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YIELD AND MINERAL CONTENT OF EDIBLE CARROT DEPENDING ON CULTIVATION AND PLANT PROTECTION METHODS

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ABSTRACT

The aim of this study has been to determine the effect of cultivation and plant protection on the content of macro- and micronutrients and yield of roots in edible carrots. The cultivation of carrot according to the principles of integrated farming resulted in a higher root mass as well as a higher total and commercial yield than in the ecological cultivation system. The plant protection had a positive effect on the root mass only in ecological cultivation. The content of crude ash in carrot roots ranged from 71.25 to 80.10 g kg^{-1} d.m. Roots of carrots from the integrated system contained more N-total and potassium than the ones from the ecological system. In general, carrots originating from the integrated system contained more Zn and Mn, while those grown ecologically had more Cu and Ni. After storage, the content of N-total, K, Na, Ca and Mg in carrot roots increased. Meanwhile, the P concentration tended to decrease. The plant protection methods have significant effect on the content of N-total and K and microelements. The content of nitrates (V) was modified more extensively in roots of carrots grown in the integrated system than in ecological system.

Key words: *Daucus carota* L., integrated and ecological system, N-NO_3, macroelements, microelements

INTRODUCTION

In 2010–2012 Poland's share in the harvest of vegetables among all the European Union member countries was 8.5%. Carrot account for 15.4% the vegetable production in our country [Nosecka 2013]. In 2013, 743,000 tons of carrots were harvested from the total acreage of 19,100 ha, and the average yield was 38.9 t ha^{-1}. The annual consumption of vegetables per capita in Poland is 102 kg, of which carrots make up 20 kg [Rocznik Statystyczny Rolnictwa 2014]. Carrot (*Daucus carota* L.) is grown and consumed all over the world. This vegetable is easy to grow, produces high yields, is suitable for production of different foodstuffs and can be stored for a long time. In human diet, carrots are a valuable source of beta-carotene (provitamin A), several vitamins (B_1, B_2, C, PP), fibre, sugars and mineral salts – mainly K, as well as Ca, P, Mg and microelements. Carrots possess a high nutritional quality owing to their antibacterial action as well as soothing and regulating effect on the digestive tract. The health benefits of eating carrots arise from the content of antioxidants (carotenoids), which provide this vegetable with antioxidant and anticancer properties [Arscott and Tanumihardjo 2010, Sharma et al. 2012].

Consumers are increasingly aware of the quality and nutritional value of the food they eat. This rising

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interest in food safety and quality stimulates a growing demand for the food grown ecologically. In line with the ecological food production principles, use of agrochemicals (mineral fertilizers, pesticides, etc.) on ecological fields is limited. The plant content of macro- and microelements is affected by the climate and soil conditions, fertilization, irrigation, application of biostimulators, genotypes of cultivars as well as the conditions in which plants are stored and processed [Dyśko and Kaniszewski 2007, Negrea et al. 2012, Singh et al. 2012, Kwiatkowski et al. 2013, Smoleń et al. 2014, Kwiatkowski et al. 2015]. According Hoefkens et al. [2009] and Krejčová et al. [2016], cultivation system (conventional or organic) has little impact on the macronutrient content of minerals in carrot roots. Crops attacked by pathogens and pests synthesize phenolic compounds characterized by strong cytotoxic properties. These compounds are involved in the induction of defense mechanisms of plants exposed to biotic stress [Brandt and Molgaard 2001]. The content of phenolic compounds is higher in organic carrots than in carrots grown in integrated production plantations. Thus, the organic farming system seems preferable for growing carrots [Cwalina-Ambroziak et al. 2014]. Plant growth regulators (Bio-Algeen S-90 and Kelpak SL and the growth biostimulator Asahi SL reduced the incidence and severity of the some disesase of potato [Cwalina-Ambroziak et al. 2015]. The objective of our experiment has been to observe the effect of a cultivation system and plant protection method on the content of macro- and microelements in roots of edible carrot.

