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CULTIVATION SYSTEM VERSUS THE CONTENT OF MINERALS IN CARROT (*Daucus carota* L.) ROOTS

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ABSTRACT

The aim of this research has been to analyse the effect of a cultivation system on the content of minerals in carrot roots. Roots of two carrot cultivars (Koral and Bolero) grown in organic plantations and plantations maintained according to integrated agriculture guidelines were chosen for the study. The thermal and moisture conditions differentiated the content of macro- and microelements more than the cultivation system or genotype specific traits of the cultivars did. In general, a significantly higher content of the analysed minerals was observed in the first year of the experiment. Carrot grown in the integrated system contained higher amounts of N and Mg as well as Cu, Zn and Mn, while organic carrot roots had more P, Fe and Pb. The late *cv*. Koral contained significantly more P as well as Mg and Cu, Zn and Pb, while the cultivar Bolero was richer in N. With respect to the other elements, no differences were determined between the cultivars. After storage, the content of N in roots of both cultivars decreased, while the levels of the other macronutrients was higher. Larger changes in the content of N, Na, Mg and Ca were detected in roots of the carrot from organic plantations, while P and K differed more in carrot roots from the integrated system.

Key words: *Daucus carota*, organic system, integrated system, macroelements, microelements

INTRODUCTION

The annual consumption of table carrot (*Daucus carota* L.) in Poland reaches about 20 kg per capita [Statistical… 2015]. Carrot is a rich source of β-caroten (provitamin A), vitamins (B_1, B_2, C, PP), fibre, sugars and mineral salts, mainly potassium but also calcium, phosphorus, magnesium and micronutrients.

Our interest in safe and good quality food stimulates the demand for agicultural produce originating from organic farms. According to the principles of organic production, application of agrichemicals (mineral fertilisers, plant protection agents) should be restricted. Effective protection against pathogens during the growing season of plants raises yields of vegetables. Carrot from a conventional plantation can contain residual amounts of pesticides and a much higher content of nitrates than organic carrot [Bender et al. 2009]. An alternative to fungicides used in integrated production [Bounds et al. 2006] is to sow healthy seeds of cultivars with an elevated resistance to pathogens and to implement agrotechnical and biological control measures [Ratajkiewicz et al. 2011]. In response to an invasion of pathogens and plant pests, plants synthesize phenolic compounds, which participate in the activation of defence mecha-

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nisms of plants submitted to a biotic stress [Brandt and Molgaard 2001]. According to Cwalina-Ambroziak et al. [2014], carrot from organic fields contains more phenolics than carrot grown according to the integrated agriculture rules. Hence, organic farming creates suitable conditions for the cultivation of this vegetable.

The content of minerals in the plant is affected by the climate and soil conditions, fertilisation, irrigation, application of biostimulators, the genotype of a particular cultivar or variety, as well as the conditions created during the storage of harvested plants and their processing [Warman and Havard 1997, Dyśko and Kaniszewski 2007, Platta and Kolenda 2009, Negrea et al. 2012, Singh et al. 2012, Kwiatkowski et al. 2015]. While the genetic variation and environmental conditions have a considerable influence on the content of minerals in edible carrot roots, a cutivation system only slightly modifies its yield [Warman and Havard 1997, Masamba and Nguyen 2008, Bender et al. 2009, Hoefkens et al. 2009, Bender et al. 2015, Krejčová et al. 2016, Wierzbowska et al. 2017].

The purpose of this study has been to analyse the effect of a cultivation system on the content of minerals in roots of edible carrot.

MATERIALS AND METHODS

Plant material. Two carrot cultivars: early Bolero and late Koral, were grown in 2011–2012, on plantations run in the integrated agriculture (Journal of Laws of 2004. No. 11, item 94, as amended) and organic farming systems (Journal of Laws of 2004, No. 93, item 898, as amended), and located in north-eastern Poland (fig. 1).

