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EFFECT OF VARIED NPK FERTILISATION ON THE YIELD SIZE, CONTENT OF ESSENTIAL OIL AND MINERAL COMPOSITION OF CARAWAY FRUIT (*CARUM CARVI* L.)

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Abstract

Fertilisation is the main factor stimulating yields of herbaceous plants, including yields of active substances per area unit.

The aim of the research was to evaluate the yielding and chemical composition of fruits of cv. Kończewicki caraway grown in a pure stand and supplied different rates of mineral fertilizer. The results are derived from a controlled, one-factor, micro-plot experiment set up with four replications in a split-plot design. The experimental factor consisted of NPK mineral fertilisation introduced into soil at the following rates per hectare: A_0 – without mineral fertilisation, A_1 – 103.9 kg NPK (37.5 kg N+17.6 kg P+4 8.8 kg K), A_2 – 209.8 kg NPK (75 kg N+35.2 kg P+ 99.6 kg K), A_3 – 314.7 kg NPK (112.5 kg N+52.8 kg P+ 149.4 kg K). Mineral fertilisation in the control increased the caraway fruit yield, the yield of essential oil as well as the content of total nitrogen. The rates of 209.8 kg NPK ha^{-1} and 314.7 kg NPK ha^{-1} caused a distinct decrease in the content of essential oil in caraway fruits compared with the unfertilized treatment and with the fertilisation rate of 103.9 kg NPK ha^{-1}. Mineral fertilisation, in general, significantly decreased the content of total phosphorus, calcium, magnesium and sodium, although it did not differentiate substantially the content of potassium in caraway fruits.

Key words: caraway, NPK fertilisation, macronutrients, essential oil.

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WPŁYW ZRÓŻNICOWANEGO NAWOŻENIA NPK NA WIELKOŚĆ PLONU, ZAWARTOŚĆ OLEJKU ETERYCZNEGO I SKŁAD MINERALNY OWOCÓW KMINKU ZWYCZAJNEGO (*CARUM CARVI* L.)

Abstrakt

Nawożenie jest głównym czynnikiem podnoszenia plonów roślin zielarskich oraz wydajności substancji czynnych z jednostki powierzchni. Celem badań była ocena plonowania oraz składu chemicznego owoców kminku zwyczajnego odmiany Kończewicki uprawianego w siewie czystym, pod wpływem zróżnicowanego nawożenia mineralnego. Wyniki pochodzą ze ścisłego, jednoczynnikowego doświadczenia mikropoletkowego, założonego w czterech powtórzeniach metodą losowanych bloków. Czynnikiem doświadczenia było nawożenie mineralne NPK zastosowane doglebowo w następujących dawkach na 1 ha: A_0 – bez nawożenia mineralnego, A_1 – 103,9 kg NPK (37,5 kg N+17,6 kg P+48,8 kg K), A_2 – 209,8 kg NPK (75 kg N+35,2 kg P+99,6 kg K), A_3 – 314,7 kg NPK (112,5 kg N+52,8 kg P+149,4 kg K). Nawożenie mineralne w odniesieniu do obiektu kontrolnego powodowało zwiększenie plonu owoców kminku zwyczajnego, plonu olejku eterycznego, a także zawartości azotu ogólnego. Pod wpływem dawek 209,8 kg NPK ha^{-1} oraz 314,7 kg NPK ha^{-1} stwierdzono wyraźne zmniejszenie zawartości olejku eterycznego w owocach w porównaniu z obiektem bez nawożenia i nawożonego dawką 103,9 kg NPK ha^{-1}. Nawożenie mineralne powodowało na ogół istotne zmniejszenie zawartości fosforu ogólnego, wapnia, magnezu oraz sodu, natomiast nie różnicowało wyraźnie koncentracji potasu w owocach kminku.

Słowa kluczowe: kminek zwyczajny, nawożenie NPK, makroelementy, olejek eteryczny.

INTRODUCTION

Caraway (*Carum carvi* L.) is one of the oldest spices and medicinal plants in the world. It is a biennial plant, which grows in the wild and on plantations. Caraway is one of the most popular spices, hence its production in Poland reaches 2 thousand ha (SEIDLER-ŁOŻYKOWSKA 2009). Poland is the world's leader in the production of this species. Its high content of essential oil, often above 4% (KLUSZCZYŃSKA 2002), makes the Polish caraway very highly valued on the global markets.

