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Variability in macroelement content in the aboveground part of *Helianthus tuberosus* L. at different nitrogen fertilization levels

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ABSTRACT

The contents of nitrogen (N), potassium, phosphorus, calcium, magnesium and sodium were estimated in tubers of Jerusalem artichoke *Helianthus tuberosus* coming from the field experiment conducted over 2010–2012. The experimental factors were the cultivars of Jerusalem artichoke cvs. Albik and Rubik and different nitrogen fertilization levels, against phosphorus and potassium fertilization and the full dose of manure. Determination of elements in the soil and the dry weight of the aerial parts are performed by standard methods. When using a fixed level of phosphorous-potassium fertilizer, the highest sodium content was obtained at a level of 50 kg N/ha, magnesium and sulphur at a dose of 100 kg of N, nitrogen – 150 kg N/ha, potassium and calcium – in the objects of fertilizer phosphorus-potassium, and phosphorus – in the building control without fertilization. Cv. Albik proved to be more abundant in mineral elements than cv. Rubik. The latter was characterized by a higher stability of characteristics.

Keywords: animal fodder; topinambour; biomass; macronutrients; nutrition

Owing to its nutritional and energy value, Jerusalem artichoke (*Helianthus tuberosus* L.) is becoming an increasingly important component of animal fodder. It is used in the fodder industry for manufacturing protein concentrates for feeding animals (Sawicka 2002, He et al. 2010, Marien 2012, Izsáki and Kádi 2013). Fresh aboveground mass of *Helianthus tuberosus* contains a lot of vitamins (carotene, ascorbic acid, riboflavin, nicotinic acid, etc.) and mineral salts (Sawicka and Kalembasa 2008, Izsáki and Kádi 2013). The application of high levels of mineral fertilization, especially with nitrogen (N), can reduce the content of mineral nutrients in aboveground parts of Jerusalem artichoke. The aim of the study was to assay macronutrients in the aboveground parts of two cultivars of *Helianthus tuberosus* L. as affected by different levels of mineral fertilization.

MATERIAL AND METHODS

Aboveground parts of Jerusalem artichoke, grown on experimental plots at the Experimental Field Station in Parczew (51°64'N, 22°90'E), in the years 2010–2012, were used as the study material. The field experiment was conducted on Haplic Luvisol soils, whose surface humus layers consist of loamy sand, had acidic or slightly acidic pH (5.1–5.9) and contained medium concentrations of organic matter. The organic matter content in the soil was found to be 1.82%. The soil contained a very high concentration of available phosphorus, a high concentration of potassium, a medium concentration of magnesium, a low concentration of boron, a medium concentration of iron, a low concentration of copper and high concentrations of manganese and zinc. The experiment was set up by the random sub-blocks method in triplicate. Each plot was 20 m^2 in size. The Jerusalem artichoke cvs. Albik and Rubik were the primary factor and mineral fertilization at the following doses: $N_0P_0K_0$ – as control and $N_0P_{44}K_{125}$; $N_{50}P_{44}K_{125}$; $N_{100}P_{44}K_{125}$; $N_{150}P_{44}K_{125}$; $N_{200}P_{44}K_{125}$, converted to the elemental forms of the fertilizers, against a full dose of manure (30 t/ha) was the secondary factor. All the cultivation meas-

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ures were performed in accordance with the good agricultural practice principles.

Samples of aboveground mass were taken for the chemical analyses during the harvest from 10 Jerusalem artichokes from every plot. The following were assayed in dry matter (DM): total nitrogen – on a Perkin Elmer CHN autoanalyser (USA), sulphur content – by nephelometry (Cary, USA), total phosphorus, potassium, calcium, magnesium and sodium – in the stock solution obtained after tubers were dry-mineralised in a muffle furnace at the temperature of 450°C. The raw ash obtained in a porcelain crucible was poured over with hydrochloric acid HCl (1:1) in order to dissolve the carbonates and to separate silica (SiO_2) and evaporated on a sand bath. 10 cm^3 of 5% HCl was used to obtain a solution containing chlorides of the metals under study and phosphoric (V) acid. The solution was transferred to a 100 cm^3 volumetric flask, separating silica on a dense filter. The concentrations of the macronutrients under analysis were assayed in the prepared solutions by the ICP-AES (inductively coupled plasma-atomic emission spectrometry), on a Perkin Elmer Optima 3200 RL apparatus (USA) with argon plasma, using the following wavelengths: for P – 214.914; K – 766.490; Ca – 315.887; Mg – 285.213; Na – 330.237 nm. The apparatus operation parameters were: RF power – 1300 W, cooling argon flow rate – 15 L/min, auxiliary argon flow rate – 0.5 L/min, nebulising argon – 0.8 L/min, and the sample feeding rate – 1.5 mL/min.