Fig. 1. Location of carrot plantations

The plantations maintained in the organic agriculture system were situated in the Province of Warmia and Mazury, in the villages Godki (GPS coordinates 53°49'59.88" N, 20°16'0.12"E) – Abruptic Luvisols and Dystric Brunic Arenosols soil (R IVa-V) [IUSS… 2015], ridge cultivation with 2 rows each at 6–8 cm spacing and Tomaszkowo (GPS 53°43'04"N, 20°24'32"E) – Abruptic Luvisols soil (R IVa), ridge cultivation with 2 rows each at 6–8 cm spacing; in Podlasie Province, in the village Taraskowo (GPS 53°12'32"N, 22°16'00"E) – Abruptic Luvisols and Dystric Brunic Arenosols soil (R IVb-V), ridge cultivation with 2 rows each at 6–8 cm spacing and in Kujawsko-Pomorskie Province in the village Zgniłobłoty (GPS 53°16'59.88"N, 19°13'59.88"E) – Haplic Luvisols soil (R IIIa-IIIb), flat cultivation rows spacing of 35 to 40 cm. The surface area of the fields was up to 0.5 ha. Farmyard manure (FYM) at dose 25 t ha^{-1} was supplied under the preceding crops. The plantations were weeded mechanically and manually. Pathogens (*Alternaria dauci*, *A. radicina* and *Erysiphe heraclei*) were controlled with the biological preparation Grevit 200 SL (0,2% grapefruit extract; at dose 1.5 dm^3 ha^{-1}), and the growth biostimulator Asahi SL (0.1% solution; nitrophenols naturally occurring in plants: sodium o-nitrophenol, sodium p-nitrophenol, sodium 5-nitroguaiacol; at dose 0.5 dm^3 ha^{-1}) was applied in stress conditions.

The integrated plantations covering an area over 5 ha were located in the Province of Warmia and Mazury in the villages Królikowo (GPS 53°34'21"N, 20°15'12"E) – Abruptic Luvisols, soil class IVb, cultivated on field patches with 6 rows each at 6 cm spacing; Mielno (GPS 53°30'43"N, 20°11'38"E) – Abruptic Luvisols soil (R IVb), ridge cultivation with 2 rows each at 6–8 cm spacing; Rywociny (GPS 53°09'58.5"N, 20°09'22.2"E) – Abruptic Luvisols soil (R IVb), ridge cultivation with 2 rows each at 6–8 cm spacing and in Kujawsko-Pomorskie Province in the village Szpiegowo (GPS 52°41'30"N, 19°14'02"E) – Haplic Luvisols soil (R IIIb), ridge cultivation with 2 rows each at 6–8 cm spacing). The plantations were fertilised with FYM (at dose 25 t ha^{-1} was supplied under the preceding crops) and mineral fertilisers, in line with the recommendations by the Institute of Horticulture in Skierniewice (in the autumn of the previous year: P – 26.2–34.9 kg ha^{-1}, as triple superphosphate; K – 125–166,7 kg ha^{-1} as 50% potassium salt in the spring before sowing: N – 80–110 kg ha^{-1} as urea). Before sowing, the seeds were dressed against the carrot fly (*Psila rosae*) using the seed dressing preparation Marshal 250 DS (25% carbosulfan; at dose 70 g kg^{-1} seeds). Pathogen control consisted of a double spray of plants with Signum 33 WG (6.7% pyraclostrobin and 26.7% boscalid; at dose 1 kg ha^{-1}) and Amistar 250 SC (25% azoxystrobin; at dose 0.6 dm^3 ha^{-1}). The plantations were weeded chemically, using the herbicide Linurex 500 SC, as well as mechanically and manually.

In both cultivation systems, the preceding crops were cruciferous vegetables, cereals or a mixture of grasses and clover. Agrotechnical treatments were carried in line with the recommendations by the Institute of Horticulture in Skierniewice (autumn: cultivated aggregate, harrow; spring: harrow, cultivator, redliner formation and seeds sowing). Carrot seeds were sown in an amount of 1,200,000 to 2,000,000 seeds ha^{-1}. Quality seed of carrot were sown from the end of April to early May (27.04––3.05.2011; 27.04–10.05.2012) and harvested from the end of September to early October (30.09––7.10.2011, 28.09–5.10.2012), in booth years of the study. Thirty roots of table carrot were sampled randomly from each plantation, of which 5 roots were taken for chemical analyses (macro- and microelements). The remaining roots were stored for 5 months in piles layered with sand, and afterwards their content of macroelements was assayed.

Chemical analyses. In order to determine macroelements, dried and ground plant material was wet mineralised in concentrated sulphuric(VI) acid with hydrogen doxide as an oxidant. The N-total content was detrmined spectrophotometrically according to the hypochloride method [Baethgen and Alley 1989]; P was determined with the vanadate-molybdate method, K, Ca and Na were assayed with the atomic emission spectrophotometric method, while Mg was analysed with atomic absorption spectrophotometry

[Ostrowska et al. 1991]. The content of crude ash was analysed with the gravimetric method, having dry mineralised the plant material at 550°C, and after dissolving ash in HCl at a concentration of 0.5 mol dm^{-3} the content of Cu, Zn, Mn, Fe and Ni was determined by atomic absorption spectrophotometry (AAS). To determine the content of boron, comminuted plant material was dry mineralised (520°C) in the presence of calcium oxide, and the ash was dissolved in 0.5 mol HCl dm^{-3}. The content of boron was determined with the H-azomethine colorimetric method [Benedycka and Rusek 1994].

