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Effect of fertilization on the growth rate of aboveground part of Jerusalem artichoke

Wpływ nawożenia mineralnego na tempo wzrostu części nadziemnej słonecznika bulwiastego

Summary. The research was based on the field experiment conducted in 2013–2015 at the Experimental Station of the University of Life Sciences, in Parczew (51°38'24"N, 22°54'02"E), on podzolic soil. The experiment was established using the split-split-plot method in three replications. The factors of the first order were three cultivars: 'Albik', 'Rubik' and 'Violet de Rennes'. The second order factor was mineral fertilization ($N_0P_0K_0$ – as standard object and P_{43}, K_{124}, N_{100}, $P_{43}K_{124}$, $N_{50}P_{43}K_{124}$, $N_{100}P_{43}K_{124}$, $N_{150}P_{43}K_{124}$), calculated as the elemental form of fertilizers. As the basic fertilization, bovine manure was used in the amount of 30 $t \cdot ha^{-1}$. The aim of the research was to develop the basis for managing the fertilization of Jerusalem artichoke, which will allow to obtain the maximum increase of aboveground part of this species. It was found that for the rate of plant growth, the most optimal fertilization was manure and mineral fertilization in the amount of 100 kg of $N \cdot ha^{-1}$ in the nitrate-ammonium form. The phosphorus-potassium fertilization, despite the use of manure, significantly reduced the growth of plants in comparison with the standard object.

Key words: Jerusalem artichoke, mineral fertilization, growth rate, cultivars

INTRODUCTION

At present, with the still growing demand and consumption of fuels, many branches of the economy are seeking to reduce the exploitation of shrinking resources of conventional energy resources. The activities of research centers are aimed at improving the methods of increasing the share of renewable energy sources in energy-generating technologies on a global scale. One of such sources is energy stored in a green biomass. One of the most important species of energy plants is Jerusalem artichoke. It can be used in numerous production and municipal processes, because it has energy stored in green biomass [Kasprzak et al. 2012, Sawicka 2010, 2016, Skiba et al. 2016]. As defined in the Directive of the European Parliament, "biomass" is "a biodegradable fraction of products, waste or residues of biological origin from agriculture, including plant and animal substances, forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction waste, including industrial and municipal waste of biological origin" [Dyrektywa (UE) 2018/2001]. Jerusalem artichoke is a species that has great prospects in the production of biomass for energy purposes. As one of the few species, it can be used extensively for energy purposes, i.e. green mass as biogas, dry stems for the production of solid biofuels, and tubers for ethanol production [Sawicka and Kalembasa 2013, Sawicka 2016, Danilcenko et al. 2017]. It is one of the most effective species in transforming the solar energy into a dry mass of plants, both in terms of quantity and quality [Sawicka 2010, 2016]. Plants cultivated for energy purposes should have high yields of dry matter per hectare, significant annual growth and high calorific value. In addition, they must be resistant to adverse weather conditions and diseases and pests as well as have low soil requirements [Sawicka 2016, Kowalska 2017]. One of the most popular energy plants is Jerusalem artichoke, various cultivars and clones of which are grown on perennial plantations, although it is an annual plant. This species belongs to the C3 type plant; it is a short day plant, reacting to long days with inhibition of generative development [Spagnoletta et al. 2006, Kays and Nottingham 2008, Sawicka 2010, 2016, Danilcenko et al. 2017]. The development cycle of early cultivars lasts 18–20 weeks (between mid-April and mid-October), while for late cultivars – 26–28 weeks (from mid-April to mid-November) [Skiba et al. 2016, Sawicka 2010, 2016]. Fertilization of this species, for energy purposes use, has not been studied and documented so far. Therefore, the aim of the research was to develop such a method and form of mineral fertilization, which will allow to obtain the maximum increase in aboveground mass of Jerusalem artichoke.