The results were subjected to the statistical analysis using analysis of variance Statistica 10 PL software (StatSoft, Tulsa, USA). Significant differences determined by the Tukey's test. Variability coefficients for each attribute were also calculated.

The distribution of temperatures and rainfall during the years of the study varied. The first half of the vegetation period in 2010 was wet and warm, while the other was dry. April and May in 2011 were humid and chilly and June and July were extremely dry. May and June in 2012 were wet and chilly, whereas the other months were dry or extremely dry.

RESULTS AND DISCUSSION

The value of aboveground parts of *Helianthus tuberosus* as fodder for animals and material for the production of fodders (protein concentrates, dried fodders, etc.), as well as for energy generation, is demonstrated by their mineral composition. The average content of the macronutrients under study in the dry matter of leaves and stalks was (g/kg): nitrogen – 27.25, potassium – 34.791, phosphorus – 2.791, calcium – 0.883, magnesium – 0.474, sulphur – 1.074, sodium – 1.747. Skiba (2014) examined the mineral composition of the aboveground parts of Jerusalem artichoke and found it to contain the largest amount of potassium (30.54 g/kg); the other macronutrients were arranged in the following sequence: nitrogen (17.04 g/kg) > calcium (1.584 g/kg) > magnesium (2.39 g/kg) > phosphorus (1.58 g/kg) > sulphur (1.20 g/kg) > sodium (0.84 g/kg). According to the standards adopted by Bergmann (1992), the aboveground parts of Jerusalem artichoke under study contained sufficient amounts of potassium, phosphorus and small amounts of calcium and magnesium, whereas the content of sulphur and sodium was above the optimum values. Nitrogen, phosphorus and potassium (NPK) are the main nutrients necessary to ensure growth of the aboveground parts of Jerusalem artichoke. The N:P ratio determines the yield of aboveground parts and tubers of Jerusalem artichoke (He et al. 2010). The content of phosphorus and potassium in above-ground parts lay within the normal limits (Bergmann 1992). A slightly higher content of potassium in stalks and leaves of Jerusalem artichoke was found by Sawicka (2002), and twice lower was found in wild forms of *H. tuberosus* by Seiler (1988). The content of magnesium in the aboveground parts of *H. tuberosus* ranged from 0.39–0.56 g/kg of dry matter. Twice higher content of the element was found in tubers of the species by Sawicka and Kalembasa (2008). Comparable amounts of magnesium in this part of Jerusalem artichoke were found by Sawicka (2002) and much larger amounts (1.70 g/kg) by Seiler (1988) in wild forms of *Helianthus tuberosus*. This macronutrient has an antagonistic action towards K^+ and NH_4^+ ions – it decreases their uptake and binds with different enzymes, forming bridge-type ionic bonds, for example, with proteins and ATP, and it also takes part in regulation of pH in the cell (Starck 2010). The role of calcium in plantations of Jerusalem artichoke is very important because the element determines the equilibrium of nutrients in food and fodder. The content of calcium in dry matter as determined in this study was too low, which should be associated with the mutual antagonistic effect of potassium and calcium. This

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adversely affected the quality of biomass measured as the calcium-to-potassium ratio. Sawicka (2002) reports that susceptibility to calcium deficiency is genetically conditioned. The content of sodium in aboveground parts of Jerusalem artichoke was excessive (1.53–2.06 g/kg DM). Similar amounts of the element were found in those parts of the plants by Seiler and Campbell (2004) and much smaller were found by Skiba (2014). According to Starck (2010), the element is beneficial to plants because it can replace potassium and it makes plants resistant to water stress. The content of sulphur in the above-ground mass of *H. tuberosus* ranged from 0.97–1.24 g/kg of their dry weight. According to Yildiz et al. (2008), the content of sulphur in the dry matter of young plants is higher than in old ones.