Fruits of *Fructus Carvi* (*Fructus Cari carvi*) collected in the second year of growth are used to make medications and as a spice (PANK, KRŰGER 1998), whilst both fruits and essential oil (*Fructus et Oleum Carvi)* serve as pharmacopeial material. Caraway fruits typically contain up to 82 cm^3 kg^{-1} of essential oil, which mainly consists of carvone (52%) and limonene (45%) (OLLE, BENDER 2010). Fruits also include fatty oil (up to 22%), protein compounds (up to 25%) as well as sugars, flavonoids, organic acids, coumarin derivatives, mineral salts and other compounds (KLUSZCZYŃSKA 2002). The extracts from caraway fruits have mostly relaxant, carminative, bile-forming, cholagogic, diuretic, diaphoretic, lactating, anti-inflammatory, tranquilising, expectoranting and antibacterial effects (DYDUCH et al. 2006). They stimulate the secretion of saliva, gastric acid and pancreatic juice, but also inhibit fermentation processes in intestines (KLUSZCZYŃSKA 2002).

A high demand from the herbaceous plant processing industry for high quality material calls for launching research on raising the yielding of plants without decreasing the content of active compounds. For caraway fruits, the content of essential oil, particularly carvone, is extremely important (SEIDLER-ŁOŻYKOWSKA 2009). Better yields and quality of harvested produce can be achieved when suitable agronomic technologies are implemented, (KWIATKOWSKI, KOŁODZIEJ 2005), especially proper mineral fertilisation (KOZERA, NOWAK 2010, KOZERA, MAJCHERCZAK 2011). The biochemical processes which stimulate the formation and accumulation of specific compounds are connected with assimilation, respiration as well as the uptake and absorption of minerals. Deficiency as much as excess of particular minerals can disturb the biosynthesis and, consequently, decrease the content of active compounds. Production of herbal plants is distinguished by an effort to achieve a high content of active substances, the key criterion in yield quality assessment, possibly by application of low rates of fertilisation.

The aim of the research was to evaluate the yielding and content of minerals and essential oil in fruits of caraway grown at different rates of mineral fertilisation.

MATERIAL AND METHODS

The research was based on the results of a controlled, multiple, one-factor, micro-plot experiment carried out in 2006-2009 at the Experimental Station of the Faculty of Agriculture and Biotechnology, University of Technology and Life Sciences in Bydgoszcz, located at Wierzchucinek (53°26' N, 17°79' E). Caraway was grown in a pure stand. The experiment was set up in a split-plot design with four replications. The experimental factor was NPK fertilisation applied at the following rates per hectare: A_0 – without mineral fertilisation, A_1 – 103.9 kg NPK (37.5 kg N +17.6 kg P+48.8 kg K), A_2 – 209.8 kg NPK (75.0 kg N+35.2 kg P+99.6 kg K), A_3 – 314.7 kg NPK (112.5 kg N+52.8 kg P+149.4 kg K). In the first year, Polifoska 6 (6-20-30) was applied pre-sowing at rates of 200 kg ha^{-1}, 400 kg ha^{-1} as well as 600 kg ha^{-1}. Nitrogen fertilisation was supplemented with ammonium nitrate, applied after plant emergence at rates 75, 150 and 225 kg ha^{-1}, respectively. In the second year, Polifoska 6 was used at the onset of plant growth while the ammonium nitrate treatment was performed 2 to 3 weeks later.

In both years, spring barley was the preceding crop. The experiment was performed in Haplic Luvisol, good rye complex soil of neutral reaction (pH_{KCl} – 6.7). The content of available forms of phosphorus was 63 mg P kg^{-1}, potassium – 114 mg K kg^{-1}, magnesium – 51 mg Mg kg^{-1} of soil.

