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The effect of nitrogen fertilizer form and foliar application on the concentrations of twenty-five elements in carrot

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ABSTRACT

Among all elements taken into consideration in this research (Al, As, B, Ba, Be, Bi, Ca, Co, Cr, Fe, Ga, In, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sr, Ti and V), only the concentration of Na in the 'Kazan F_1' carrot was affected by the interaction of foliar application and nitrogen fertilization. In the case of plants fertilized by $Ca(NO_3)_2$, foliar application significantly raised Na concentration in storage roots. Compared to the control, all applied nitrogen fertilizers (results analysed independently from the foliar application factor) increased concentrations of Mg and Se in carrot. Fertilization with $(NH_4)_2SO_4$ resulted in a decrease of Ba and Mo concentrations and an increase of Mn concentration, while fertilization with $Ca(NO_3)_2$ raised the contents of Sr and Be in carrot. Foliar application (analysed independently from nitrogen fertilization) considerably increased Bi and Be concentrations, yet it did not affect the contents of other elements in storage roots.

INTRODUCTION

Nitrogen fertilizers most frequently contain nitrogen in its oxygenated form ($N-NO_3$) present in physiologically alkaline fertilizers, or in its reduced form ($N-NH_4$ and $N-NH_2$), present in physiologically acid fertilizers. Apart from nitrogen, nitrogen fertilizers can contain other nutrients elements such as Ca, K, Mg and Na (a group of physiologically alkaline fertilizers: calcium nitrate, potassium nitrate, magnesium nitrate and sodium nitrate) or S and Cl (a group of physiologically acid fertilizers: ammonium sulfate and ammonium chloride). Depending on the content of reduced or oxygenated forms of nitrogen, or accompanying nutrients, fertilizers can variously affect chemical properties of soil (Czekała and Jakubus 2006, Diatta and Grzebisz 2006) and invoke varied physiological effects in plants, e.g. on the level of nitrate accumulation (Rożek 2000, Smoleń et al. 2006) or heavy metal accumulation (Gębski 1998, Maier et al. 2002, Sady and Smoleń 2004, Rodríguez-Ortíz et al. 2006, Hassan et al. 2005, 2008).

In comparison with oxygenated forms of nitrogen, fertilization with reduced forms of nitrogen normally causes an increased level of heavy metal accumulation in plants. This was also showed in the works of many authors (Gębski 1998, Sady and Smoleń 2004). The majority of studies examining the effect of a particular form of nitrogen fertilizer on the mineral content of plants are dedicated to assessing their interaction on the accumulation level of individual heavy metals in plants (Gębski and Mercik 1997, Rodríguez-Ortíz et al. 2006, Hassan et al. 2008). Few authors took a comprehensive approach to assess the effect of various forms of nitrogen on the content of macro- and micronutrients and heavy metals in plants (Jurkowska et al. 1981, Jurkowska and Rogóż 1981, Maier et al. 2002, Smoleń and Sady 2008). There is no work in the literature that would comprehensively evaluate the effect of nitrogen forms combined with foliar application on the content of macro- and micronutrients, heavy metals and trace elements in plants.

This research aimed at assessing $Ca(NO_3)_2$, NH_4NO_3, $(NH_4)_2SO_4$ and $CO(NH_2)_2$ and the foliar application effect on the concentration of twenty five elements (Al, As, B, Ba, Be, Bi, Ca, Co, Cr, Fe, Ga, In, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sr, Ti and V) in carrot storage roots.

MATERIAL AND METHODS

In 2004 – 2005 the 'Kazan F_1' carrot was cultivated in latticed containers 60 × 40 × 20 cm, placed in an open field under shade-providing fabric. The containers were filled with a medium silt loam (35% sand, 28% silt and 37% clay) with the mean content of organic substance of 3.25%. The pH_{H_2O} soil reaction was 7.29, pH_{KCl} 6.70, while total salt concentration was on the level of 0.45 EC in mS cm^{-1}. In both years of the study the soil (topsoil 0-30 cm), classified as alluvial soil, was obtained from the same field in the Mydlniki district of Krakow in Poland.