Statistical analysis. The research results were processed statistically in a Statistica 10® software package. Differences between mean values were determined by Tukey's test at a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

The data collated in Table 1 show that the total precipitation in the first year was higher than the multi-annual mean sum of precipitations. The highest rainfall surplus occurred in the village Taraskowo (+30.4%), and smaller ones were recorded in the area monitored by the meteorological station in Olsztyn (+14.1%) and Lidzbark Welski (+11.5%). The smallest divergence from the multi-annual sum of precipitations was recorded in the villages Szpiegowo and Rywociny. July was the wettest month, with the total of rainfall three-fold higher than the multi-year average. In the second year, except in the village Szpiegowo, the sum of precipitations during the carrot growing season was also higher than the multi-annual average. The wettest months were June and July. During the whole period covered by the study, the average temperatures in the growing season were generally higher than the multi-annual average temperatures for the same time of the year.

Vegetables are a valuable source of minerals in human diet. Ekholm et al. [2007] demonstrated that the content of mineral ingredients in plant products had decreased over the past decades. According to Smoleń [2008], the climate and soil conditions affect the quantity and quality of carrot yields more than nitrogen fertilisation. In our experiment too, the thermal and moisture factors in both years significantly differentiated the content of crude ash and most of the minerals in carrot roots (tab. 2 and 3). Conversely, the cultivation system and the genotype of the cultivars had no significant influence on the amount of crude ash in carrot roots. Organic carrot contained on average about 61.54 g kg^{-1} d.m., while carrot from the integrated system had 62.15 g kg^{-1} d.m. of crude ash. The average content of crude ash in roots of the early cultivar Bolero was 59.73 g kg^{-1} d.m., while roots of the late *cv.* Koral had 63.96 g kg^{-1} d.m. of this component. These results are about 10% to 20% lower than reported by others [Lisiewska et al. 2006, Tadesse et al. 2015, Wierzbowska et al. 2017].

According to Pietola and Salo [2000], the soil abundance of nutrients as well as the weather conditions and the plant's development phase have a stronger influence on the content of P, K and Mg than cultivation treatments, and more intensive nitrogen fertilisation leads to an increase in the $N\text{-}NO_3^-$ content in carrot roots.

Analogously to the content of crude ash, the concentrations of nitrogen, phosphorus and magnesium in carrot roots were significantly differentiated in the particular years, and the content of these elements depended on the cultivation system as well as the plant's genotype (tab. 2 and 3). Except nitrogen in organic carrot and nitrogen and calcium in carrot grown in the integrated system, more macroelements were contained in roots harvested in the first year. Carrot grown in the integrated system contained on average 11.02 g N and 1.31 g Mg kg^{-1} d.m. while organic carrot had just 9.05 g N and 1.07 g Mg kg^{-1} d.m. In turn, the highest amounts of phosphorus (3.16 g P kg^{-1} d.m.) were determined in organic carrot. Significantly more P and Mg appeared in the late cv. Koral, while cv. Bolero accumulated more nitrogen. With respect to sodium, high variability coefficients indicate that the content of this element in carrot roots was highly varied depending on the weather conditions, cultivar characteristics and site where it was grown.