MATERIAL AND METHODS

The research was based on the field experiment conducted in 2013–2015 at the Experimental Station of the University of Life Sciences, in Parczew (51°38'24"N, 22°54'02"E), on podzolic soil. The experiment was established using the split-split-plot method in three replications. The factors of the first order were three cultivars: 'Albik', 'Rubik' and 'Violet de Rennes'. The second order factor was mineral fertilization ($N_0P_0K_0$ – as standard object and P_{43}, K_{124}, N_{100}, $P_{43}K_{124}$, $N_{50}P_{43}K_{124}$, $N_{100}P_{43}K_{124}$, $N_{150}P_{43}K_{124}$), calculated as the elemental form of fertilizers on a background of the full manure rate 30 $t \cdot ha^{-1}$. Nitrogen was added in the nitrate-ammonium form (ammonium nitrate 34%) and amide (46% urea). Doses over 100 kg of kg $N \cdot ha^{-1}$ were applied in 2 terms: 2/3 before planting and 1/3 after emergence of plants, in phase 14 according to the BBCH scale. Tubers were planted every 40 cm in a row, and the distance between rows was 62.5 cm [Bleinholder et al. 2005]. Cultivars of Jerusalem artichoke used in the experiment varied in terms of the length of the growing season ('Albik' and 'Rubik' – medium late and 'Violet de Rennes' – late). In all the years of research, the forecrop of Jerusalem artichoke was winter oilseed rape. During the growing season, in every year of the experiment, measurements and observations of the plant growth rate were carried out every 10 days [Bleinholder et al. 2005].

Statistical analysis of results was performed using the analysis of variance (ANOVA). The significance of variability sources was tested using the "F" Fischer-Snedecor test. The significance of differences between t mean values characterizing the studied factors was estimated applying the Tukey test at the significance level $p_{0.05}$.

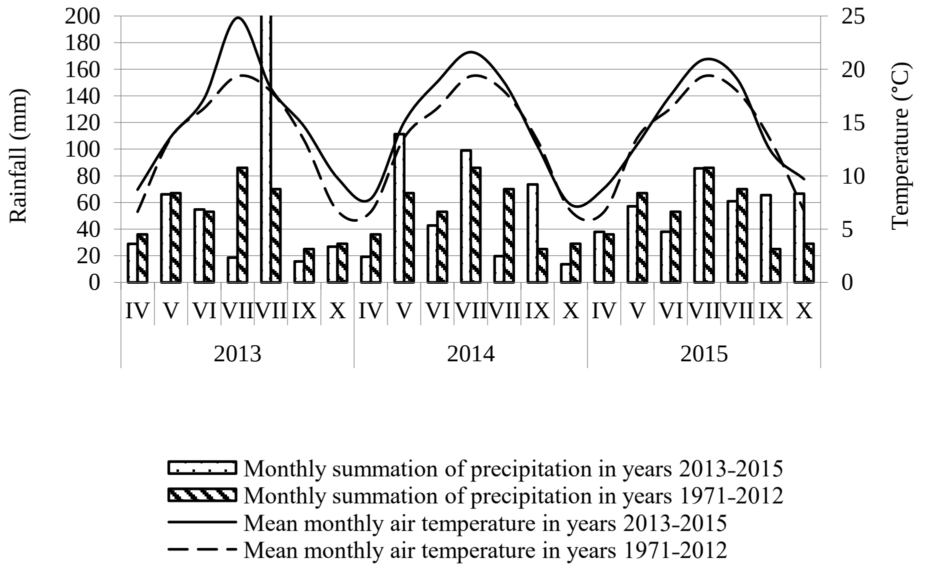

Fig. 1. Comparison of rainfall and air temperature during the growing season of *Helianthus tuberosus* in 2013–2015, with the average perennial according to the meteorological station of the COBORU, Experimental Station for the Evaluation of Varieties, Uhnin

Distribution of temperatures and precipitations in the study years varied (Fig. 1). The year 2013 was warm and dry, except for extremely humid August. In 2014, the warmest month was July, and the coldest month October. The period April–October of that year was characterized by the lowest sum of rainfall, compared to the remaining years of research. It alternated between extremely dry and extremely moist months. In 2015, the meteorological conditions of the growing season were quite stable. The average air temperature was 14.2°C, which was a deviation from the standard for many years by 1.2°C. The period April–August, in which the average sum of rainfall was 55.9 mm, can be considered as average, while September – too wet, and October – extremely humid.

RESULTS

Soil conditions. The experiment was carried out on podzolic soil developed from clay sands, good rye complex, IVb bonitation class [WRB 2014]. According to the percentage of sand, dust and clay fraction, it is a granulometric subgroup of loamy sand. The pH value determined in 1 mol KCl, ranging from 5.97 to 6.77 indicates that the soil was slightly acidic (Tab. 1).