Seeds were sown on 20.04.2004 and on 27.04.2005. The content of assimilable nutrient forms during the vegetation period was maintained on the following levels: P 80 mg, K 120 mg, Mg 80 mg, and 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 in 2004 and on 25.04 and 1.07 in 2005. Nutrients were applied to the soil as fertilizers: KH_2PO_4, K_2SO_4 (as soluble fertilizer produced by Yara), $MgSO_4 \cdot 7H_2O$ with microelements (comprising: 0.35% Mn, 0.3% Cu, 0.2% Zn, 0.05% B and 0.01% Mo, produced by Intermag) and $CaCO_3$ (produced by EKO-WAP). The fertilizer $MgSO_4 \cdot 7H_2O$ with microelements supplied the soil with about 2.5 mg Cu and 1.66 mg Zn per dm^{-3}. The soil was fertilized with nitrogen three times during the vegetation period (i.e. on 20.04, 5.07 and 23.08 in 2004, and on 25.04, 1.07 and 22.08 in 2005), based on the results of the soil chemical analysis to supplement the N-mineral content to the level of 100 mg dm^{-3} of soil.

The research comprised two sub-blocks with plant foliar application and without foliar nutrition. In the sub-block with foliar application the plants were sprayed three times (on 30.06, 6.08 and 24.08 in 2004 and 28.06, 1.08 and 23.08 in 2005) with 2% of urea solution, 1% of Supervit R fertilizer solution and again with 2% urea solution. Supervit R brand fertilizer contains (percentage by weight): 3.5% N (1.0% N-NO_3, 2.5% N-NH_2), 3.4% K_2O, 0.6% MgO, 0.04% Mn and 0.02% B, Cu, Ti and Zn – each, 0.012% Fe and 0.001% Mo. The following combinations with soil fertilized with nitrogen were distinguished within the sub-blocks: 1 – control (unfertilized with nitrogen), 2 – $Ca(NO_3)_2$, 3 – NH_4NO_3, 4 – $(NH_4)_2SO_4$ and 5 – $CO(NH_2)_2$. Nitrogen was applied to the soil as fertilizer produced by: $Ca(NO_3)_2$ (as soluble fertilizer) – Yara, NH_4NO_3, $CO(NH_2)_2$ – Zakłady Azotowe, Puławy, $(NH_4)_2SO_4$ – Zakłady Azotowe, Tarnów.

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 from the sub-block where foliar application was not applied. The soil reaction pH was assessed by potentiometer (Nowosielski 1988) and organic matter with the Tiurin method modified by Oleksynowa (Komornicki et al. 1991).

Every year, disintegrated plant material (carrot storage roots) was dried at 70°C, and subsequently ground in a laboratory grinder and stored in tightly packed plastic bags. After the end of a two-year research cycle, the stored plant material (collected in the years 2004 – 2005) was mineralized in 65% super pure HNO_3 (Merck no. 100443.2500) in a CEM MARS-5 Xpress microwave oven (Pasławski and Migaszewski 2006).

Soil samples collected after the end of cultivation were dried in the open air, ground, sieved with 1 mm mesh sieve and stored in tightly packed plastic bags. After the end of the experiment cycle, soil samples were extracted with

0.01 M $CaCl_2$ (Houba et al. 1997). The content of twenty-five elements (Al, As, B, Ba, Be, Bi, Ca, Co, Cr, Fe, Ga, In, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sr, Ti and V) in mineralized plant material and soil extracts (except of Ca in soil extracts) was determined using the ICP-OES method (Houba et al. 1997, Pasławski and Migaszewski 2006) with the use of a Prodigy Teledyne Leeman Labs USA spectrometer. The ICP-OES instrument was calibrated using Merck's ICP multi-element standard no. VI and no. XVI and Inorganic Ventures ICP single element standards of K, Mg, Ca and Na.