Caraway's growth and development largely depended on the weather during in the plant growth season. The mean air temperature over the vegetative period, from March to October in the sowing year and from March through July in the harvest year was similar to the multi-year mean for the above months (Table 1). However, the two years were completely different in total rainfall. In the whole growing season of 2006/2007, there was a deficit of precipitations, for example in June and July 2006 the mean total rainfall corresponded to just 40.2% and 34.3% of the mean multi-year total for these months, respectively. The shortage of rainfall inhibited vegetation, especially the root system, which – when well developed – enhances the success of overwintering of plants and fruit-bearing in the successive year. In April 2007, the total rainfall was 10.2 mm lower than the long-term mean. Heavy rains in June (105 mm) and July (104.7 mm) delayed the caraway harvest. In the successive vegetative period (2007/2008), the rainfall deficit occurred in May and June 2008, when the mean total rainfall fell down to 27.1% and 28.6% of the multi-year total, respectively. In the 2008/2009 season, the rainfall deficit in April 2009 accounted for 98.6% and slowed down the caraway vegetation, while the heavy rain in July resulted caused uneven fruit ripening.

Table 1

Air temperature (°C) and precipitation (mm)

Month	Growing cycles						Mean - year	
	2006/2007		2007/2008		2008/2009			
	temp.*	precip.**	temp.	precip.	temp.	precip.	temp.	precip.
March	-1.5	27.4	5.0	47.9	3.0	61.2	1.8	24.3
Apr	7.1	77.0	8.5	17.6	7.6	38.7	7.3	27.8
May	12.5	59.9	13.8	73.1	13.2	11.5	13.0	42.4
June	16.8	21.8	18.2	105.5	17.6	15.5	16.2	54.2
July	22.4	24.2	18.0	104.7	19.2	58.7	18.0	70.6
Aug	16.6	129.0	17.8	42.1	17.8	95.5	17.5	54.7
Sep	15.2	40.6	12.4	37.6	12.4	20.2	13.2	40.4
Oct	9.6	12.1	6.9	19.9	8.4	80.0	8.3	32.2
March--Oct	12.3	392.0	12.6	448.4	12.4	381.3	11.9	346.6
March	5.0	47.9	3.0	61.2	2.4	43.7	1.8	24.3
Apr	8.5	17.6	7.6	38.7	9.8	0.4	7.3	27.8
May	13.8	73.1	13.2	11.5	12.3	85.3	13.0	42.4
June	18.2	105.5	17.6	15.5	14.3	57.4	16.2	54.2
July	18.0	104.7	19.2	58.7	18.6	118.0	18.0	70.6
March--July	12.7	348.8	12.1	185.6	11.5	304.8	11.3	219.3

*mean monthly air temperature, **sum of monthly precipitation

The harvest took place in June and July. It was performed manually, by cutting plants from an area of 3 m^2 area and then drying them up. Ripe caraway was threshed in a small plot harvester. For the purpose of chemical analyses, representative samples of 0.50 kg of fruits each were taken from each plot. Once they were ground and wet mineralized in sulphuric acid (VI), the following were determined: total nitrogen with Kjeldahl method; total phosphorus by colorimetry with ammonium; potassium, calcium and sodium molybdate with the flame photometry method; magnesium by atomic absorption spectroscopy. The concentration of essential oil extracted from ground caraway fruits was determined with the direct method (Farmakopea Polska 2008) by distillation with water vapour in a Deryng apparatus with a closed water cycle. Based on the yield size and the content of essential oil in the fruits, oil efficiency per hectare was calculated.

The analyses were performed at the Laboratory of Safe Food Production Technology Support, in an apparatus purchased under the project titled *Second Stage of the Establishment of a Regional Innovation Centre*.

The results were statistically verified using the analysis of variance for a one-factor design, and the differences between means were evaluated with Tukey's test at the level of significance of α = 0.05.

RESULTS AND DISCUSSION

In the present research, the mean yield of caraway fruits was 0.97 t ha^{-1} (Table 2). The yields from the first two research years were significantly lower than in the third year: 0.97, 0.70 versus 1.24 t ha^{-1}, and fell in the lower limits of the yielding potential of that species, which ranges from 0.6 to 2.5 t ha^{-1} (Bouwmeester et al. 1995). Caraway yield depends on the local weather conditions, which can drastically depress the profitability of growing this herb whenever they turn unfavourable for the species (Bouwmeester, Smid 1995). Another factor which affects caraway yields is the type of soil on which it is grown (Bouwmeester et al. 1995).