Table 1. Meteorological data

Year	Month	Organic cultivation						Integrated cultivation			
		Taraskowo (Myszyniec)*		Zgniłobłoty (Lidzbark Welski)		Godki, Królikowo Tomaszkowo, Mielno (Olsztyn)		Rywociny (Mława)		Szpiegowo (Płock-Trzepowo)	
		rainfall (mm)	temperature (°C)	rainfall (mm)	temperature (°C)	rainfall (mm)	temperature (°C)	rainfall (mm)	temperature (°C)	rainfall (mm)	temperature (°C)
2011	IV	45.5	9.1	24.8	9.6	32.2	9.5	30.0	10.3	17.0	10.8
	V	51.3	13.2	45.9	13.4	46.1	13.2	64.7	13.5	45.3	14.2
	VI	72.9	17.6	37.6	18.1	61.1	17.4	44.5	17.7	42.3	18.3
	VII	215.8	18.3	198.3	17.9	222.2	18.0	182.5	17.8	200.1	18.0
	VIII	59.0	17.5	56.4	17.6	65.3	17.7	58.7	17.8	41.6	18.6
	IX	20.3	13.4	24.1	13.7	20.8	14.2	16.0	14.0	18.1	15.0
	X	24.7	6.9	13.4	7.9	31.6	8.4	9.6	7.9	11.4	8.9
Total/Mean		489.5	13.7	400.5	14.0	479.3	14.1	406.0	14.1	375.8	14.8
2012	IV	58.2	7.8	49.2	8.3	73.0	8.2	59.9	8.5	45.1	9.3
	V	51.9	13.6	25.1	14.4	57.3	13.6	38.5	14.4	27.8	15.1
	VI	84.3	15.4	107.8	15.4	96.1	15.1	105.7	15.5	74.1	16.3
	VII	85.4	19.5	82.7	19.4	104.6	18.8	77.3	19.4	70.8	19.8
	VIII	54.5	17.1	54.2	18.0	44.3	17.5	44.8	17.9	47.6	18.6
	IX	33.9	12.9	36.4	13.4	42.1	13.6	29.2	13.6	47.9	14.3
	X	43.5	6.8	37.7	7.2	72.3	7.6	40.5	7.4	30.3	8.2
Total/Mean		411.7	13.3	393.1	13.7	489.7	13.5	395.9	13.8	343.6	14.5
Average from 1985–2010	IV	35.4	7.8	29.6	7.3	40.8	7.3	38.7	7.8	35.3	8.2
	V	48.6	13.6	51.8	13.1	57.1	12.7	52.1	13.3	44.5	13.6
	VI	68.2	16.3	63.8	15.9	75.0	15.4	73.5	15.8	64.2	16.0
	VII	63.5	18.5	74.7	18.0	74.9	17.7	70.5	18.0	72.3	18.2
	VIII	59.3	17.6	49.3	17.4	61.8	17.2	52.8	17.6	54.4	18.0
	IX	63.4	12.4	47.9	12.2	57.9	12.3	58.6	12.5	50.1	13.0
	X	37.0	7.6	41.9	7.5	52.7	7.9	40.1	7.8	32.5	8.4
Total/Mean		375.4	13.4	359.0	13.1	420.1	12.9	386.3	13.3	353.3	13.7

* Location of the nearest meteorological station according to the Institute of Meteorology and Water Management – National Research Institute (IMGW-PIB)