MATERIAL AND METHODS

Field experiment. A controlled field experiment was carried out in 2011–2012, at the Agricultural Experimental Station of the University of Warmia and Mazury in Olsztyn, Poland, located in Bałcyny (53°36'N, 19°51'E, Poland). Carrot was grown according to the recommendations of integrated and ecological farming. The experiment was set up on arable soil of good quality (R IIIa) proper lessive soil (IUSS Working Group WRB, 2011). Prior to the experiment, the soil pH measured in 1 mol KCl dm^{-3} was 5.35–5.70. The concentrations of available forms of macroelements were as follows: P – 84.0–88.6, K – 182.7–193.0, Mg – 68.0–75.6 mg kg^{-1} of soil. The soil also contained 8.9–9.3 g kg^{-1} of organic carbon and 0.91–0.98 g kg^{-1} N-total (in both farming systems, plots were located close to one another; soil samples were collected in accordance with the relevant standard, and the data were averaged). Plots covering 8 m^2 (7.2 m^2 for harvest) each were established in a random block design, with four replications. The preceding crop in both cultivation systems was medium early potato. Ecologically grown carrots were seeded in a field that had been used for ecological farming for 3 years, in the third year after manure application. The integrated farming plots received mineral fertilization adjusted to the soil richness and the demand of carrot for nutrients. The fertilization regime therefore consisted of a pre-seeding application of 70 kg N ha^{-1} (34% ammonium nitrate), 35 kg P ha^{-1} (40% superphosphate), 140 kg K ha^{-1} (60% potassium salt) and top dressing with 50 kg N ha^{-1} (34% ammonium nitrate). Quality seeds of the carrot cultivar Koral were sown at the end of April (26–28 April). All agrotechnical treatments were performed as recommended by the Institute of Horticulture in Skierniewice. Weeding was mechanical and manual. The experiment was carried out under the conditions of natural infection. The ecological cultivation system included plant protection preparations which are approved of in ecological farming. The integrated cultivation system involved biological, biotechnological and chemical plant protection preparations recommended by the IPP-NRI in Poznań, which were applied immediately after spotting the first signs of a disease (tab. 1). Carrots were harvested at the end of September (28–30 September). After harvest, the yield of carrot roots was determined root mass, main yield, commercial yield [UN/ECE Standard FFV-10], participation of commercial in total yield, and were collected randomly from each plot 5 roots (from commercial yield) for chemical analyses. All chemical analyses were made in duplicate. The remaining commercial roots were stored for 5 months in piles layered with sand. Afterwards, macroelements and nitrates (V) were determined in samples of stored carrot roots.

Table 1. Design of the experiment

Integrated cultivation		Ecological cultivation	
I Int.	no plant protection	I Ecol.	no plant protection
II Int.	EM-1 to soil; seed dressing Grevit 200 SL; 3x spray Grevit 200 SL (every 7–10 days)	II Ecol.	EM-1 to soil; seed dressing Grevit 200 SL; 3 × spray EM (every 7–10 days)
III Int.	seed dressing T; 3x Grevit spray 200 SL (every 7–10 days)	III Ecol.	seed dressing Grevit 200 SL; 3 × spray Grevit 200 SL (every 7–10 days)
IV Int.	seed dressing T; spray with Asahi SL; alternately (every 10–14 days) 2 × spray with Bravo 500 SC and Tiotar 800 SC	IV Ecol.	seed dressing Grevit 200 SL; spray with Asahi SL; alternately (every 7–10 days) 2 × spray with Grevit 200 SL and Tiotar 800 SC
V Int.	seed dressing EM-1; spray Asahi SL; alternately (every 10–14 days) 2 × spray with Grevit 200 SL and Bravo 500 SC	V Ecol.	seed dressing EM-1; spray Asahi SL; alternately (every 7–10 days) 2 × spray with Grevit 200 SL and Tiotar 800 SC

Table 2. Weather conditions

Month	Temperature (^oC)			Amount of precipitation (mm)		
	2011	2012	1961–2010	2011	2012	1961–2010
April	9.7	8.4	7.7	33.7	44.7	29.8
May	13.6	13.9	12.6	41.5	42.5	61.1
June	17.5	15.2	15.8	56.2	107.2	69.5
July	18.0	19.0	17.5	171.9	112.2	82.5
August	18.1	17.9	17.1	83.6	25.7	74.9
September	14.6	14.0	12.8	38.9	41.0	57.4
Mean/Total	15.3	14.7	13.9	425.8	373.3	375.2

Table 3. Parameters of carrot root yields after harvest (average results from 2011–2012)

	Objects of experiment	Root mass (g)	Total yield (t ha^{-1})	Commercial yield (t ha^{-1})	Share of commercial yield in total (%)
Integrated cultivation	I Int.	178.7^{a*}	76,5^{a}	57.1^{a}	75.1^{a}
	II Int.	160.0^{abc}	75.6^{a}	58.2^{a}	78.0^{a}
	III Int.	154.1^{bcd}	76.6^{a}	57.7^{a}	75.6^{a}
	IV Int.	163.0^{ab}	77.5^{a}	58.8^{a}	77.0^{a}
	V Int.	180.6^{a}	76.5^{a}	55.6^{ab}	74.4^{a}
	Mean	167.3^{A}	76.5^{A}	57.5^{A}	76.0^{A}
Ecological cultivation	I Ecol.	135.3^{d}	62.9^{b}	45.9^{c}	73.8^{a}
	II Ecol.	151.0^{bcd}	63.7^{b}	48.4^{ab}	76.6^{a}
	III Ecol.	143.5^{bcd}	61.0^{b}	46.6^{c}	77.0^{a}
	IV Ecol.	150.6^{bcd}	61.0^{b}	44.4^{c}	73.6^{a}
	V Ecol.	138.2^{cd}	62.7^{b}	48.9^{ab}	78.2^{a}
	Mean	143.7^{B}	62.3^{B}	46.8^{B}	75.8^{A}