The tested mineral fertilisation had a significant effect on caraway yielding. Caraway fruit yield was distinctly higher in all the fertilization treatments than in the control. Significantly the highest fruit yield was obtained at the rate of 314.7 kg NPK ha^{-1}. It was 0.42 t ha^{-1} higher than the yield collected from the control. A significant yield increase was also recorded after the application of mineral fertilisation at the rate of 209.8 kg NPK ha^{-1} (A_2): 0.37 t ha^{-1} higher than the control. The fruit yield increase for treatments A_1 was also significant: 0.22 t ha^{-1}. According to Kołodziej (2006), fertilisation is the key factor increasing yields of herbal plants and the efficiency of active substances per area unit. Soil deficit of any of the three basic nutrients, especially nitrogen, can significantly decrease yields and the content of active substances (Kordana et al. 1998).

Table 2

Yielding and essential oil content in fruits of caraway

Functional quality	Year	Fertilisation treatments				Mean
		A_0	A_1	A_2	A_3	
Fruits yield (t ha^{-1})	2007	0.72	0.94	1.09	1.14	0.97
	2008	0.62	0.67	0.75	0.77	0.70
	2009	0.81	1.21	1.42	1.50	1.24
	2007-2009	0.72	0.94	1.09	1.14	0.97
	$LSD_{0.05}$ for: years – 0.053, fertilisation – 0.068 fertilisation in years: 2007 – 0.095, 2008 – 0.080, 2009 – 0.219					
Essential oil content ($cm^3 kg^{-1}$)	2007	48.8	49.4	46.9	45.6	47.7
	2008	53.8	54.9	52.4	51.3	53.1
	2009	51.3	51.9	50.0	48.1	50.3
	2007-2009	51.3	52.0	49.7	48.3	50.3
	$LSD_{0.05}$ for: years – 0.97, fertilisation – 0.75 fertilisation in years: 2007 – 2.64, 2008 – n.s., 2009 – 2.43					
Essential oil yield (kg ha^{-1})	2007	35.06	46.52	50.94	51.98	46.13
	2008	33.34	36.55	39.01	39.34	37.06
	2009	41.65	62.90	71.25	72.42	62.05
	2007-2009	36.68	48.66	53.73	54.58	48.41
	$LSD_{0.05}$ for: years 2 1.497, fertilisation – 1.349 fertilisation in years: 2007 – 2.553, 2008 3.022, 2009 – 4.353					

A_0 – with no mineral fertilisation, A_1 – 103.9 kg NPK ha^{-1}, A_2 – 209.8 kg NPK ha^{-1},
A_3 – 314.7 kg NPK ha^{-1},
n.s. – non-significant differences

Interestingly, although rate A_3 contained 50% more nutrients than A_2, the caraway fruit yield collected from that treatment was just 4.6% higher, hence the difference was not significant. Some authors have considered the economic aspect of higher fertiliser rates in caraway cultivation. The report by Floot (1990) showed that 75 kg N ha^{-1} is the highest and economically viable nitrogen rate for this species.

Essential oils are among the most common active substances found in plants and their therapeutic properties are broadly used in treatment of illnesses (Król, Kapka-Skrzypczak 2011). In caraway, the essential oil is found in an entire plant, although fruits are the richest source – 1-6% (Sedláková et al. 2003). Fruits harvested in the present experiment had a relatively high mean content of essential oil: 50.3 cm^3 kg^{-1} (Table 2). The highest content of oil was found in fruits collected from the fertilisation treatment with the lowest rate of NPK (A_1): 52.0 cm^3 kg^{-1}. However, it was not significantly higher than in the control. Any successively higher NPK fertilisation rate significantly decreased the content of oil to 3.12% (A_2) and 5.85% (A_3) of the control. Similar tendencies were observed in each year. Significantly the highest oil content was determined in caraway fruits collected in 2008 (an average of 53.1 cm^3 kg^{-1}), but the inter-treatment differences were not significant. The lowest content of oil, 47.7 cm^3 kg^{-1}, was found in schizocarps harvested in 2007. Results of studies on caraway reported in recent years are varied, one reason being highly changeable and different weather conditions during the plants' growth. Thus, it is difficult to evaluate the effect of fertilisation on the content of essential oil in herbal materials. In the present study, the lower total rainfall in the second year of vegetation (2008) enhanced the accumulation of oil in fruits, whereas more rainfall in 2007 decreased its content in schizocarps. According to Rőhricht et al. (1996), the oil content in material is more strongly affected by habitat conditions than nitrogen fertilisation. Ezz El-Din et al. (2010) reported an increase in the oil content in caraway fruits under the effect of increasing nitrogen rates. As reported by Dzida (2007), more intensive nitrogen fertilisation increased the oil content in thyme herbage.