The cultivar properties proved to be a significant modifying factor for the content of nitrogen, potassium, phosphorus, sodium and sulphur in tubers of these plants. Cv. Albik contained significantly more potassium, phosphorus and sodium than cv. Rubik which, in turn, contained more nitrogen and sulphur than cv. Albik. The variability coefficient (V) was low, which indicates that the attributes under study are generally stable. The content of potassium, magnesium, sulphur and sodium in the aboveground parts of cv. Rubik proved to be more stable than in the cv. Albik, in which the contents of nitrogen, phosphorus and calcium were more stable. The content of sulphur proved to be the most stable and the content of calcium was the least stable (Table 1). An important role in the variability of macronutrient content in the aboveground parts of *H. tuberosus* was played by genotypic variability, associated with cultivar-related attributes. According to Sawicka (2002), genotypic variability contributes 46.7–98.3% to the overall variability of macronutrients. In the opinion of Seiler and Campbell (2004), phenotypic variability, both of cultivars and of wild forms of Jerusalem artichoke, in terms of every feature of the chemical composition of tubers, is a combined effect of genetic and environmental variability. They showed the high value of genotypic variation components for N, K, S and Na, which can be potentially improved by selection. The contribution of genotypic variability for P, Mg and Ca was low, which can indicate that improvement of the features by selection will be difficult.

Mineral fertilization applied in the experiment had a significant effect on the content of all the elements analysed in this study (Table 2). Phosphorus and potassium fertilization was found to have caused a significant decrease in the nitrogen content in the aboveground parts of Jerusalem artichoke compared to the control. An increase in the dose of nitrogen to 150 kg/ha, against a constant dose of phosphorus and potassium did not have a significant effect, whereas the dose of 200 kg N/ha significantly decreased the content of the element in the aboveground parts under analysis compared to the control. A significant increase in the potassium content was found to be caused by phosphorus and potassium fertilization alone, compared to the control. Nitrogen fertilization significantly decreased the concentration of the element in the aboveground mass of *H. tuberosus*, and its lowest concentration was recorded in plots where the dose of 200 kg N/ha was applied. The highest concentrations of phosphorus in the parts of plants under analysis were found on the control plot (no fertilization) and the lowest was on the plot where the dose of 100 kg N/ha was applied. A further increase in nitrogen fertilizer dose increased the content of phosphorus in aboveground parts compared to the dose of 100 kg N/ha,

Table 1. The macroelements content (g/kg) in dry matter of aboveground part of *Helianthus tuberosus*

	Cv. Albik		Cv. Rubik		$LSD_{0.05}$
	mean	*V*	mean	*V*	
Nitrogen	25.940	20.979	28.570	25.879	0.112
Potassium	36.000	11.756	33.580	11.016	0.496
Phosphorus	2.891	22.970	2.692	23.765	0.090
Calcium	0.887	23.660	0.880	31.480	ns
Magnesium	0.478	20.234	0.471	7.980	ns
Sodium	1.803	22.211	1.691	19.236	0.059
Sulphur	1.048	5.110	1.100	4.980	0.040

V – coefficient of variability; ns – not significant at $P > 0.05$; *LSD* – least significant difference

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Table 2. Influence of mineral fertilization on the nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), sulphur (S) and sodium content (Na) (g/kg) in dry matter of aboveground part of *Helianthus tuberosus* (mean for two cultivars)

Fertilization	N	K	P	Ca	Mg	S	Na
0	28.890	39.650	3.161	0.778	0.464	1.078	1.556
PK	24.450	41.352	3.081	1.048	0.421	0.994	1.700
N_1PK	27.083	33.245	2.804	0.870	0.404	1.051	1.983
N_2PK	27.010	30.871	2.351	0.905	0.561	1.183	1.717
N_3PK	29.192	35.060	2.773	0.914	0.464	1.112	1.779
N_4PK	26.900	28.562	2.570	0.786	0.531	1.024	1.775
Mean	27.250	34.791	2.791	0.883	0.474	1.074	1.747
$LSD_{0.05}$	0.279	1.240	0.380	0.070	0.041	0.101	0.178