Table 1. Soil characterization by agronomic categories

Years	The percentage of fractions having a diameter (mm ø)			Soil type [acc. WRB 2014]	pH in 1 mol $KCl \cdot dm^{-3}$	Organic substance (% dry mass)
	2.0–0.05	0.05–0.002	<0.002			
2013	71.0	24.0	4.0	pg	6.22	1.86
2014	71.0	27.0	2.0	pg	6.77	1.62
2015	72.0	25.0	3.0	pg	5.97	2.15
Mean	71.4	25.4	3.0	–	–	1.88

Results were determined in Regional Agrochemical Station in Lublin; pg – loamy sand

The content of organic matter in the soil, determined by the weight method, was 1.88%, and humus in the plough layer of the soil 13.4 $g \cdot kg^{-1}$. The carbonate content was 0.21% of the soil. This soil was also characterized by very high abundance in available phosphorus (11.4 $mg \cdot 100\ g^{-1}$ soil) [PN-R-04023:1996], high in potassium (13.2 $mg \cdot 100\ g^{-1}$ soil) [PN-R-04022:1996/Az1:2002], medium magnesium (3.4 $mg \cdot 100\ g^{-1}$ soil) [PN-R-04020:1994/Az1:2004], low boron (0.56 $mg \cdot 100\ g^{-1}$ air-dry matter) [PN-R-04018:1993], medium iron (685 $mg \cdot 100\ g^{-1}$ air-dry matter) [PN-R-04021:1994] and low in copper (1.47 $mg \cdot 100\ g^{-1}$ air-dry matter) [PN-R-04017:1992]; medium in manganese (151.67 $mg \cdot 100\ g^{-1}$ air-dry matter) [PN-R-04019:1993] and high in zinc (8.20 $mg \cdot 100\ g^{-1}$ air-dry matter) [PN-R-04016:1992].

Plant growth rate. The fastest, initial rate of plant growth was 'Albik', but only up to the 30th day of observation. After that time, the cultivar 'Violet de Rennes' started to grow much faster. The slowest growth rate characterized the 'Rubik'. On the 80th day of observation, the growth rate of 'Albik' was significantly inhibited, while plants of the 'Rubik' cultivar started to grow more intensively (Fig. 2).

Figure 3 shows the average growth rate of Jerusalem artichoke plants in individual years of research. Until the 30th day of observation, plants grew the fastest in 2014, and considering further observation days, it was noted that plants in 2015 were characterized by a faster growth rate. In 2013, plants grew the most slowly up to the 80th day of observation, followed by their most intense growth, compared to the increase in 2013–2015.

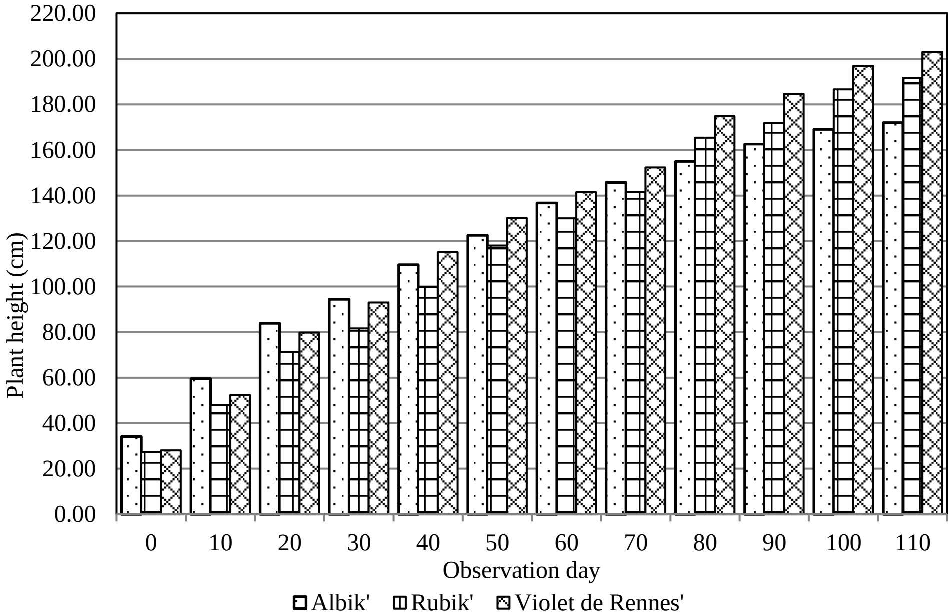

Fig. 2. Plant growth rate of *Helianthus tuberosus* over time depending on cultivar and fertilization (mean for 2013–2015)