It is possible to improve oil efficiency by increasing its content in plant material or by raising plant yield per area unit. High yields are unattainable without providing plants with adequate growth and development conditions, including optimal mineral fertilisation. With that in mind, it is essential to look for such fertilisation methods which will increase yield of herbal material but not decrease its content of active substances. Another consideration is to ensure high quality of the final product and production profitability (Bielski et al. 2011). The mean essential oil yield in the tested caraway fruit yield was 48.41 kg ha^{-1}.There was a significantly higher oil yield from the fertilised variants than from the control (Table 2). The highest essential oil yields in caraway fruits were found after the application of 314.7 kg NPK ha^{-1} (54.58 kg ha^{-1}) and 209.8 kg NPK ha^{-1} (53.73 kg ha^{-1}). The yields were 48.8% and 46.5% higher, respectively, than from the control. Significantly the lowest mean oil yield (37.06 kg ha^{-1}) was in 2008 while the highest oil efficiency per hectare was found in 2009 (62.05 kg ha^{-1}).

Caraway fruits are also a rich source of potassium, magnesium, phosphorus as well as micronutrients (Kluszczyńska 2002). In the present research, a significant effect of NPK fertilisation on the chemical composition of caraway fruit was found (Table 3). All the different rates of NPK fertiliser clearly increased the mean content of total nitrogen in fruits. The highest total nitrogen content was reported in the fertilisation treatment with the rate of 314.7 kg NPK ha^{-1}, and the difference was 11.6% compared with the control.

Considerable variation was observed in the mean content of total nitrogen in fruits between the years: from 29.69 g kg^{-1} (2008) to 36.00 g kg^{-1} (2007). Significantly most nitrogen was recorded in fruits collected in 2007.

Interestingly, rates A_2 and A_3 were the only ones which induced a clear increase in total nitrogen in fruits, as compared with the control. At the lowest rate (103.9 kg NPK ha^{-1}), there was an increase in the mean content of N in fruits, although the differences were not significant. Dzida (2007), reporting on the effect of increasing nitrogen fertilisation on the chemical composition of thyme herbage, also observed increased accumulation of minerals, including total nitrogen. Nitrogen is an essential element in agrotechnical practise employed for caraway cultivation (Evenhuis et al. 1999). In plants, this is a very mobile element, which is indispensable in biosynthesis of protein, a key building material of the plant, whose content in caraway fruits reaches 25% (Kluszczyńska 2002). Nitrogen is involved in enzymatic and metabolic processes; it participates in synthesis and transfer of energy; it is also a component of chlorophyll (Ezz El-Din et al. 2010).

This research has demonstrated a significant effect of fertilisation on the total phosphorus accumulation in fruits (Table 3). In fruits from the fertilisation treatments with phosphorus, the content of this element was significantly lower than the control. The biggest decrease in the content of phosphorus was in fruits from the fertilisation treatment with the rate of 209.8 kg NPK ha^{-1} (the difference reached 6.3%). The highest mean content of total phosphorus in fruits (7.01 g kg^{-1}) was noted in 2009. In the other years, its content was less than 20.3% (2007) and 16.5% (2008). Interestingly, the NPK fertiliser rates in the first year (2007) did not result in any significant changes in the content of total phosphorus in fruits, as compared with the control, which was analogous to the results reported by Dzida and Jarosz (2006a), who did not show any distinct effect of varied nitrogen and potassium fertilisation on the content of phosphorus in marjoram herbage.