0 – control; PK – $P_{44}K_{125}$; N_1PK – $N_{50}P_{44}K_{125}$; N_2PK – $N_{100}P_{44}K_{125}$; N_3PK – $N_{150}P_{44}K_{125}$; N_4PK – $N_{200}P_{44}K_{125}$ (kg/ha); *LSD* – least significant difference

but it was lower than in the control plot (Table 2). The content of calcium was significantly highest in the plots fertilized only with phosphorus and potassium fertilizers. Intensification of mineral fertilization brought about a decrease in calcium content in aboveground parts, with the lowest content of the element found in plots fertilized with 200 kg N/ha, compared to phosphorus and potassium fertilization. An increase in the content of magnesium and sulphur in aboveground parts of Jerusalem artichoke was brought about by fertilization with 100 kg N/ha in combination with phosphorus and potassium fertilization. A further increase in the dose of the macronutrient did not result in an increase in the concentration of these elements. The highest content of sodium in stalks and leaves of Jerusalem artichoke was found in plots fertilized with 50 kg N/ha and the lowest was in the control plot (Table 2). Sawicka (2002) reports that a high dose of nitrogen fertilizers can increase the content of potassium, calcium, magnesium and decrease the concentration of phosphorus in the aboveground parts of Jerusalem artichoke. According to Skiba (2014), nitrogen fertilization has the most beneficial effect on the content of phosphorus, potassium and calcium, whereas it adversely affects the content of sulphur in the aboveground parts of Jerusalem artichoke. She found the average nitrogen and potassium content in these parts of the plants to be the highest on plots fertilized with 50 kg N/ha, against the phosphorus and potassium fertilization. The same form of nitrogen, at the dose of 150 kg N/ha, had the most beneficial effect on the accumulation of calcium, magnesium and sodium. The application of amide nitrogen at 150 kg N/ha increased the content of phosphorus and sulphur. It was been proved that fertilization with an increased dose of nitrogen significantly decreases the biological value of tubers of the species. Fodder abundant with phosphorus (one of the more important macronutrients in production of animal protein) is a proof of sufficient, or even excessive, mineral fertilization with this element.

The cultivars under study reacted differently to mineral fertilization in terms of nitrogen, potassium, phosphorus, sulphur and sodium content (Table 3). The highest content of nitrogen in aboveground parts of Jerusalem artichoke of cv. Albik was found in the plants in plots fertilized with 200 kg N/ha and in cv. Rubik – with 150 kg N/ha, against constant doses of phosphorus and potassium fertilization. The content of phosphorus in aboveground parts of the cv. Rubik was the highest in the plants grown in the control plot, whereas that in cv. Albik – in the plot where phosphorus and potassium fertilization was applied. The highest content of potassium in the above-ground parts of Jerusalem artichoke of both the cultivars under study was found in the plants grown in plots where phosphorus and potassium fertilization alone was applied. The lowest content of the element was found in cv. Albik in plots where the dose of 50 kg N/ha was applied and in cv. Rubik – in plots where 200 kg N/ha was applied (Table 3). The highest content of sulphur in both cultivars was found in the plants grown in the plots where nitrogen fertilizer was applied at 50 kg N/ha, in combination with the phosphorus and potassium fertilization, and the lowest content was in cv. Albik

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Table 3. Influence of cultivars and mineral fertilization on the nitrogen (N), potassium (K), phosphurus (P), calcium (Ca), magnesium (Mg), sulphur (S) and sodium content (Na) in dry matter of aboveground part of *Helianthus tuberosus* tubers (g/kg)

Cultivar	Fertilization	N	K	P	Ca	Mg	S	Na
Albik	0	27.24	40.54	3.09	0.83	0.43	1.18	1.53
	PK	22.61	42.52	3.34	1.07	0.43	0.99	1.81
	N_1PK	26.58	31.13	2.99	0.74	0.39	1.03	1.91
	N_2PK	24.52	32.92	2.41	1.00	0.56	1.24	1.80
	N_3PK	26.86	35.91	2.54	0.99	0.48	1.12	1.85
	N_4PK	27.80	32.99	2.94	0.88	0.54	1.04	1.92
Rubik	0	30.54	38.76	3.23	0.72	0.53	0.97	1.58
	PK	26.28	40.18	2.83	1.02	0.41	1.00	1.59
	N_1PK	27.58	35.35	2.62	1.00	0.42	1.07	2.06
	N_2PK	29.49	28.82	2.29	0.82	0.56	1.13	1.64
	N_3PK	31.52	34.21	2.99	0.95	0.45	1.11	1.71
	N_4PK	26.01	24.14	2.20	0.78	0.52	1.01	1.57
$LSD_{0.05}$		0.56	2.48	0.76	ns	ns	0.20	0.36

0 – control; PK – $P_{44}K_{125}$; N_1PK – $N_{50}P_{44}K_{125}$; N_2PK – $N_{100}P_{44}K_{125}$; N_3PK – $N_{150}P_{44}K_{125}$; N_4PK – $N_{200}P_{44}K_{125}$ (kg/ha); *LSD* – least significant difference; ns – not significant

in the plots with phosphorus and potassium alone and in the cv. Rubik in the control plot (Table 3). A different reaction of the cultivars under study to fertilization with nitrogen in regard to nitrogen, potassium, phosphorus, sulphur and sodium was a result of their different capacity for accumulation in aboveground parts and their reaction to nitrogen fertilization. When considering sodium content, it was found that the cultivars under study reacted differently to mineral fertilization. There was no significant reaction to the fertilization in cv. Albik, whereas the largest amounts were accumulated in cv. Rubik already when the lowest dose of nitrogen was applied (Table 3).

