA 10;

□ year 2004, ■ year 2005; n.s.- not significant

Foliar nutrition with various combinations of solutions used for the experiments significantly affected Cu and Zn content in carrot (Table 2). Storage roots of plants fed by foliarly applied Urea+Mo contained markedly more Cu in relation to plants from the other experimental treatments, except for plants fed individually with urea. The highest concentrations of Zn were found in storage roots of plants receiving foliar nutrition with urea and the lowest in those from treatment No. 6 (BA). Roots of carrot cultivated in 2005 contained over 2.5 times more Zn than plant roots cultivated in 2004. In both years of the experiment similar levels of carrot Cu concentrations were noted. No significant effect of interaction of foliar nutrition and years of research on Cu concentration in carrot was revealed (Fig. 1). However, interaction of these factors had a marked effect upon Zn content in carrot. In 2004 the least contents of Zn were detected in storage roots of plants fed with foliarly applied Urea+Mo+BA, whereas the greatest amounts were found in the roots of plants sprayed with Urea+Mo +BA+sucrose solution. On the other hand in 2005 the lowest Zn content in carrot was found in BA 10 treatment, whereas the highest in plants fed individually with urea.

Soils from individual experimental treatments after carrot cultivation differed significantly with respect to their pH reaction and the content of readily available forms of Cd, Cu and Zn (Table 3). Soil from treatment 5 - Urea+Mo+BA+sucrose revealed the lowest pH reaction, while from 6-BA treatment the highest. The highest contents of both Cd and Cu were noted in the soil from treatment No. 3 Urea+Mo. The lowest Cd concentration was detected in the soil from treatment No. 7-BA 10, while the lowest Cu and Zn content was found after cultivation of plants fed individually with urea. The highest Zn concentration was assessed in the treatment sprayed with Urea+Mo.

The soil after carrot cultivation in both years of the experiment markedly differed with its pH and readily soluble forms of Cd, Cu and Zn (Table 3). Significantly higher pH and contents of Cu and Zn in soil were noted in 2004. Higher concentrations of readily available Cd forms were assessed in the soils after carrot cultivation in 2005 in comparison with 2004.

Table 3. Soil reaction and content of the available forms of cadmium, copper and zinc in soil after carrot cultivation – means for 2004-2005

Mean for objects with foliar nutrition	pH _{H₂O}	(mg · kg ⁻¹ of soil)		
		Cd	Cu	Zn
Control	6.42	0.56	5.20	48.59
Urea	6.46	0.58	3.91	44.34
Urea+Mo	6.38	0.71	5.18	51.27
Urea+Mo+BA	6.51	0.68	4.65	46.56
Urea+Mo+BA+sucrose	6.32	0.63	4.51	50.84
BA	6.64	0.57	4.48	47.95
BA 10	6.51	0.54	5.01	50.59
LSD _{0.05}	0.073	0.123	0.265	6.830
Mean for year of research				
Year 2004	6.92	0.56	6.56	52.40
Year 2005	6.01	0.66	2.85	44.78
LSD _{0.05}	0.039	0.066	0.142	3.841

A significant interaction of foliar nutrition and years of experiment was demonstrated for the soil pH reaction and the contents of readily available forms of Cd and Cu in soil after carrot cultivation, but no effect of such interaction of the above mentioned factors was revealed on Zn concentrations in the soil (Fig. 2). In both years of the investigations the soil from the treatment No. 5 Urea+Mo+BA+sucrose was characterized by the lowest pH, whereas the soil from 6-BA revealed the highest pH. However, considering absolute values of numbers, the differences revealed in the soil pH reaction (between treatments in the individual years of the experiment) were relatively small. For Cd, in 2004 the lowest contents of this element were assessed in the soil from treatment 4-Urea+Mo+BA, while the highest in the soil where plants fed with Urea+Mo

mixture were growing. In the same year of research lower and similar to each other Cd concentrations were noted in the soil from the other treatments. On the other hand in 2005 approximate, no statistically different Cd contents were noted in the soil from all experimental treatments. The lowest Cu concentrations in 2004 was assessed in the soil from treatment 2-Urea and 4-Urea+Mo+BA +sucrose, whereas the highest in treatment 6-BA. However, in 2005 the soil from the treatment receiving Urea+Mo+BA foliar nutrition was characterized by the lowest copper concentrations, whereas the highest were found in the soil from treatment Urea+Mo.