* Data designated with same letters in column do not differ significantly at $P \leq 0.05$

Chemical analyses. The plant material, dried and ground for determination of macroelements, was wet mineralized in concentrated sulphuric acid (VI) with hydrogen dioxide as an oxidant. The N-total content was determined spectrophotometrically by the hypochlorite method [Baethgen and Alley 1989], P was assessed spectrophotometrically by the vanadium-molybdate method, while the concentrations of K, Ca and Na were measured by atomic emission spectrometry, and the content of Mg was checked by atomic absorption spectrophotometry. The content of crude ash was assessed by the weight method, after dry mineralization of the plant material at a temperature of 550°C. Having digested ash in HCl of the concentration of 0.5 mol dm^{-3}, the content of Cu, Zn, Mn, Fe and Ni was determined by atomic absorption spectrophotometry (AAS). For determination of boron, comminuted plant material was dry mineralized (520°C) in the presence of calcium oxide and the resulting ash was dissolved in 0.5 mol HCl dm^{-3}. Subsequently, the content of boron was determined colorimetrically using azomethine-H [Benedycka and Rusek 1994]. Fresh matter of carrot roots after harvest and storage was submitted to determination of nitrates (V), performed spectrophotometrically with salicylic acid [Caldo et al. 1975].

Statistical analysis. The results underwent statistical analysis aided by the software package STATISTICA 10 (ANOVA), and differences between the means were compared by the Tukey's test at the level of significance $p \leq 0.05$. Correlation coefficients for the content of macroelements in roots of edible carrot were calculated.

RESULTS AND DISCUSSION

The temperatures during the plant growing season 2011 and 2012, except for June 2012, were higher than the multi-year mean temperatures recorded in the same months (tab. 2). The amounts of precipitation during the plant growing season diverged from the multi-annual mean amounts (+50.6 and -1.9 mm, respectively). The distribution of rainfall in the consecutive months was markedly different from the average distribution in 1961–2010. In the first year of the experiment, after some precipitation shortage noted in May and June, there were abundant rainfalls in July and August (208 and 112% of the monthly average, respectively). The end of growing season was marked by rain deficit. Also, in the second year of the research, a spell of dry weather (approximately 70% of the multi-year precipitation average) occurred during the germination and emergence of carrot plants (in May). Following heavy rains in June and July (154 and 136% of the multi-annual average, respectively), a considerable moisture deficit appeared, in August (about 29% of the 1961–2010 precipitation average). Due to comparable temperature and humidity conditions in the analyzed growing seasons, mean values for years were presented in the Tables (for results).

Yield of carrot roots. Carrots grown in the integrated system produced by about 16% more single root mass than the ones cultivated ecologically (tab. 3). The smallest roots (135.3 g) were harvested when carrot was grown in the ecological system without plant protection measures (I Ecol.), while the largest roots were grown in the V Int. variant (180.6 g). The total and commercial yield of roots from the integrated system was significantly higher than in the ecological system. The share of commercial yield in the total one was 73.6–78.0% and did not depend on a cultivation system or plant protection measures. Studies conducted by Warman and Havard [1997] as well as Fjelkner-Moding et al. [2000] showed that yields from organic fields are slightly lower than those from conventional plantations. In a study by Karkleliené et al. [2012], hybrid carrot varieties grown in an ecological cultivation system yielded 10–20% better than (F1) crossbred varieties. According to Kwiatkowski et al. [2013], biostimulators (Asahi SL, Bio-Algeen S90, Tytanit) had a positive effect on the volume of commercial yields of carrot roots, by diminishing the number of small, infected or deformed roots in the total yield. Another treatment that has been found to improve the total and commercial yield of carrot roots is the ploughing of a stubble field left after legumes.