Statistical calculations of the obtained results were performed with the use of the ANOVA module of Statistica 7.1 PL for $p < 0.05$. Significance of variations was assessed with the help of variance analysis. In case of significance of changes, homogenous groups were determined on the basis of the Duncan test. A more detailed description of the experiment was presented in the earlier work (Smoleń and Sady 2007 a).

RESULTS

As shown by statistical analysis, among all examined elements (Al, As, B, Ba, Be, Bi, Ca, Co, Cr, Fe, Ga, In, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sr, Ti and V) there was a significant effect of the interaction between foliar application and nitrogen fertilization only in the case of Na content in carrot storage roots (Tables 1 and 2). The roots of plants fertilized with $Ca(NO_3)_2$ and with foliar application contained the highest amounts of Na. It shall be noted that they contained apparently higher amounts of Na than the plants fertilized with $Ca(NO_3)_2$ without foliar application.

The form of nitrogen fertilizer (analysed irrespective of foliar application) significantly affected the concentrations of Mg, Ba, Mn, Sr (Table 1) as well as Be, Mo and Se (Table 2) in carrot storage roots. When compared to the control, all forms of applied nitrogen fertilizers caused a distinctive increase in the Mg content in carrot. A similar tendency was revealed in case of Se; however, the storage roots of plants fertilized with $Ca(NO_3)_2$ and NH_4NO_3 were characterized by comparable concentrations of this element to the control plants. When compared with other combinations, fertilization with $(NH_4)_2SO_4$ resulted in a significant decrease of Ba and Mo concentration, and an increase in Mn concentration, while fertilization with $Ca(NO_3)_2$ evidently raised Sr and Be in carrot.

Foliar application (analysed irrespective of nitrogen fertilization) considerably increased the concentration of Bi and Be in carrot, with no effect on the content of other elements tested (Tables 1 and 2).

Table 1. Concentrations of K, Mg, Ca, Na, Al, B, Ba, Bi, Fe, Ga, Mn, Sr, and Ti in carrot storage roots depending on nitrogen fertilization, foliar application and the co-operation of foliar application × fertilization, data are means from years 2004 – 2005

Combinations		K	Mg	Ca	Na	Al	B	Ba	Bi	Fe	Ga	Mn	Sr	Ti
		(% d.w.)				(mg kg^{-1} d.w.)								
Without foliar application	Control	2.83	0.14	0.40	0.37 a*	128.7	20.1	18.6	1.8	145.1	2.0	11.1	15.6	6.9
	$Ca(NO_3)_2$	2.89	0.20	0.45	0.43 ab	94.7	22.4	14.9	2.4	101.1	2.0	9.4	22.2	5.3
	NH_4NO_3	2.78	0.20	0.47	0.47 abc	120.9	23.4	15.6	2.2	135.4	2.0	12.6	17.5	7.7
	$(NH_4)_2SO_4$	3.00	0.19	0.48	0.52 abc	112.4	25.3	13.1	2.1	129.9	2.0	22.5	16.9	7.3
	$CO(NH_2)_2$	2.84	0.18	0.45	0.54 bc	123.6	23.3	17.4	1.9	126.7	2.0	11.4	17.1	6.4
With foliar application	Control	2.65	0.16	0.41	0.45 ab	125.2	20.9	19.7	2.5	134.6	2.0	10.9	16.7	6.7
	$Ca(NO_3)_2$	3.47	0.22	0.54	0.61 c	148.1	28.6	17.4	2.8	154.1	2.1	12.9	28.0	6.9
	NH_4NO_3	2.48	0.19	0.43	0.47 abc	115.7	21.5	15.0	2.4	122.4	1.9	11.4	16.3	5.3
	$(NH_4)_2SO_4$	2.65	0.18	0.44	0.49 abc	137.6	23.2	10.8	2.6	156.0	2.1	22.2	16.6	6.9
	$CO(NH_2)_2$	2.39	0.19	0.44	0.41 ab	87.6	21.1	17.1	2.9	101.5	2.1	10.7	16.6	4.4
Means for fertilization:														
Control		2.74	0.15 a	0.41	0.41	126.9	20.5	19.2 b	2.2	139.9	2.0	11.0 a	16.2 a	6.8
$Ca(NO_3)_2$		3.18	0.21 b	0.50	0.52	121.4	25.5	16.1 b	2.6	127.6	2.1	11.1 a	25.1 b	6.1
NH_4NO_3		2.63	0.20 b	0.45	0.47	118.3	22.4	15.3 ab	2.3	128.9	2.0	12.0 a	16.9 a	6.5
$(NH_4)_2SO_4$		2.83	0.18 b	0.46	0.50	125.0	24.3	11.9 a	2.4	143.0	2.0	22.3 b	16.7 a	7.1
$CO(NH_2)_2$		2.62	0.19 b	0.44	0.48	105.6	22.2	17.2 b	2.4	114.1	2.0	11.1 a	16.8 a	5.4
Means for foliar application:														
Without foliar application		2.87	0.18	0.45	0.47	116.1	22.9	15.9	2.1 a	127.6	2.0	13.4	17.9	6.7
Foliar application		2.73	0.19	0.45	0.49	122.8	23.0	16.0	2.6 b	133.7	2.0	13.6	18.8	6.0