Weather conditions in the years of study had a significant effect on the content of all the macronutrients under study in the aboveground parts of *H. tuberosus* (Table 4). The highest contents of potassium, phosphorus, calcium, magnesium in the aboveground parts of the species were found in 2010, and the lowest was in 2011; the highest content of sodium was found in 2011 and of nitrogen and sulphur in 2012. Varied weather conditions during the years of study affected the calcium content in the aboveground parts of *H. tuberosus*. Significant increases in the content of the element caused by phosphorus and potassium fertilization compared to the control plot were observed in 2010 and 2012 (Table 4). Variability of the soil and weather environment significantly modified the level of all the macronutrients in the aboveground parts. According to Seiler (1988), Harmankaya et al. (2012), Izsáki and Kádi (2013) diversity of the environment in which Jerusalem artichoke grows modifies the processes of internal regulation. Therefore, variability may occur within the plant, the main stem and lateral shoots and it may be linked to the years and place of cultivation. Pražnik et al. (1998) and Sawicka (2002) showed that the environmental conditions, especially weather conditions, have the greatest effect on the accumulation of magnesium in the aboveground parts. High concentrations of the element are favoured by high rainfall and medium average air temperature.

The element content ratios are very important in the aboveground parts of *H. tuberosus*, especially those intended for fodder. The proportions of

Table 4. Influence of the years on the macroelements content (g/kg) in dry matter of aboveground part of *Helianthus tuberosus*

Macroelement	2010	2011	2012	$LSD_{0.05}$
Nitrogen	26.360	27.320	28.083	0.167
Potassium	35.570	33.841	34.950	0.744
Phosphorus	2.870	2.722	2.791	ns*
Calcium	0.937	0.830	0.883	0.042
Magnesium	0.486	0.462	0.474	0.024
Sodium	1.677	1.817	1.747	0.107
Sulphur	0.865	1.175	1.182	0.061

LSD – least significant difference; ns – not significant

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minerals in the parts of Jerusalem artichoke under study depended on their content. The potassium-to-calcium and potassium-to-magnesium ratios, which are the most important for nutrition, proved to be too high in the material under study. An excessive concentration of potassium in the dry matter of these parts of *H. tuberosus* could not counterbalance the deficit of calcium or the optimum content of magnesium. Similar observations regarding the element ratios in the aboveground parts of Jerusalem artichoke were presented by Skiba (2014). They showed that changes in the proportions between K, Ca and Mg ions depend on the cultivation system.

These results justify the need for separate studies aimed at determination of precise nutritional needs of Jerusalem artichoke in regard to phosphorus, potassium and magnesium. Since phosphorus and potassium deficit in Poland is quite frequent, studies should be initiated in order to verify the valid limit numbers for these elements in soil.

In conclusion, the genetic features of *H. tuberosus* cultivars grown on light soils, as well as mineral fertilization determined the content of macronutrients in its aboveground parts. Cv. Albik contained more minerals than cv. Rubik, which indicates its greater usability as fodder and for the fodder industry. The following were found in the aboveground parts of Jerusalem artichoke against a constant level of phosphorus and potassium fertilization: the highest content of nitrogen on plots where nitrogen was applied at 150 kg N/ha, the highest content of phosphorus on control plots, the highest content of potassium and calcium on plots fertilized only with phosphorus and potassium, the highest content of magnesium and sulphur on plots where nitrogen was applied at 100 kg N/ha and the highest content of sodium was in combinations fertilized with 50 kg N/ha. Achieving a high nutritional value of *H. tuberosus* is possible by rational mineral fertilization, especially with nitrogen. With a constant level of phosphorus and potassium fertilization, the highest content of nitrogen, magnesium, calcium and sodium in the aboveground parts of the plant was found on plots fertilized with 50 kg N/ha.

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