No significant effect of NPK fertilisation on the potassium content in fruits of *Carum carvi* L. was demonstrated. Its content ranged from 16.22 g K kg^{-1} in fruits from treatment A_1 to 16.79 g K kg^{-1} from treatment A_2 (Table 3). Dzida and Jarosz (2006b), investigating savory herbage, recorded similar effects produced by nitrogen-potassium fertilisation. The fertiliser rates did not differentiate the content of potassium in 2009, although it was higher than in fruits from the control. The effect of the applied fertilisation rates on the potassium content in 2007 and 2008 was not obvious. In 2008, a significant increase in the potassium content in fruits was reported up to rate A_2. On the other hand, in 2007, rate A_1 significantly decreased the content of potassium versus the control, whilst the other rates did not differentiate it, which implies an evident effect of the weather conditions on potassium in fruits. Other reports point to a considerable variation in the content of that element in herbaceous plants depending on the region where they grow (Ajasa et al. 2004) and the soil's abundance in available forms of nutrients (Sheded et al. 2006).

The average content of calcium in caraway fruits was 5.96 g Ca kg^{-1}. Similarly to phosphorus, the different mineral fertilisation levels significant-

Table 3

Macronutrients content in caraway fruits (g kg^{-1})

Nutrient	Year	Fertilisation treatments				Mean
		A_0	A_1	A_2	A_3	
Total nitrogen	2007	34.13	35.25	36.96	37.66	36.00
	2008	28.00	28.95	30.03	31.78	29.69
	2009	32.92	34.31	35.77	36.58	34.89
	2007-2009	31.68	32.84	34.25	35.34	33.53
	$LSD_{0.05}$ for: years – 0.137, fertilisation – 0.099 fertilisation in years: 2007 – n. s., 2008 – 0.338, 2009 – 0.317					
Total phosphorus	2007	5.73	5.53	5.53	5.59	5.59
	2008	6.20	5.71	5.63	5.87	5.85
	2009	7.16	7.12	6.71	7.06	7.01
	2007-2009	6.36	6.12	5.96	6.17	6.15
	$LSD_{0.05}$ for: years – 0.137, fertilisation – 0.099 fertilisation in years: 2007 – n. s., 2008 – 0.338, 2009 – 0.317					
Potassium	2007	16.85	15.53	16.48	16.48	16.34
	2008	15.34	15.72	16.06	15.52	15.66
	2009	16.96	17.42	17.82	17.56	17.44
	2007-2009	16.38	16.22	16.79	16.52	16.48
	$LSD_{0.05}$ for: years – 0.393, fertilisation – n.s. fertilisation in years: 2007 – 0.693, 2008 – 0.268, 2009 – n.s.					
Calcium	2007	7.19	6.63	5.96	5.73	6.38
	2008	7.10	6.80	6.70	6.25	6.71
	2009	5.36	4.99	4.46	4.36	4.79
	2007-2009	6.55	6.14	5.71	5.45	5.96
	$LSD_{0.05}$ for: years – 0.139, fertilisation – 0.135 fertilisation in years: 2007 – 0.308, 2008 – 0.378, 2009 – 0.425					
Magnesium	2007	3.70	3.30	3.16	3.62	3.44
	2008	4.29	3.95	3.99	3.93	4.04
	2009	3.93	3.62	3.58	3.63	3.69
	2007-2009	3.97	3.62	3.58	3.72	3.72
	$LSD_{0.05}$ for: years – 0.103, fertilisation – 0.065 fertilisation in years: 2007 – 0.319, 2008 – 0.239, 2009 – 0.206					
Sodium	2007	0.31	0.27	0.25	0.27	0.27
	2008	0.34	0.29	0.29	0.34	0.32
	2009	0.31	0.27	0.27	0.29	0.29
	2007-2009	0.32	0.28	0.27	0.30	0.29
	$LSD_{0.05}$ for: years – 0.017, fertilisation – 0.022 fertilisation in years: 2007 – 0.027, 2008 – 0.006, 2009 – n.s.					

A_0 – with no mineral fertilisation, A_1 – 103.9 kg NPK ha^{-1}, A_2 – 209.8 kg NPK ha^{-1},
A_3 – 314.7 kg NPK ha^{-1},
n.s. – non-significant differences

ly decreased the content of that element in fruits compared with the unfertilised treatment. This tendency was observed in all the years (Table 3). Kołodziej (2011), who investigated the effect of NPK fertilisation on the chemical composition of European goldenrod, found a decrease in the content of calcium in the herbage of that plant.