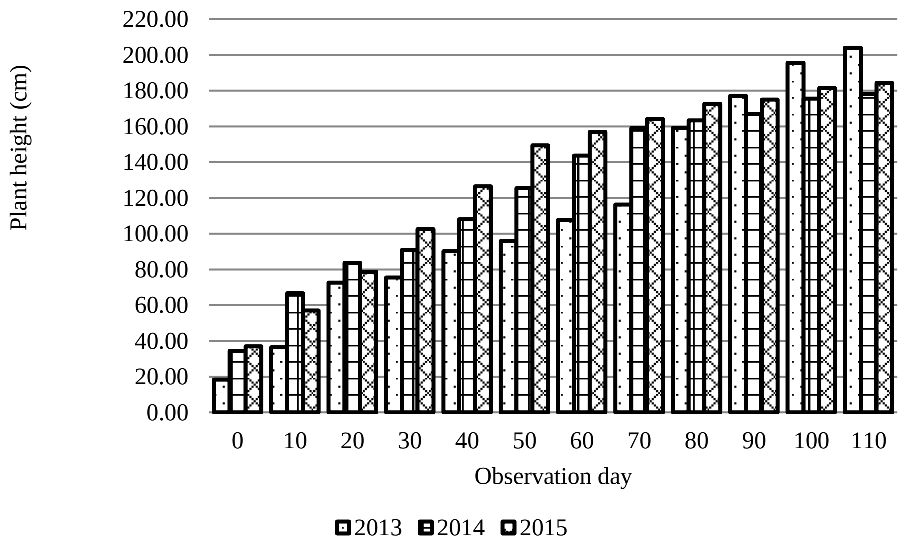

Fig. 3. Growth rate of *Helianthus tuberosus* plants in the time, in 2013–2015 (average cultivars and fertilization)

Table 2. Growth rate of *Helianthus tuberosus* plants depending on the mineral fertilization (average years and cultivars)

Day	Fertilization *											
	Standard object	K	Nm	Nsm	P	PK	PK+N1 m	PK+N1 sm	PK+N2 m	PK+N2 sm	PK+N3 m	PK+N3 sm
0	34.52	29.88	30.07	33.06	32.12	26.63	27.37	27.04	28.08	31.23	27.38	31.19
10	59.64	51.49	55.88	60.69	58.61	48.02	48.94	45.73	50.66	55.51	51.54	53.71
20	84.69	76.47	82.31	88.16	83.91	66.10	72.04	66.69	79.12	83.17	76.56	80.81
30	96.59	86.24	95.01	98.16	93.69	74.64	85.92	75.94	91.77	97.27	87.58	93.04
40	114.71	106.18	113.29	114.53	113.17	86.61	103.16	91.73	113.93	115.94	111.07	113.23
50	128.06	126.76	130.16	130.79	126.53	98.27	118.73	107.53	126.48	130.14	127.72	131.20
60	137.78	129.77	141.04	141.42	136.64	112.43	131.30	121.26	138.04	143.59	141.08	158.08
70	146.68	139.08	151.84	163.80	148.11	126.76	142.27	134.78	145.96	154.33	151.03	152.84
80	165.16	159.81	169.56	168.22	167.21	159.06	157.27	154.08	161.43	175.83	172.89	169.90
90	173.88	167.42	180.67	175.71	176.23	156.84	165.60	164.49	170.03	185.76	181.63	178.40
100	185.72	180.41	193.50	185.60	187.21	166.81	175.96	173.87	181.89	197.69	194.20	187.16
110	190.27	185.85	197.61	192.52	191.63	172.01	180.00	181.04	185.21	202.12	198.14	190.22

*Standard object ($N_0P_0K_0$); P – 43 kg P·ha^{-1}; K – 124 kg K·ha^{-1}; sm (nitrate-ammonium), m – (urea) – 100 kg N·ha^{-1}; PK ($P_{43}K_{124}$); N1 – $N_{50}P_{43}K_{124}$; N2 – $N_{100}P_{43}K_{124}$; N3+PK – $N_{150}P_{43}K_{124}$ kg·ha^{-1}