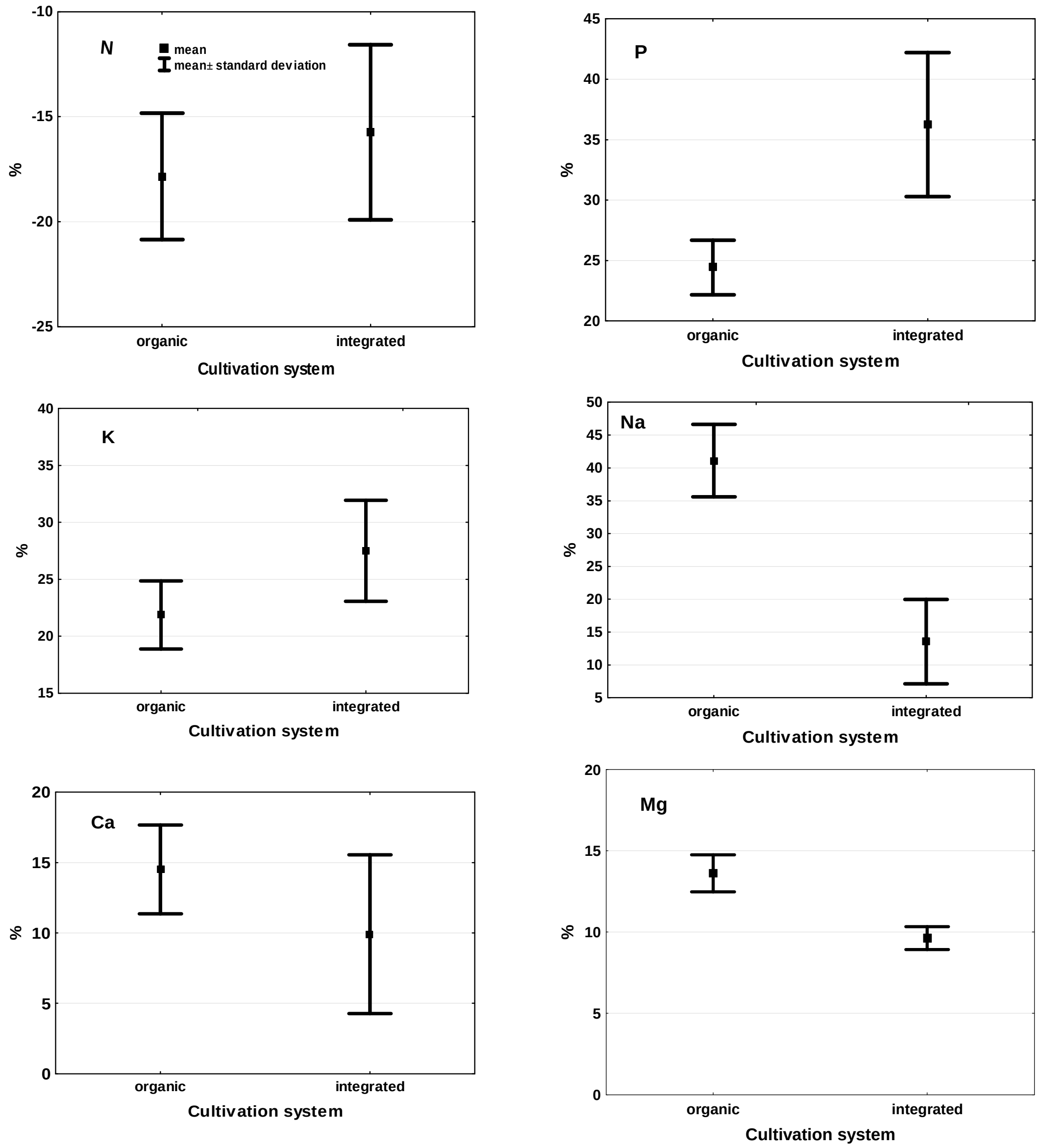

Fig. 2. Changes in the content of macroelements in carrot rots after five months of storage

In a controlled field experiment, it was demonstrated that carrot from the integrated cultivation system contained 8.02–10.89 g kg^{-1} N-total, and organic carrot had just 5.94–7.87 g kg^{-1} N-total [Wierzbowska et al. 2017]. According to Bender et al. [2009, 2015], a cultivation system had no influence on the content of dry matter, total sugares, soluble solids or P, K, Ca and Mg in carrot roots. In turn, Ekholm et al. [2007] showed a higher content of calcium, magnesium and phosphorus in organic carrot, and more potassium in carrot from conventional fields. In another study, juice from carrots grown conventionaly had a significantly higher content of N-NO_3 and N-NH_4 as well as Mg and Na, while juice obtained from organic carrot contained more Ca [Domagała-Świątkiewicz and Gąstoł 2012].

In an experiment conducted by Lisiewska et al. [2006], the content of phosphorus and magnesium in carrot roots was approximately the same as achieved in our study, while that of potassium and calcium was much lower (less by *ca* 40% and 30%, respectively). On the other hand, the concentration of sodium was three-fold higher. Nicolle et al. [2004], having tested 20 carrot cultivars, demonstrated that the content of minerals (Na, Mg, K, Ca, Fe and Zn) in roots was largely dependent on a genotype.

Storage conditions belong to the factors influencing the nutritional quality of root vegetables [Leclerc and Miller 1992]. In this study, the content of minerals in carrot roots changed during storage compared to the amounts determined immediately after harvest (fig. 2). The content of nitrogen decreased in the carrot from both cultivation systems, while the concentrations of the other mineral elements increased. Higher N losses were noted in roots of the carrot from organically managed fields than from the integrated system (less N by 18 and 16%, respectively). Likewise, the content of Na, Ca and Mg increased more in roots of organic carrot (by 41, 14 and 14%, respectively) than in roots of carrot grown in the integrated system (by 14, 10 and 10%, respectively). On the other hand, the quantities of phosphorus and potassium underwent larger changes in roots of the carrot from integrated cultivation (by 36 and 27%, respectively) than in organic carrot roots (by 24 and 22%, respectively). In another study by Wierzbowska et al. [2017], larger changes in the content of macroelements were detected in stored roots of organic carrot than in ones grown in line with integrated agriculture. After five-month storage, organic carrot contained significantly more soluble solids (TSS) and β-carotene, suggesting that it is less sensitive to the unfavourable changes occurring during the storage time [Bender et al. 2015]. Wszelaczyńska and Pobereżny [2011] reported that the content of magnesium was just 1% lower than in roots analysed immediately after harvest. The content of Mg, Na and K decreased while the concentrations of P, Ca and N did not change in roots of carrot treated with biotimulators [Szczepanek et al. 2015].

Table 2. Results of the analysis of variance for the content of minerals in carrot roots

Elements	Years of research (Y)	Cultivation system (CS)	Cultivar (C)	Interaction			
				Y × CS	Y × C	C × CS	R × CS × C
Crude ash	*	ns	ns	ns	ns	ns	ns
N	**	**	*	**	ns	ns	**
P	**	**	**	ns	ns	*	ns
K	**	ns	ns	**	ns	ns	ns
Na	**	ns	ns	ns	*	ns	ns
Ca	**	ns	ns	*	ns	*	ns
Mg	**	**	**	**	ns	ns	ns
Cu	ns	**	*	ns	ns	ns	ns
Zn	**	*	**	ns	ns	ns	ns
Mn	ns	**	ns	ns	ns	ns	ns
Fe	**	**	ns	ns	ns	**	ns
B	ns	ns	ns	ns	ns	ns	ns
Ni	ns	ns	ns	ns	ns	ns	ns
Pb	**	**	**	*	ns	ns	ns
Cr	*	ns	ns	ns	*	ns	ns

* significantly at $P \leq 0.05$, ** significantly at $P \leq 0.01$, ns – not significantly

Table 3. Content of crude ash and macroelements in carrot roots (g kg^{-1} d.m.)