* Means in columns followed by different letters are significantly different at $p < 0.05$

Table 2. Concentrations of As, Be Co, Cr, In, Li, Mo, Ni, Pb, Sb, Se, and V in carrot storage roots depending on nitrogen fertilization, foliar application and the co-operation of foliar application × fertilization, data are means from years 2004 – 2005

Combinations		As	Be	Co	Cr	In	Li	Mo	Ni	Pb	Sb	Se	V
		(µg kg^{-1} d.w.)											
Without foliar application	Control	326.3	14.6	67.6	1080.6	324.0	203.4	76.3	1680.6	188.3	565.2	744.5	309.3
	$Ca(NO_3)_2$	347.6	15.7	55.7	427.5	564.8	134.1	56.0	677.0	172.7	421.0	1026.2	188.5
	NH_4NO_3	280.3	14.4	67.5	448.8	375.4	189.9	28.0	806.5	132.5	537.7	1214.2	251.1
	$(NH_4)_2SO_4$	813.7	16.0	69.4	592.6	381.5	191.7	3.3	1173.9	301.3	655.8	1293.2	226.6
	$CO(NH_2)_2$	696.1	14.7	59.5	562.6	480.3	185.8	27.0	809.0	248.5	308.6	1204.7	258.9
With foliar application	Control	438.0	15.2	52.0	695.6	322.7	189.3	41.3	650.7	271.6	337.1	1001.6	285.3
	$Ca(NO_3)_2$	605.3	20.8	83.2	1094.7	451.8	256.3	61.2	1095.5	258.0	891.7	1294.1	309.6
	NH_4NO_3	286.1	17.1	77.2	819.9	422.2	178.1	27.8	2032.5	204.5	786.1	998.6	242.4
	$(NH_4)_2SO_4$	552.8	17.4	98.9	831.0	360.1	233.1	11.3	1098.8	231.2	703.3	1441.8	338.2
	$CO(NH_2)_2$	944.0	17.4	62.0	621.2	513.9	139.0	30.5	833.2	238.1	523.8	1650.8	166.1
Means for fertilization:													
Control		382.2	14.9 a	59.8	888.1	323.3	196.3	58.8 b	1165.7	230.0	451.1	873.1 a	297.3
$Ca(NO_3)_2$		476.5	18.2 b	69.5	761.0	508.3	195.2	58.6 b	886.2	215.3	656.3	1160.2 ab	249.1
NH_4NO_3		283.2	15.8 a	72.4	634.3	398.8	184.0	27.9 ab	1419.5	168.5	661.9	1106.4 ab	246.7
$(NH_4)_2SO_4$		683.2	16.7 ab	84.2	711.8	370.8	212.4	7.3 a	1136.3	266.3	679.6	1367.5 b	282.4
$CO(NH_2)_2$		820.0	16.0 a	60.7	591.9	497.1	162.4	28.8 ab	821.1	243.3	416.2	1427.7 b	212.5
Means for foliar application:													
Without foliar application		492.8	15.1 a	64.0	622.4	425.2	181.0	38.1	1029.4	208.7	497.7	1096.6	246.9
Foliar application		565.2	17.6 b	74.7	812.5	414.1	199.2	34.4	1142.1	240.7	648.4	1277.4	268.3