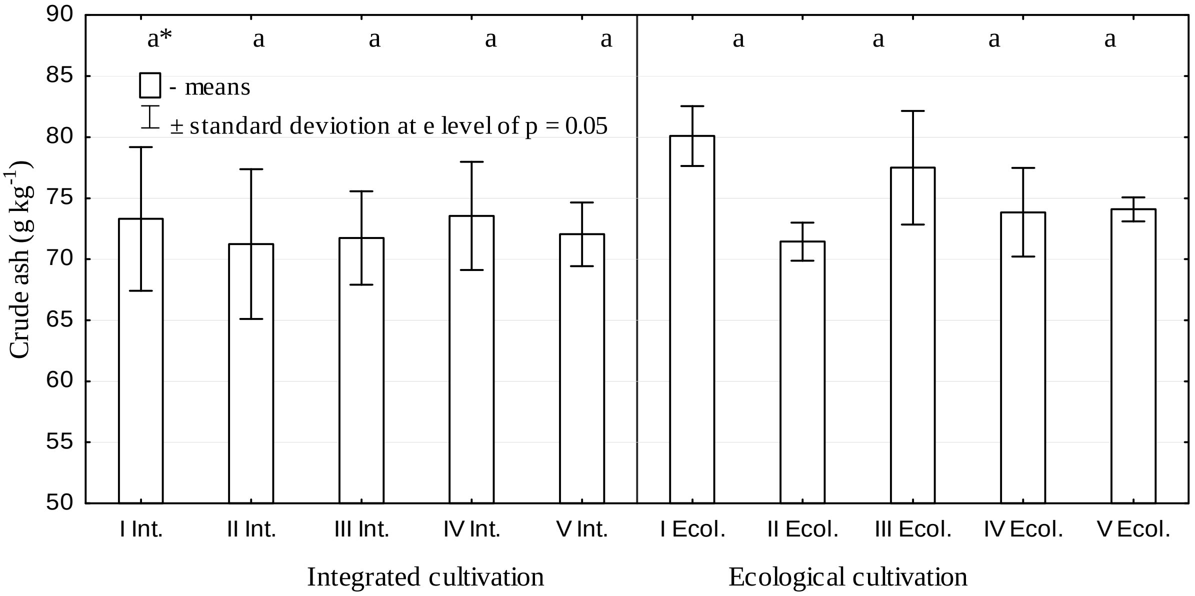

Fig. 1. Content of crude ash in carrot roots (average results from 2011–2012).
* Data designated with same letters do not differ significantly at P ≤ 0.05)

Table 4. Content of macroelements in roots of edible carrot (average results from 2011–2012)

	Objects of experiment	Content after harvest (g kg^{-1} d.m.)						Changes after storage (%)					
		N-total	P	K	Na	Ca	Mg	N-total	P	K	Na	Ca	Mg
Integrated cultivation	I Int.	10.89^{a*}	$3,90^{a}$	46.07^{a}	1.19^{a}	6.11^{a}	1.27^{a}	20.8^{d}	-15.6^{bc}	26.5^{bc}	17.3^{b}	27.7^{a}	4.9^{c}
	II Int.	10.03^{ab}	3.31^{a}	44.28^{ab}	1.03^{a}	5.52^{a}	1.22^{a}	29.9^{cd}	12.3^{c}	44.4^{ab}	45.9^{a}	15.8^{b}	13.2^{bc}
	III Int.	9.61^{abc}	3.47^{a}	44.45^{ab}	0.77^{a}	5.41^{a}	1.10^{a}	34.5^{bcd}	-10.8^{c}	21.3^{c}	46.0^{a}	10.2^{bc}	22.2^{bc}
	IV Int.	8.02^{cd}	3.20^{a}	45.90^{a}	1.12^{a}	5.38^{a}	1.26^{a}	48.7^{a}	23.1^{a}	36.0^{abc}	34.7^{ab}	8.6^{ab}	36.8^{a}
	V Int.	8.44^{bcd}	3.51^{a}	42.03^{b}	0.99^{a}	4.81^{a}	1.06^{a}	49.1^{a}	6.3^{d}	43.5^{abc}	19.9^{b}	9.3^{c}	35.1^{a}
	Mean	9.40^{A}	3.48^{A}	44.55^{A}	1.02^{A}	5.45^{A}	1.05^{A}	36.6^{A}	3.1^{B}	34.3^{A}	14.3^{A}	14.2^{A}	22.4^{A}
Ecological cultivation	I Ecol.	7.87^{d}	3.80^{a}	43.22^{ab}	1.34^{a}	4.57^{a}	1.08^{a}	50.7^{a}	-18.7^{bc}	40.1^{abc}	25.0^{ab}	9.7^{c}	19.3^{bc}
	II Ecol.	6.92^{de}	3.34^{a}	40.62^{b}	1.41^{a}	4.76^{a}	1.11^{a}	44.5^{ab}	4.0^{d}	49.6^{a}	44.2^{ab}	30.9^{a}	22.9^{bc}
	III Ecol.	6.02^{e}	3.67^{a}	43.06^{ab}	1.05^{a}	5.18^{a}	1.18^{a}	60.1^{a}	-5.3^{d}	25.0^{bc}	41.9^{ab}	9.1^{c}	32.8^{b}
	IV Ecol.	5.94^{e}	3.47^{a}	40.49^{a}	0.90^{a}	4.62^{a}	1.17^{a}	53.9^{a}	0.2^{d}	43.8^{abc}	29.8^{ab}	9.7^{c}	37.7^{a}
	V Ecol.	5.94^{e}	3.72^{a}	42.27^{b}	0.65^{a}	4.83^{a}	1.02^{a}	53.9^{a}	-13.9^{bc}	32.5^{bc}	39.7^{ab}	13.6^{bc}	39.4^{a}
	Mean	6.54^{B}	3.60^{A}	41.93^{B}	1.07^{A}	4.79^{B}	1.08^{A}	52.6^{B}	-6.7^{A}	38.2^{A}	36.2^{B}	14.6^{A}	30.4^{B}