Elements	Specification	Year					
		2011	2012	mean	2011	2012	mean
Cultivation system		organic			integrated		
Crude ash	mean ±SD	61.60 ±10.54	61.48 ±9.46	61.54 ±9.67	66.67 ±8.84	57.63 ±8.73	62.15 ±9.69
	CV (%)	17.11	15.38	15.72	13.25	15.16	15.59
N	mean ±SD	7.41 ±1.41	10.69 ±1.38	9.05 ±2.16	10.55 ±1.01	11.48 ±1.11	11.02 ±1.15
	CV (%)	19.01	12.92	23.89	9.56	9.69	10.41
P	mean ±SD	3.47 ±0.52	2.02 ±0.76	3.16 ±0.72	3.07 ±0.26	2.09 ±0.20	2.58 ±0.55
	CV (%)	14.90	26.82	22.66	8.50	9.69	21.21
K	mean ±SD	38.52 ±5.83	37.22 ±6.16	37.87 ±5.94	42.70 ±3.95	33.20 ±2.60	37.95 ±5.84
	CV (%)	15.12	16.56	15.68	9.25	7.82	15.38
Na	mean ±SD	1.20 ±0.23	0.57 ±0.21	0.89 ±0.39	1.25 ±0.34	0.49 ±0.19	0.87 ±0.47
	CV (%)	19.98	36.46	43.57	27.12	38.22	54.48
Ca	mean ±SD	3.15 ±0.36	2.30 ±0.38	4.22 ±1.15	3.21 ±0.42	4.85 ±0.56	4.03 ±0.96
	CV (%)	11.37	7.14	27.20	12.99	11.5	23.86
Mg	mean ±SD	1.45 ±0.23	0.70 ±0.16	1.07 ±0.43	1.99 ±0.21	0.63 ±0.14	1.31 ±0.74
	CV (%)	15.61	23.34	39.94	10.56	22.17	54.49
Cultivar		Koral			Bolero		
Crude ash	mean ±SD	66.90 ±7.66	61.03 ±9.20	63.96 ±8.72	61.38 ±11.31	58.08 ±9.20	59.73 ±10.10
	CV (%)	11.45	15.07	13.63	18.42	15.84	16.91
N	mean ±SD	9.44 ±1.35	11.24 ±1.23	10.34 ±1.56	11.42 ±1.23	10.94 ±1.39	11.18 ±1.30
	CV (%)	14.27	10.39	15.12	10.93	12.68	11.70
P	mean ±SD	3.40 ±0.48	2.56 ±0.38	2.98 ±0.60	2.68 ±0.48	2.23 ±0.39	2.46 ±0.49
	CV (%)	14.05	14.99	20.20	18.01	17.72	20.04
K	mean ±SD	42.36 ±7.28	35.71 ±5.86	39.03 ±7.32	36.34 ±6.04	34.52 ±3.59	35.43 ±4.98
	CV (%)	17.19	16.40	18.76	16.30	10.41	14.05
Na	mean ±SD	1.37 ±0.48	0.62 ±0.22	0.99 ±0.53	0.55 ±0.26	0.46 ±0.14	0.51 ±0.21
	CV (%)	35.44	35.86	53.46	47.52	30.16	41.55
Ca	mean ±SD	3.27 ±0.29	5.18 ±0.62	4.22 ±1.08	5.16 ±0.62	4.96 ±0.39	5.07 ±0.52
	CV (%)	8.87	11.96	25.65	11.96	7.8	10.26
Mg	mean ±SD	1.70 ±0.33	0.79 ±0.14	1.25 ±0.53	0.79 ±0.14	0.53 ±0.09	0.66 ±0.17
	CV (%)	19.59	18.01	42.49	18.01	16.24	26.32

CV – variability coefficient; SD – standard deviation

Table 4. Coefficients of correlation for the content of macroelements in carrot roots (n = 32)

Elements	N	P	K	Na	Ca	Mg
			After harvest			
N	–	–0.36*	–0.62**	–0.32	0.45**	–0.32
P	–0.27	–	0.80**	0.64**	–0.81**	0.85**
K	–0.14	0.64**	–	0.69**	–0.66**	0.77**
Na	–0.76**	0.38*	0.28	–	0.19	0.79**
Ca	0.77**	–0.33	–0.10	–0.85**	–	–0.83**
Mg	–0.63**	0.49**	0.02	0.72**	–0.77**	–
			After storage			
N	–	0.39*	0.20	–0.19	–0.18	–0.11
P	–0.38*	–	0.14	0.34	–0.16	–0.16
K	0.26	0.70**	–	–0.78**	0.60**	–0.20
Na	0.49**	0.44*	0.87**	–	–0.40*	0.38*
Ca	–0.04	0.70**	0.65**	0.48*	–	0.53**
Mg	–0.15	0.69**	0.51**	0.45*	0.71**	–