Explanations: see Table 1

Table 3. The content of Al, B, Ba, Fe, K, Mg, Mn, Na, S, As, Be, Bi, Co, Cr, Ga, In, Li, Mo, Ni, Pb, Sb, Se, Ti and V in soil after carrot cultivation – means for 2004 – 2005

Means for fertilization	Al	B	Ba	Fe	K	Mg	Mn	Na	Sr	As	Be	Bi
	(mg kg^{-1})									(μg kg^{-1})		
Control	< 0.02*	0.151 c	1.466 a	0.033	49.68 e	152.94 b	0.875 a	16.298 b	3.150 a	< 1.0	2.5 b	2.0 a
$Ca(NO_3)_2$	< 0.02	0.067 b	1.487 a	< 0.002	29.87 b	136.51 a	0.783 a	6.185 a	4.725 d	< 1.0	1.0 a	28.3 c
NH_4NO_3	< 0.02	0.043 ab	1.461 a	< 0.002	25.98 a	161.72 c	2.911 b	5.143 a	3.302 bc	< 1.0	0.5 a	6.5 ab
$(NH_4)_2SO_4$	< 0.02	0.046 ab	1.450 a	0.064	34.16 d	170.29 d	6.709 c	6.918 a	3.393 c	< 1.0	0.7 a	20.8 abc
$CO(NH_2)_2$	< 0.02	0.011 a	1.475 a	0.161	32.24 c	163.43 c	3.113 b	5.826 a	3.228 ab	< 1.0	1.0 a	22.8 bc
	Co	Cr	Ga	In	Li	Mo	Ni	Pb	Sb	Se	Ti	V
	(μg kg^{-1})											
Control	< 3.0	5.3 a	5.0	31.8 a	24.5 b	84.3 b	28.0 b	< 10.0	< 31.0	16.0	< 1.0	7.3 a
$Ca(NO_3)_2$	< 3.0	1.5 a	< 1.0	7.5 a	21.5 a	28.0 a	13.8 a	< 10.0	< 31.0	37.0	< 1.0	4.0 a
NH_4NO_3	< 3.0	3.8 a	< 1.0	3.5 a	26.0 b	34.3 a	21.3 ab	< 10.0	< 31.0	27.0	< 1.0	4.5 a
$(NH_4)_2SO_4$	< 3.0	5.0 a	7.0	13.3 a	30.5 c	28.8 a	28.8 b	< 10.0	< 31.0	< 1.0	< 1.0	5.8 a
$CO(NH_2)_2$	< 3.0	3.0 a	1.5	11.7 a	25.3 b	35.8 a	23.5 b	< 10.0	< 31.0	26.7	< 1.0	5.8 a

* – "<" means that concentrations of readily soluble forms of elements in soil were lower than the limits of its detection on the ICP spectrometer
Explanations: see Table 1