Fig. 2. Soil reaction (A) and content of the available forms of cadmium (B), copper (C) and zinc (D) in soil after carrot cultivation concerning foliar nutrition and year of research.

Objects: 1- Without of foliar nutrition, 2- Urea, 3- Urea+Mo, 4- Urea+Mo+BA, 5- Urea+Mo+BA+sucrose, 6- BA, 7- BA 10;

□ year 2004, ■ year 2005; n.s.- not significant

DISCUSSION

Soil pH reaction is considered as one of the main factors affecting the form in which heavy metals occur in the soil environment and their availability to plants (Chłopecka 1994, Gębski 1998, Kabat-Pendias & Pendias 1999). Adamec (2002) demonstrated that foliar feeding may stimulate uptake of some minerals by roots, which contributes to their accumulation in plants. On the other hand a mechanism of nutrient (which are cations) uptake by roots causes H^+ release into the rhizosphere. Hydrogen protons cause a decrease in soil pH reaction, which results in increased content of bioavailable forms of heavy metals in the substrate. According to Yang *et al.* (2005), H^+ release by root system is one of the reasons for accelerating the rate of microbiological mobilization of heavy metals in the rhizosphere and therefore increasing their accumulation in plants. Presented research results stated a significant diversification of the soil reaction

(pH) and the contents of readily available forms of Cd, Cu and Zn in soil after carrot cultivation. These results indirectly evidence the fact that foliar nutrition with individual solutions might have differently affected plant root physiological processes. These processes might have caused changes of the soil pH reaction within the rhizosphere and therefore also affect Cd, Cu and Zn phytoavailability. However, it should be mentioned that changes in the available Cd, Cu and Zn forms in soil did not directly influence on the element concentrations in carrot. In the investigations conducted simultaneously on carrot cultivation in pots (Smoleń & Sady 2007) foliar nutrition (alternately 2% urea, 1% Supervit R, 2% urea) combined with diversified soil nitrogen fertilization raised Cu contents but had no statistically significant effect on Cd or Zn contents in carrot. On the other hand, in the other studies on filed carrot cultivation (Smoleń & Sady 2006) foliar nutrition (alternately 2% urea, 1% Supervit R, 2% urea) combined with diversified soil nitrogen fertilization caused statistically significant increase in Cd accumulation level and a decline in Cu, but it did not influence Zn content in carrot storage roots. Studies conducted by Chwil & Szewczuk (2003) revealed that twice spraying of sugar beet with multicomponent Rolvit B fertilizer caused a decline in Cu, Fe and Mn content in storage roots in relation to the control. These authors did not find any significant diversification in Zn content between the researched treatments.

Results of investigations presented in this paper and the former research (Smoleń & Sady 2006, 2007) reveal that foliar nutrition effect on the uptake of nutrient microelements and heavy metals by carrot is associated both with the kind and content of components supplied to plants by this measure and applied soil fertilization with nitrogen but also soil physicochemical properties and climatic conditions during plant cultivation.

Kabata-Pendias & Pendias (1999) report that Cd is the most mobile element (counted among heavy metals), easily translocating from soils to plants. Therefore, revealed lack of statistically significant effect of foliar nutrition on Cd concentration in carrot despite diversified content of readily soluble form of this element in soil is most interesting. Studies conducted by many authors (Howden *et al.* 1995, Zenk 1996, Hall 2002, Nocito *et al.* 2002) showed that uptake of heavy metals from soils by plants is governed by a number of endogenous factors including: molecular and physiological mechanism regulating their uptake, transport, detoxification and accumulation in plant tissues. It seems that the above mentioned mechanisms might have contributed to revealed lack of foliar nutrition effect on Cd concentration in carrot. The other cause of a lack of foliar nutrition effect on Cd content in carrot might have been the fact that nutrient content in the substratum was checked and supplemented during plant cultivation. It might have weakened the efficiency of foliar nutrition influence on Cd concentrations in plants. Studies of Komosa (1990) on tomato cultivation revealed that the efficiency of foliar nutrition was the best at low plant supply in nutrients and was declining with its increase.