Integrated cultivation   Organic cultivation

* significantly at P ≤ 0.05, ** significantly at P ≤ 0.01

Concentrations of macroelements in roots of the carrot from integrated cultivation determined immediately after harvest were mutually correlated more strongly than in roots of organic carrot (tab. 4). Immediately after harvest of carrots from integrated cultivation, the N content was negatively correlated with the content of P and K, while the content of calcium changed proportionally to the quantity of N (r = 0.45**). Moreover, a negative effect of P on the concentration of Ca was determined, while the amount of P was positively correlated with the content of K, Na and Mg. The content of K in carrot correlated positively with the content of Na (r = 0.69**) and Mg (r = 0.77**), while being negatively correlated with the content of Ca. Meanwhile, Na stimulated and Ca had a negative effect on the content of Mg in carrot roots. As a result of the changes which took place during the five-month storage of carrot roots originating from the integrated system, a positive correlation occurred between the content of N and P, potassium and sodium as well as calcium and magnesium. In turn, the content of Na was reversely proportional to the content of Ca (r = –0.40*).

In organic carrot, the content of nitrogen correlated positively with the amount of calcium (r = 0.77**), but had a negative effect on the concentrations of Na (r = –076**) and Mg (r = –0.63**). The concentrations of potassium, sodium and magnesium were correlated positively with the content of phosphorus. Moreover, Ca correlated negatively with Na and Mg, while the content of Na in carrot roots changed proportionally to the amounts of Mg (r = 0.72**). In the consequence of changes taking place in stored organic carrot roots, only the content of P was reversely proportional to the concentration of nitrogen (r = –0.38*). On the other hand, the content of N was positively correlated with the content of Na, P with K, Na, Ca and Mg, while K with Na, Ca and Mg, Na with Ca and Mg and finally, Ca with Mg.

Table 5. Content of microelements and trace elements in carrot roots immediately after harvest (mg kg^{-1} d.m.)

Elements	Specification	Year					
		2011	2012	mean	2011	2012	mean
Cultivation system		organic			integrated		
Cu	mean ±SD	3.29 ±0.43	2.93 ±0.70	3.11 ±0.60	4.08 ±1.04	3.99 ±0.87	4.04 ±0.94
	CV (%)	12.93	23.78	19.17	25.36	21.78	23.32
Zn	mean ±SD	22.49 ±4.88	18.04 ±5.19	20.26 ±5,45	27.67 ±9.08	20.87 ±6.46	24.27 ±8.48
	CV (%)	21.69	28.78	26.88	32.8	30.94	34.95
Mn	mean ±SD	11.41 ±5.44	12.09 ±2.98	11.75 ±4.33	19.92 ±5.84	15.64 ±11.15	17.78 ±9.02
	CV (%)	47.72	24.68	36.87	29.3	71.31	50.74
Fe	mean ±SD	61.99 ±14.35	51.94 ±14.21	56.97 ±	55.41 ±11.34	39.55 ±5.10	47.48 ±11.82
	CV (%)	23.15	27.35	15.87	20.46	12.89	24.90
B	mean ±SD	17.79 ±1.98	17.68 ±1.39	17.73 ±1.69	17.46 ±2.40	17.02 ±2.26	17.24 ±2.30
	CV (%)	11.15	7.87	9.51	13.74	13.27	13.36
Ni	mean ±SD	0.76 ±0.41	0.70 ±0.22	0.73 ±0.32	0.97 ±0.37	0.80 ±0.39	0.88 ±0.38
	CV (%)	53.01	44.87	44.31	37.8	48.3	42.98
Pb	mean ±SD	1.32 ±0.58	1.28 ±0.44	1.30 ±0.5	1.27 ±0.37	0.83 ±0.30	1.05 ±0.40
	CV (%)	43.98	33.99	38.82	28.71	36.11	38.01
Cr	mean ±SD	0.25 ±0.11	0.23 ±0.11	0.24 ±0.10	0.25 ±0.16	0.16 ±0.07	0.21 ±0.13
	CV (%)	42.48	44.87	43.10	64.14	61.68	64.05
Cultivar		Koral			Bolero		
Cu	mean ±SD	3.84 ±1.02	3.75 ±1.02	3.79 ±1.00	3.54 ±0.71	3.17 ±0.79	3.36 ±0.76
	CV (%)	26.55	27.16	26.44	20.06	24.79	22.66
Zn	mean ±SD	26.99 ±9.59	21.72 ±7.09	24.34 ±8.72	23.17 ±4.55	17.19 ±3.42	20.18 ±4.99
	CV (%)	35.55	32.65	35.80	19.65	19.89	24.74
Mn	mean ±SD	15.22 ±6.20	14.13 ±6.58	14.67 ±6.31	15.99 ±8.15	13.60 ±9.83	14.80 ±8.96
	CV (%)	40.72	46.56	43.01	50.93	72.75	60.56
Fe	mean ±SD	59.00 ±14.88	49.69 ±14.72	54.35 ±15.31	58.40 ±11.67	41.80 ±7.73	50.10 ±12.88
	CV (%)	25.22	29.63	28.17	19.97	18.49	25.71
B	mean ±SD	17.99 ±2.03	19.00 ±1.83	18.49 ±1.91	17.48 ±1.67	15.48 ±1.92	16.48 ±2.04
	CV (%)	11.28	9.64	10.65	9.56	12.38	12.37
Ni	mean ±SD	0.95 ±0.43	0.80 ±0.34	0.88 ±0.39	0.80 ±0.31	0.70 ±0.28	0.75 ±0.29
	CV (%)	45.44	42.05	44.37	38.89	39.77	42.12
Pb	mean ±SD	1.50 ±0.44	1.34 ±0.38	1.42 ±0.41	1.10 ±0.42	0.75 ±0.28	0.92 ±0.39
	CV (%)	29.58	28.31	29.11	37.87	37.03	42.12
Cr	mean ±SD	0.27 ±0.18	0.16 ±0.07	0.21 ±0.15	0.23 ±0.11	0.24 ±0.10	0.23 ±0.10
	CV (%)	64.68	45.01	68.62	46.50	41.75	43.44