The results of the soil chemical analysis after carrot cultivation revealed a significant effect of applied fertilization on the concentrations of readily soluble forms (in 0.01 M $CaCl_2$) of B, K, Mg, Mn, Na, Sr, Be, Bi, Li, Mo and Ni, without any influence on the concentrations of Ba, Cr, In and V (Table 3). In comparison with the control, all applied nitrogen fertilizers caused a decrease in the level of B, K, Na, Be and Mo in soil. The lowest level of K was assessed in the soil fertilized with NH_4NO_3. In case of B, its content in the soil fertilized with $CO(NH_2)_2$ was 13.5 times lower than in the control. The lowest concentration of Mg and Ni and the highest of Sr and Bi was observed in the soil after $Ca(NO_3)_2$ fertilization. Soil fertilized with $(NH_4)_2SO_4$ revealed the highest amount of Mg, Mn and Li. It is worth noting that the concentration of Mn in the soil with this fertilizer was 7.6 times higher than in the control. It should also be emphasised that in the soil of all the experimental combinations, the contents of Al, As, Co, Pb, Sb and Ti were below that of the limits of their detection on the ICP spectrometer. Similar results were obtained after determination of Fe and Ga in soil fertilized with $Ca(NO_3)_2$ and NH_4NO_3, as well as in the case of Se in soil fertilized with $(NH_4)_2SO_4$. The results of earlier works (Smoleń et al. 2006) showed that the soil from individual sites of the experiments was considerably varied with regards to the reaction and content of Ca determined in the extracts prepared with 0.03 M acetic acid (Nowosielski 1988). The lowest reaction was assessed in the soil fertilized with $(NH_4)_2SO_4$ pH 6.07, and the highest in the control and after fertilization with $Ca(NO_3)_2$ pH 6.73. The highest amount of Ca (2123.4 mg dm^{-3} of soil) was noted in the site fertilized with $CO(NH_2)_2$, with the lowest content in the soil fertilized with NH_4NO_3, $Ca(NO_3)_2$ plus in the control (1823.6, 1834.9 and 2030.6 mg dm^{-3} of soil, respectively). The concentration of Ca in the soil with $(NH_4)_2SO_4$ fertilization was 2076.5 mg dm^{-3}.

DISCUSSION

The physiological reaction of plants to the treatment of foliar application can be, among others, stimulation to take nutrients by the roots (Marschner 1995, Adamec 2002). However, the research conducted by Chwil and Szewczuk (2003) showed that double spraying of sugar beet with Rolvit B multi-component fertilizer caused a decline in Cu, Fe and Mn in storage roots in comparison with the foliarly unfertilized control plants. The results of Smoleń (2008) showed that the foliar application treatments had a significant effect on Cd concentration and any significant changes in the concentrations of Fe, Mn, Pb and Zn in the radish. In our research, taking into account twenty-five elements marked in carrot storage roots, as well as Cd, Cu and Zn assessed earlier (Smoleń and Sady 2007 a), we noted a significant influence of the interaction between foliar application and nitrogen fertilization only in case of the content of Na in plants with $Ca(NO_3)_2$ fertilization. A soil chemical analysis of studied elements was performed only on the foliarly unfertilized sub-block. The lack of assessment of Na contents, as well as other elements, in the soil from foliarly fertilized sub-block impedes a fully objective evaluation of the interaction.

It is worth emphasizing that apart from an elevated level of Na, storage roots of plants with foliar application and fertilized with $Ca(NO_3)_2$ had evidently lower mass and higher nitrate content in comparison with plants fertilized similarly but without foliar application (Smoleń et al. 2006). The average correlation coefficient R^2, calculated on the basis of results presented in this and previous works (Smoleń et al. 2006), between NO_3^- and Na in carrot storage roots was statistically significant for $p < 0.05$ and was 0.86. Gorham (2007) reveals that by higher salinity of soil (caused mainly by elevated level of Na^+ and Cl^- in soil) plants have a tendency to accumulate nitrate in vacuoles. Our research, however, did not reveal excessive salinity of soil (Smoleń et al. 2006), with mean total salt concentration in soil (EC) after carrot cultivation at 0.53 mS cm^{-1}. Sodium is not an essential element for normal growth and development for plants of type C_3 (Gorham 2007), to which carrot belongs. However, our results show that despite a lower level of Na than Ca and Mg contents in soil after carrot cultivation (346 times lower than Ca and 23 times than Mg on average), mean content of Na in storage roots was comparable with the mean concentration of Ca and 2.6 times higher than Mg content. The results mentioned above may indirectly suggest that in conditions of increased NO_3^- intake by carrot (as presented in earlier results by Smoleń et al. 2006), we can observe a synergistic effect of this anion on Na^+ intake. Such a synergistic effect of NO_3^- on Na^+ and K^+ intake was already revealed by Marschner (1995) and Gorham (2007).