In conclusion it should be stated that one of the causes of foliar nutrition significant effect on Cu and Zn concentrations in carrot (at simultaneous lack of

significant differences in Cd content) may be the fact that supplementary magnesium top dressing as $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ with microelements, containing among others 0.3% Cu and 0.2% Zn was used during the plant cultivation. This fertilizer supplied into the soil about 2.5 mg Cu and 1.66 mg Zn·dm⁻³ of soil. It might have greatly affected the content of available forms of Cu and Zn in soil and in result also these elements uptake by plants.

CONCLUSIONS

It was demonstrated that plant spraying with individual solutions had different influence on dry matter and Cu and Zn content in carrot storage roots. No statistically significant effect of foliar nutrition on Cd concentrations in carrot was revealed. In both years of the experiment individual solutions applied for foliar nutrition to the same degree affected dry weight, Cd and Cu content in carrots. The soil from individual experimental treatments after carrot cultivation was significantly diversified considering its pH reaction and the contents of readily soluble forms of Cd, Cu and Zn. However, no apparent effect of either soil pH reaction or Cd, Cu and Zn soil concentrations on dry weight or Cd, Cu and Zn content in carrot was noted.

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WPLYW DOKARMIANIA DOLISTNEGO AZOTEM, MOLIBDENEM,
SACHAROZĄ I BENZYLOADENINĄ
NA ZAWARTOŚĆ SUCHEJ MASY ORAZ Cd, Cu I Zn W MARCHWI

Streszczenie

W latach 2004-2005 marchew odm. Kazan F₁ uprawiano w pojemnikach ażurowych o wymiarach 60×40×20 cm, umieszczonych na terenie otwartym pod cieniówką. Jako podłoże zastosowano glinę średnią pylastą (30% piasku, 28% pyłu, 37% ilu). Zawartość przyswajalnych form składników mineralnych uzupełniono do poziomu: 100 mg N, 80 mg P, 120 mg K, 80 mg Mg, 2000 mg Ca·dm⁻³ gleby. Trzykrotne dokarmianie dolistne roślin wykonano przy użyciu następujących roztworów: 1 - kontrola (niedokarmiane dolistnie), 2 - mocznik, 3 - mocznik+Mo, 4 - mocznik+Mo+BA, 5 - mocznik+Mo+BA+ sacharoza, 6 - BA 5 i 7 - BA 10. W tych roztworach zastosowano następujące stężenia składników: mocznik i sacharoza po 20 g·dm⁻³, 1 mg Mo·dm⁻³, benzyloadenina 5 mg·dm⁻³. W obiekcie BA 10 zastosowano benzyloadeninę w stężeniu 10 mg·dm⁻³. Dokarmianie dolistne w istotny sposób wpłynęło na zawartość suchej masy, Cu i Zn; nie miało ono natomiast wpływu na zawartość Cd w marchwi. Najwyższą zawartość suchej masy oznaczono w marchwi opryskiwanej roztworem Urea+Mo+BA+sucrose i BA 10. Najwięcej Cu zawierały korzenie spichrzowe roślin opryskiwanych roztworem Urea+Mo, a najwięcej Zn rośliny dokarmianych dolistnie tylko mocznikiem. Odnotowano istotny wpływ współdziałania zabiegu dokarmiania dolistnego w latach badań tylko w odniesieniu do zawartości Zn w marchwi. Gleba po uprawie marchwi, z poszczególnych obiektów doświadczenia, w istotny sposób różniła się pod względem odczynu oraz zawartości łatwo rozpuszczalnych form Cd, Cu i Zn.