[*] Data designated with same letters in column do not differ significantly at P ≤ 0.05

Chemical characteristics. The content of crude ash in carrot roots ranged from 71.25 to 80.10 g kg^{-1} d.m. (fig. 1) and was close to the value reported by Tadesse et al. [2015]. In general, more crude ash was determined in carrots from ecological farming, but the differences observed relative to the integrated system were not significant statistically. A much higher content of crude ash in carrot roots (210.0 g kg^{-1} d.m.) was determined by Goby and Gidenne [2008], but the authors suggested that this might have resulted from some residue of the soil's most minute fractions on carrot roots.

The roots of carrots from the integrated system contained 8.02–10.89 g kg^{-1} d.m of N-total, and those from the ecological system had 5.94–7.87 g kg^{-1} d.m. of N-total (tab. 4). In both system, the highest N-total content was found in the control plants (I Int. and I Ecol.), while the lowest one was accumulated in the plants which, apart from seed dressing and sprays against pathogens, were also treated with Asahi SL (IV Int. and V Int. as well as IV Ecol. and V Ecol.). The cultivation system or plant protection method did not have any significant impact on the P content, although the amount of this element tended to decrease in roots of the carrot from the plots protected against pathogens. The roots of carrot from the integrated system were distinguished by a higher average content of K and Ca (on average, 44.55 and 5.45 g kg^{-1} d.m.) than the roots of ecologically grown carrots (on average 41.93 i 4.79 g kg^{-1} d.m.). Same as phosphorus, the cultivation and plant protection technologies had no influence on the content of magnesium in carrot roots. More Na was determined in carrot roots from ecological system. Smoleń [2008] claims that the quality and biological value of carrot yields are more strongly affected by the climate and soil conditions than by nitrogen fertilization. Nicolle et al. [2004] conclude that, in contrast to K and Ca, the root content of Na and Mg depends on the genotype of carrot plants. Szczepanek et al. [2015] demonstrated that the biostimulator Asahi SL had no effect on the content of phosphorus, magnesium and calcium in carrot, but it did increase the concentration of potassium. Regardless of the cultivation technology, carrot is a good source of magnesium, calcium and especially potassium [Krejčová et al. 2016]. An amount of 100 g of carrot roots covers about 10–15% of the recommended daily consumption of potassium by adults (so called GD – Guideline Daily Amounts) [Jarosz 2012].

As a consequence of modifications occurring in the course of storage, the content of macroelements in the roots of ecological carrots tended to change more distinctly than in those from the integrated farming system (tab. 4). Markedly large changes (by 52.6%, on average) were noted in the N-total content. The highest increase in the potassium content was determined in carrots where effective microorganisms (EM) had been applied (II Int. – EM to soil; II Ecol. – EM to soil and sprays against pathogens). In turn, the Na content increased the most in carrots from the plots II Int., III Int. (about 46%) and II Ecol., III Ecol. (44.2 and 41.9%), while the concentration of Ca increased the highest in carrot roots harvested from the II Ecol. plots (about 31%). Analogously to the N determinations, the content of Mg tended to increase most distinctly in carrots grown organically. The highest increase in the content of this element was found in carrots from the objects IV and V in the integrated and ecological systems. Phosphorus was the only element whose content decreased in carrot roots collected from integrated (I Int. and III Int.) and ecological systems (I Ecol., III Ecol. and V Ecol.) The most severe loss of P was found in roots of control carrots.

Wszelaczyńska and Pobereżny [2011] found that after six-month storage of carrot roots the content of magnesium decreased by just 1% relative to the initial concentrations determined immediately after harvest. Szczepanek et al. [2015] analyzed the effect of biostimulators on the content of macroelements in carrot roots following a period of storage and detected lowered concentrations of Mg, Na and K, as well as unchanged concentrations of P, Ca and N. Whereas in the study Wierzbowska et al. [2016], in the consequence of the transformations occurring in potato tubers during their storage, their content of mineral components increased. According to Smoleń et al. [2014], when growing carrot for long-term storage, it is recommended to avoid large quantities of nitrogen fertilizers (especially in the form of calcium nitrate) if they are applied together with iodine, in order to reduce the loss of root mass and prevent lower quality of harvested roots.