The aboveground parts of Jerusalem artichoke increased their height the fastest after application of 100 kg of N·ha^{-1} in the form of nitrate-ammonium, without phosphate-potassium fertilization, in comparison with the standard object (Tab. 2). Plants grew slower than in the object without fertilization, where fertilization was applied: phosphorus-potassium, potassium, nitrogen in the amide form to a dose of 100 kg N·ha^{-1} and ammonium nitrate in an amount of 50 kg N·ha^{-1}, on the background phosphorus-potassium fertilization. More intensive growth rate was observed after 50 days from planting in objects where the full dose of nitrogen in the amide form and ammonium nitrate was used, starting from the 100 kg N·ha^{-1} dose, against the background of phosphorus-potassium fertilization. Application of 150 kg of N·ha^{-1} in the amide form together with phosphorus-potassium fertilization, influenced the faster growth of Jerusalem artichoke plants only after 60 days from planting (Tab. 2).

The average height of *Helianthus tuberosus* plants was 122.4 cm. The highest growth of plants was distinguished by the ‘Violet de Rennes’, both in comparison with ‘Albik’ and ‘Rubik’. The latter cultivar was characterized by the lowest growth among the tested ones. Between ‘Albik’ and ‘Rubik’, no significant difference in the value of this feature was observed (Tab. 3).

Table 3. Height of *Helianthus tuberosus* plants (cm)

Experimental factors		Height of plants
Cultivars	‘Albik’	120.12
	‘Rubik’	118.70
	‘Violet de Rennes’	128.42
	$LSD_{0.05}$	6.14
Fertilization*	Standard object	126.47
	K	119.95
	Nm	128.41
	Nsm	129.39
	P	126.26
	PK	107.85
	PK+N1m	120.81
	PK+N1sm	112.02
	PK+N2m	122.72
	PK+N2sm	124.09
	PK+N3m	126.74
	PK+N3sm	128.32
	$LSD_{0.05}$	18.41
Years	2013	110.72
	2014	124.12
	2015	132.40
	$LSD_{0.05}$	6.14
Mean		122.41

*description as below Tab. 2

Mineral fertilization, regardless of the genetic features of the cultivar, shaped this morphological feature of plants. The application of phosphorus-potassium fertilizers alone significantly reduced the growth of plants, compared to the standard object. Application of nitrogen up to 100 kg of $N \cdot ha^{-1}$, regardless of its form, used in conjunction with phosphorus-potassium fertilization, tended to reduce the growth of Jerusalem artichoke plants, compared to the standard object. On average, the highest growth of *Helianthus tuberosus* plants was recorded after application of 100 kg $N \cdot ha^{-1}$ in the nitrate-ammonium form, against the full dose of manure without phosphate-potassium fertilization; however, it was significantly higher only on application of phosphorus-potassium fertilization (PK), fertilization with potassium alone and NPK fertilization with the lowest dose of nitrogen (Tab. 3).

The effect of mineral fertilization on plant height depended on the cultivar (Figure 4). In the case of 'Albik' and 'Rubik' cv., significant decrease in plant height was observed after application of phosphorus-potassium fertilization alone. A significant increase in the height of 'Albik' plants in comparison to the fertilization of PK was observed only after application of a combined nitrogen fertilization from 100 kg of N·ha^{-1}, against the background of constant fertilization of PK and manure fertilization. In turn, 'Rubik' was characterized by the largest increase in the object fed only with nitrogen in the form of nitrate-ammonium, in comparison with the fertilization of PK and the total fertilization of PK and 50 kg of N·ha^{-1} in the nitrate-ammonium form. In the case of 'Violet de Rennes', only the highest dose of nitrogen in the form of nitrate-ammonium, against the background of PK fertilization and full manure dose, gave positive effects in the form of significant plant growth, compared to fertilization of 50 kg N·ha^{-1}, on background of phosphorus-potassium fertilization (Fig. 4).