The results of our research show that foliar application treatment inconsiderably influences the degree of plant nutrition in micro- and macro-components and the levels of heavy metal accumulation and trace elements in carrot storage roots. Foliar nutrition treatment (analysed independently from nitrogen fertilization) resulted only in raised Bi and Be as well as Cu (Smoleń and Sady 2007 a) concentration in carrot storage roots. The results of previous research (Smoleń and Sady 2006, 2007 b) revealed that the effect of the foliar application treatment on the intake of micronutrients and heavy metals depends equally on the kind and concentration of components applied to plants in this treatment as well as applied soil nitrogen fertilization, physical-chemical properties of soil and climate conditions during cultivation.

As was revealed, under the influence of applied forms of nitrogen fertilizers, significantly varied values of readily soluble forms (in 0.01 M $CaCl_2$) of B, K, Mg, Mn, Na, Sr, Be, Bi, Li, Mo, and Ni in soil after carrot cultivation were marked only by an impact on the concentrations of Mn and Sr in carrot storage roots. Together with elevated contents of Mn in carrot fertilized with $(NH_4)_2SO_4$, we could observe an increased level of readily soluble forms of this element in the soil. In comparison to other combinations of our experiment, a raise in Mn forms available for the plants in the soil fertilized in this way could be connected with a considerable decrease in soil reaction (Smoleń and Sady 2007 a), which was already presented in the results of Badora's (2002) and Łabętowicz and Rutkowska's (2002) research. Other results in the scope of the effect of nitrogen form on Mn concentration in potato leaves were presented by Maier et al. (2002). These authors revealed an apparent increase in Mn concentration in the leaves fertilized with $Ca(NO_3)_2$ when compared with fertilization with $CO(NH_2)_2$ and $(NH_4)_2SO_4$.

Kabata-Pendias and Pendias (1999) inform that Sr is a little-active element in plants and it is accumulated in older leaves, roots and bulbs. Mean content of Sr in carrot storage roots is marked within 1.5-130 ppm d.w. The same authors reveal that the mechanism of Sr intake is in a way similar to the Ca intake mechanism; yet, despite corresponding biochemical properties, Sr cannot replace Ca in physiological functions. According to the research cited by these authors, Ca exerts an antagonistic influence on the concentration of Sr in roots and stems of beans. Tyler and Olsson (2001), after soil liming with $CaCO_3$, revealed an elevated level of Sr soil solution as a result of ion exchange of Sr with Ca in the soil sorption complex. Similarly, our research shows that fertilization with $Ca(NO_3)_2$, in comparison with the control and fertilization with other nitrogen fertilizers, resulted in raised contents of a readily soluble form of Sr in soil as well as its elevated concentrations in carrot. In earlier studies (Smoleń and Sady 2008), the heads of 'Langendijker' red cabbage plants fertilized with $Ca(NO_3)_2$ and $CO(NH_2)_2$ were characterized by the highest content of Sr as well as Al, Mn, Zn, Cd and Mo in comparison to the control (unfertilized with nitrogen) and plants fertilized with $(NH_4)_2SO_4$ and NH_4NO_3. Kalembasa and Wysokiński (2008) revealed increased concentrations of Sr in corn after fertilization with CaO and sludge sediments combined with CaO. The results of our research and those presented in other works (Kalembasa and Wysokiński 2008, Smoleń and Sady 2008) show that calcium introduced into soil both in the form of $Ca(NO_3)_2$ as well as CaO can influence the increase of Sr intake by plants. Yet, research by Rosen et al. (2006) reveals that Sr has a synergistic impact on Ca intake.