The concentrations of macroelements in carrot roots were mutually correlated more often immediately after harvest than after storage (tab. 5). After harvest, positive correlations appeared between N and Ca (r = 0.447*), P and K (r = 0.919**) or Na (r = 0.885**), as well as between potassium and sodium (r = 0.841**) or magnesium (r = 0.442*) in the integrated system of cultivation. Simultaneously, a negative effect of calcium on the concentrations of phosphorus (r = -0.760**), potassium (r = -0.730**), sodium and magnesium was detected. In the stored carrot root coming from the integrated cultivation, the content of phosphorus was positively correlated with potassium (r = 0.647**) and sodium (r = 0.468*). Also, a positive relationship emerged between K and Na concentrations, while calcium was found to have a negative effect on phosphorus (r = -0.550*). In the ecological cultivation system, directly after harvest, the P content correlated with the content of K (r = 0.647**) and Mg (r = 0.726**). Similar relationships were obtained for potassium and magnesium (r = 0.903**). On the other hand, the content of Ca was negatively correlated with the content of P, K and Mg. After six-month storage, the content of P and Mg remained positively correlated, while the correlation of the Ca content with K and Na was still negative. Some researchers have observed negative correlation between the uptake of N and the uptake of K by carrot [Negrea et al. 2012, Szczepanek et al. 2015]. According to Negrea et al. [2012], an increased accumulation of N may depress the content of Mg. This kind of a relationship was not confirmed in our study or by Szczepanek et al. [2015], probably because the nitrogen fertilization level as well as the nitrogen concentration in carrot roots were relatively small.

Immediately after harvest, the content of nitrates (V) was similar to the amount reported by Majkowska-Gadomska et al. [2009]. In our experiment, it reached 112–240 mg NO_3^- kg^{-1} f.m. in the roots of carrots grown in the integrated system and 105–208 mg NO_3^- kg^{-1} f.m. in the roots of ecologically grown carrots (fig. 2). Most of this nitrogen form was detected in the roots of carrots from treatment III Int., following pre-sowing application of the seed dressing preparation T and triple spraying of carrot plants with Grevit 200 SL. During the transformations that took place in stored carrot roots, the amount of nitrates (V) increased four-fold in roots of carrots from the integrated system and three-fold in roots of ecological carrots. In both cultivation systems, the highest content of NO_3^- was determined in roots of carrots from the variants IV Int. and V Int. as well as IV Ecol. and V Ecol., which had been treated with the biostimulator Asahi SL in addition to seed dressing and sprays. The content of nitrates (V) depends on the type of a cultivation technology (in particular in stored carrot roots). The nitrates (V) are undesirable components of the human diet and acceptable daily intakes (ADIs) is 5 mg kg b.w. per day [Commission Regulation 2002]. Hoefkens et al. [2009] demonstrated that the content of nitrates in carrot roots and potato tubers was lower in ecological than in conventional plant cultivation systems. Lima and Vianello [2011] reported higher concentrations of nitrates(V) in conventionally grown vegetables. Krejčová et al. [2016] did not show any significant differences in the accumulation of nitrates in roots of carrots grown in different cultivation systems. Gajewski et al. [2009] and Majkowska-Gadomska et al. [2009] showed differentiated accumulation of nitrates depending on a carrot cultivar. Laser stimulation of seeds [Mikos-Bielak and Koper 2003] as well as biostimulators applied in carrot cultivation [Kwiatkowski et al. 2015] significantly decreased the content of NO_3^- in carrot roots. Another experiment conducted by Wierzbowska et al. [2015] demonstrated that a five-month storage period resulted in an elevated content of N-total and $N\text{-}NO_3^-$, in potato tubers, while the content of $N\text{-}NH_4^+$ declined. Gajewska et al. [2009] found more nitrates (V) in carrot bought on street markets in the autumn and winter period (202.2 mg kg^{-1}) than in the ones purchased in spring and summer (184.4 mg kg^{-1}). Carrots stored in an industrial warehouse contained more nitrates (V) than ones stored in a fridge [Wrona 2012]. Prolonged storage time, especially at a higher temperature, contributed to a decrease in the nitrate (V) content of carrot roots. Wrzodak and Elkner [2010] reported that the content of NO_3^- decreased by 14% in roots of conventionally grown carrot and by 17% in ecological carrot roots after seven-month storage.