CV– variability coefficient; SD – standard deviation

The content of trace elements in carrot roots is correlated with the quantities of available forms of these elements in soil [Smoleń et al. 2010]. According to Szabó and Czellér [2009], the content of heavy metals in soil has a stronger effect on the concentration of these elements in leaves than in roots, which is confirmed by positive coefficients of correlation between the content of Ni, Cu and Mn in soil and in carrot leaves. It was only the content of manganese in roots that was dependent on the soil content of this element.

The content of microelements and trace elements presented in this report it similar to the ones reported in the literature [Warman and Havard 1997, Lisiewska et al. 2006, Krejčová et al. 2016, Wierzbowska et al. 2017]. Irrespective of a cultivation system, the weather conditions had a significant effect on the content of zinc, iron, lead and chromium in carrot roots (tab. 2 and 5). A significantly higher concentration of these components was noted in the first year of the experiment. Carrot grown in the integrated system contained significantly higher amounts of copper, zinc and manganese, while organic carrot roots had more iron and lead. A higher content of copper, zinc and lead was found in roots of the late cv. Koral, but no cultivar-specific differences were detected in the content of the other elements. High coefficients of variability, especially for the content of Ni, Pb, Cr and Mn, suggest that a growing conditions has much influence on the concentrations of these elements in the plant. Ekholm et al. [2007] determined a higher content of iron and copper in organic carrot, while more manganese, zinc, nickel, cadmium and lead were determined in carrot grown in line with conventional methods.

Bosiacki and Tyksiński [2009] reported that over the last several years, the content of Mn in commercially available roots of table carrots has halved while the content of zinc and iron has increased. In turn, the content of copper has not changed much. According to Smoleń et al. [2012], neither the level of nitrogen fertilisation nor the form of nitrogen fertiliser had any effect on the content of Pb or Cr in carrot roots, while the concentration of Fe and Mn increased in response to doses of N fertiliser.

CONCLUSION

The temperatures and precipitations caused larger differences in the content of macro- and microelements in carrot roots than the cultivation systems or the genotypes of plants. In general, a higher concentration of these elements (except N in carrot grown in both systems and Ca – in the integrated system) was determined in the first year of the study. Carrot grown in the integrated system contained more N, Mg, Cu, Zn and Mn, while organic carrot had more P, Fe and Pb in roots. Significantly more P and Mg as well as Cu, Zn and Pb accumulated in roots of the late cv. Koral, while the early cv. Bolero contained more nitrogen. With respect to the other elements, no significant inter-cultivar differences were observed. The content of macroelements in roots of carrot from integrated cultivation, immediately after harvest, was mutually correlated more strongly than in roots of organic carrot. After storage, roots of the carrot from both cultivation systems contained less nitrogen, while the concentrations of the other elements increased. Slightly higher losses of nitrogen were detected in roots of the carrot from organic plantations than from integrated cultivation.

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