As a result of mineral fertilisation, the magnesium content in fruits was lower than in the control by 8.8% (rate A_1), 9.8% (rate A_2), and by 6.3% (rate A_3), respectively. Such a tendency occurred in all the years. Most magnesium was accumulated in caraway fruits collected in 2008 (4.04 g Mg kg^{-1}). In the other two years (2007 and 2009), the content was 14.9% and 8.7% lower, respectively (Table 3). The literature stresses that magnesium is essential for various physiological processes, in which it plays numerous roles, for example it participates in the formation of chlorophyll, controls the water balance of plants and facilitates the synthesis of many chemical compounds (Panak 1997). The plants take up magnesium throughout the vegetative period, but mostly during the most intensive growth. The content of this nutrient in plants depends on its availability in soil, which can be changed quite considerably by soil moisture (Mikiciuk, Seidler 2004). Golcz et al. (2003) point to a higher demand of plants for magnesium when their yielding is stimulated by nitrogen fertilisation. A high demand of the tested caraway plants for Mg could have decreased its content in the fruits.

The NPK mineral fertilisation, as compared with the control, clearly decreased the content of sodium in caraway fruits (Table 3). The significantly lowest content of this element (0.27 g Na kg^{-1}) was determined in fruits collected from the fertilisation treatment with the medium NPK rate (A_2). The highest sodium content, like that of magnesium, was recorded in fruits collected in 2008 (0.32 g Na kg^{-1}). The year 2009 was exceptional in that that the mineral fertilisation did not differentiate significantly the sodium content in caraway fruits. Amounts of sodium available to plants depend mostly on the content of available forms of Na in soil, total rainfall and plant species (Adaszyńska, Swarcewicz 2011). The sodium content in herbs is not high relative to amounts of other macronutrients (Arceusz et al. 2008).

Based on results of this experiment, it was concluded that the yield volume and quality were highly varied by the weather conditions during the growing seasons in each year. Interestingly, as caraway has a two-year growth cycle, it is especially sensitive to rainfall deficit during the vegetative period, which can inhibit flowering and fruit-bearing until the third year of growth (Kołodziej 2010). It is very important to ensure all the best agrotechnical conditions to caraway plants, especially in the first year of cultivation, in order to avoid the delay of flowering to the third year of cultivation. Under the influence of the highest rate (314.7 kg NPK ha^{-1}), the highest mean fruit yield and the essential oil yield were produced, which suggests that the essential oil yield is more strongly correlated to the fruit yield increase than to the changes in its content in schizocarps. The yield increase is one of the ways of increasing the efficiency of essential oil per area unit in oilseed crops (BIELSKI et al. 2011). Under the fertilisation dose mentioned above, the fruits also accumulated most total nitrogen. The content of total nitrogen, total phosphorus as well as magnesium and sodium in fruits reported after the application of 314.7 kg NPK ha^{-1} was significantly higher than after the rate of 209.8 kg NPK ha^{-1}, which is recommended for caraway growing in soils moderately rich in available forms of nutrients (KOŁODZIEJ 2010). The NPK rate of 209.8 kg NPK ha^{-1} resulted in fruits accumulating significantly more essential oil and calcium than fruits from plants treated with the highest NPK rate. The use of the lowest NPK rate (103.9 kg NPK ha^{-1}) enhanced the accumulation of essential oil in fruits, whose content of which was distinctly higher compared with the other fertilisation treatments. The present research results show that optimisation of caraway fertilisation, mostly to produce a high yield of high-quality material, is a promising option, which is worth further investigations.

CONCLUSIONS

1. Increasing mineral fertilisation rates, as compared with the control, resulted in caraway fruits producing a significantly higher fruit yield, higher yield of essential oil and improved total nitrogen content.

2. The rates of 209.8 and 314.7 kg NPK ha^{-1} distinctly decreased the content of essential oil in caraway fruits compared with the control or the rate of 103.9 kg NPK ha^{-1}.

3. In general, the application of mineral fertilisation resulted in caraway fruits presenting a significant decrease in the content of total phosphorus, calcium, magnesium and sodium. However, the potassium content was not so evidently differentiated.

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