Table 5. Correlation coefficients for the content of macroelements in roots of edible carrot (average results from 2011–2012)

	Element	N	P	K	Na	Ca	Mg
Integrated cultivation	N	–	-0.440	-0.300	-0.210	-0.100	0.003
	P	-0.160	–	0.647**	0.468*	-0.550*	0.210
	K	-0.340	0.919**	–	0.846**	-0.350	-0.260
	Na	-0.320	0.865**	0.841**	–	-0.240	-0.230
	Ca	0.447*	-0.760**	-0.730**	-0.780**	–	-0.300
	Mg	-0.100	0.412	0.472*	0.314	-0.580**	–
Ecological cultivation	N	–	0.129	0.392	-0.160	-0.070	-0.140
	P	0.200	–	0.335	-0.110	-0.020	0.448*
	K	0.318	0.910**	–	0.183	-0.580**	-0.160
	Na	0.401	0.105	0.330	–	-0.630**	0.306
	Ca	-0.060	-0.730**	-0.850**	-0.260	–	0.224
	Mg	0.270	0.726**	0.903**	0.428	-0.880**	–

After storage | After hervest

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

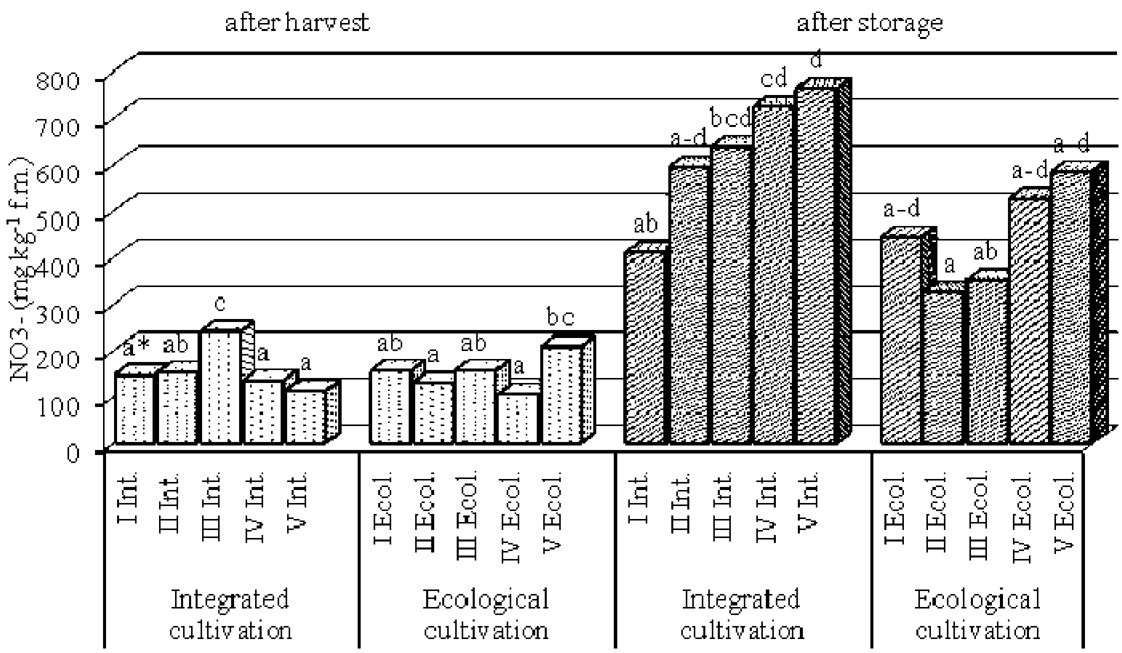

Fig. 2. Content of NO_3^- in roots of edible carrot (average results from 2011–2012).
* Data designated with same letters do not differ significantly at P ≤ 0.05

Table 6. Content of microelements in roots of edible carrot after harvest (average results from 2011–2012)

	Objects of experiment	Cu	Ni	Zn	Mn	Fe	B
		mg kg^{-1} d.m.					
Integrated cultivation	I Int.	4.05^{c*}	1.31^{ab}	11.88^{ab}	10.91^{ab}	61.13^{a}	20.85^{b}
	II Int.	3.05^{e}	0.98^{b}	10.02^{ab}	9.71^{ab}	58.52^{ab}	19.66^{c}
	III Int.	4.13^{ab}	1.18^{b}	13.00^{a}	13.25^{a}	47.61^{ab}	21.85^{b}
	IV Int.	3.27^{bc}	0.87^{b}	10.79^{ab}	9.97^{ab}	41.10^{b}	21.63^{b}
	V Int.	4.35^{ab}	0.68^{b}	10.94^{ab}	11.12^{ab}	48.63^{ab}	23.91^{a}
	Mean	3.77^{B}	1.00^{B}	11.33^{A}	10.99^{A}	51.40^{A}	21.58^{A}
Ecological cultivation	I Ecol.	4.74^{a}	2.57^{a}	9.78^{ab}	8.70^{b}	55.09^{ab}	18.45^{d}
	II Ecol.	3.77^{abc}	1.51^{ab}	8.81^{b}	9.67^{ab}	45.75^{b}	16.58^{e}
	III Ecol.	3.92^{abc}	1.12^{b}	9.67^{ab}	11.37^{ab}	54.02^{ab}	18.17^{d}
	IV Ecol.	3.82^{abc}	1.23^{ab}	8.22^{b}	9.46^{ab}	52.30^{ab}	20.06^{bc}
	V Ecol.	4.55^{a}	1.01^{b}	8.61^{b}	10.78^{ab}	51.35^{ab}	19.83^{c}
	Mean	4.16^{A}	1.49^{A}	9.02^{B}	10.00^{B}	51.70^{A}	18.62^{A}