The lower the reaction of soil, the less molybdenum available for the plants in the soil (Marschner 1995, Łabętowicz and Rutkowska 2002). However, our research showed that despite a statistically significant drop in soil reaction after the use of $(NH_4)_2SO_4$ (Smoleń et al. 2006), we did not observe a decline in the content of a readily soluble form of Mo in soil after carrot cultivation in comparison to other combinations. It could have been caused by a comparably small decline of soil reaction (by 0.4-0.7 pH), which occurred at a relatively high soil pH in 6.07-6.77. It is worth noting that the revealed decrease of molybdenum content in carrot after fertilization with $(NH_4)_2SO_4$ might have resulted from the inhibitive effect of sulphate ions (SO_4^{2-}) on the plant intake of molybdate ions from the soil (MoO_4^{2-}) (Marschner 1995). It appears that the plants' decreased molybdenum supply could have been one of the reasons for increased concentrations of nitrate in storage roots of fertilized carrot $(NH_4)_2SO_4$ (Smoleń et al. 2006), as molybdenum plays the role of the cofactor of nitrate reductase – an enzyme responsible for nitrate reduction in plants (Campbell 1999). It shall be noted, however, that both in leaves (Wojciechowska et al. 2006) as well as in storage roots of carrot (Smoleń et al. 2006), no apparent effect of $(NH_4)_2SO_4$ fertilization on the level of nitrate reductase activity was revealed.

CONCLUSIONS

1. Taking into consideration all elements (Al, As, B, Ba, Be, Bi, Ca, Co, Cr, Fe, Ga, In, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sr, Ti and V), there was a significant effect of the interaction between foliar application and nitrogen fertilization only in the case of Na content in carrot storage roots. In comparison with the plants unfertilized foliarly, a considerable increase in the content of Na in storage roots after foliar application was observed in plants fertilized with $Ca(NO_3)_2$.
2. In comparison with the control plants unfertilized with nitrogen, all applied fertilizers caused an increase in the content of Mg and Se in carrot.
3. Fertilization with $(NH_4)_2SO_4$ resulted in decreased concentrations of Ba and Mo and increased Mn, while fertilization with $Ca(NO_3)_2$ had a significant effect on elevated concentrations of Sr and Be in carrot.
4. Foliar application considerably raised the contents of Be and Bi, but had no influence of the concentrations of other elements: Al, As, B, Ba, Ca, Co, Cr, Fe, Ga, In, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sr, Ti and V.

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WPŁYW FORMY AZOTU I DOKARMIANIA DOLISTNEGO NA ZAWARTOŚĆ DWUDZIESTU PIĘCIU PIERWIASTKÓW W MARCHWI

Streszczenie: Spośród uwzględnionych w badaniach pierwiastków (Al, As, B, Ba, Be, Bi, Ca, Co, Cr, Fe, Ga, In, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sr, Ti oraz V) stwierdzono istotny wpływ interakcji dokarmiania dolistnego z nawożeniem azotem jedynie w odniesieniu do zawartości Na w marchwi ‘Kazan F_1’. W przypadku roślin nawożonych $Ca(NO_3)_2$ dokarmianie dolistne powodowało istotne zwiększenie zawartości Na w korzeniach spichrzowych. W porównaniu do kontroli zastosowane nawozy azotowe (wyniki analizowane niezależnie od czynnika dokarmiania dolistnego) powodowały zwiększenie zawartości Mg i Se w marchwi. Nawożenie $(NH_4)_2SO_4$ powodowało istotne zmniejszenie zawartości Ba i Mo oraz zwiększenie zawartości Mn, a nawożenie $Ca(NO_3)_2$ powodowało istotne zwiększenie zawartości Sr i Be w marchwi. Dokarmianie dolistne (analizowane niezależnie od nawożenia azotem) w istotny sposób zwiększyło zawartość Bi i Be w marchwi, nie miało natomiast wpływu na zawartość pozostałych pierwiastków w korzeniach spichrzowych.

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