[*] Data designated with same letters in column do not differ significantly at $P \leq 0.05$

The content of copper in carrot roots ranged from 3.05 to 4.74 mg kg^{-1} d.m. (tab. 6). In the ecological cultivation system, the highest copper content was determined in carrot grown without plant protection (I Ecol.), while among the integrated cultivation variants, most copper accumulated in roots of carrot grown in the treatment V Int. Carrots from ecological cultivation had about 10.3% more copper in roots than carrots from the integrated system. In both cultivation system, application of effective microorganisms (II Int. and II Ecol.) decreased the content of Cu in carrots root. More nickel (by 49% on average) accumulated in roots of carrot grown according to the principles of ecological farming. In both cultivation system, the highest nickel content was determined in carrot grown without plant protection (I Ecol. and I Int.), and lowest in V Int. and V Ecol. treatments. The content of Zn was within 8.22–13.0 mg kg^{-1} d.m. Carrots from integrated cultivation contained by about 25% more zinc in their roots than ecologically grown ones. Significantly more Zn and Mn accumulated in roots of carrots from the integrated system treatment including seed dressing T and triple spraying with Grevit 200 SL (III Int.). In turn, the lowest content of Mn was determined in roots of carrots grown in the ecological system without plant protection (I Ecol.). The Fe content ranged from 41.10 to 61.13 mg kg^{-1} d.m. In both cultivation systems, the highest root content of Fe was determined in carrot grown without protection against pathogen (I Int. and I Ecol.). The concentration of boron was within 16.58–23.91 mg kg^{-1} d.m., and the carrot grown in the integrated system contained, on average, 16% more of this element. Significantly the highest content of B was determined in carrot from the variant V Int., which – apart from biological and biotechnological preparations (EM, Asahi SL and Grevit 200 SL) – was treated the fungicide Bravo 500 SC. Quantities of microelements found in carrot roots depend on cultivation system and plant protection. The content of Cu in the analysed carrot roots was similar to amounts reported by Krejčová et al. [2016], while the content of Mn and B resembled the one determined by Warman and Havard [1997]. In turn, the concentration of

Fe proved to be two-fold higher and the content of Zn was about 50% lower than reported by the cited authors. According to Nicolle et al. [2004], the Fe content in carrot depends on the genotype of a carrot cultivar. Concentrations of Fe, Zn and Ca can be enhanced through genetic engineering methods used in carrot cultivation as well as through fertilization. Krejčová et al. [2016] state that carrot is a good source of Cu, Mn and Zn, able to satisfy much of the human demand for these elements. According to these authors, has proven that excess concentrations of heavy metals occur mostly in samples of vegetables homegrown for own use. The highest risk in the home cultivation of vegetables is due to insufficient knowledge regarding the chemical properties of soil in which plants grow. Results reported by Warman and Havard [1997] implicate small differences in the content of microelements in carrots from conventional and organic fields. According to Kelly and Bateman [2010], differences in concentrations of Mn, Ca, Cu and Zn in vegetables from ecological and conventional systems are most probably a consequence of a higher incidence of mycorrhizal fungi in ecological plantations, and the content of these elements might indicate the suitability of soils for ecological farming. These researchers noted a higher content of Ca, Zn and Cu in vegetables from a conventional plantation and a higher Mn content in vegetables grown ecologically.

CONCLUSIONS

1. Cultivation of carrots in the integrated system led to a higher root mass as well as a higher total and commercial yield than obtained from organic cultivation. The share of commercial yield in the total one did not depend on the system of cultivation.

2. Roots of carrots from the integrated system contained more N-total, potassium and calcium than ones produced in the organic system. The cultivation systems and plant protection methods did not have any significant effect on the content of the remaining macroelements.

3. In the consequence of the transformations occurring in carrot roots during their storage, their content of nitrogen, potassium, sodium, calcium and magnesium increased, while the content of phosphorus tended to decrease. The content of macroelements (N-total, P, Na and Mg) changed more extensively in roots of carrots grown in the ecological system.

4. During the storage, the content of nitrates (V) increased more in roots of carrots from the integrated system than in those produced organically.

5. The content of microelements in carrot roots was relatively small. In general, more Zn and Mn was contained in roots of carrots from the integrated system, while more Cu and Ni accumulated in roots of organic carrots.

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