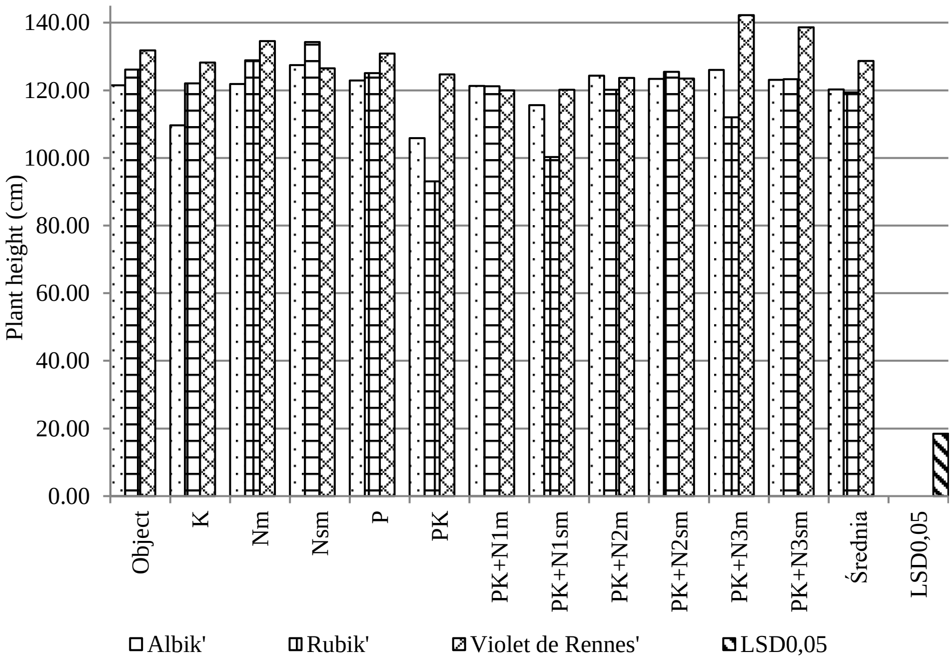

Fig. 4. The height of *Helianthus tuberosus* plants depending on the variety and mineral fertilization (mean 2013–2015)

Meteorological conditions also significantly modified the plant height (Tab. 3). The highest growth was achieved in Jerusalem artichoke plants in warm and optimally humid 2015, and the lowest in 2013, which was characterized by warm and dry vegetation, except for extremely humid August. In 2014, with extremely dry to extremely humid weather during the growing season, the plants were significantly lower than in 2015, which was the optimal year, but significantly higher than in 2013.

DISCUSSION

Most of the important characteristics of Jerusalem artichoke are subject to high phenotypic variability depending on the interaction of various environmental factors and genotype. Diversity of the environment, in which *Helianthus tuberosus* plants are located, causes the modification of internal regulation processes, both within the bush and ridge, plant variability in the field, variability associated with the years and towns [Paungbut et al. 2015].

The basic factor limiting the dynamics of the proper growth of *Helianthus tuberosus* biomass is deficiency of nitrogen, which is taken up by the plant from the soil. It is introduced into the soil in the form of nitrate, ammonium or amide. Each of these three forms has a specific system of action in the soil. Nitrate nitrogen, slightly slower ammonium, is taken up fastest by plants. On the other hand, amide nitrogen is available to plants only after transformations in the soil into ammonium and nitrate form [Kozłowski et al. 2006, Jariene et al. 2016]. As it results from the conducted research, both the deficiency and excess of nitrogen have negative effects on a plant height. According to Kozłowski et al. [2006] and Fotyma [2011], nitrogen from mineral fertilizers is included in the cycle of nitrogen changes in the soil. From the dose provided, plants use approximately 50%, whereas 20% is immobilized and the rest is lost. Each of the nitrogen forms tested exerted different influence on the tested yield characteristics, since each of them has a specific system of changes in the soil. The ammonium form is well absorbed in the soil, while the slower one absorbed by the plants, also works well at low temperatures, is a typical pre-sowing form. The use of nitrogen in the form of nitrate-ammonium, e.g. in the form of ammonium nitrate, promotes development of the root system, better branching, absorption of phosphorus, sulfur, boron, or elements that stimulate the proper branching of plants, photosynthesis, plant resistance to abiotic factors, etc. Its contribution limits the accumulation of nitrates in tubers and roots [Grześkowiak 2007, Jariene et al. 2016]. The amide form, present in urea, decomposes in the soil, first to the nitrate-ammonium form and later to the nitrate. It was therefore a slower form than the ammonium nitrate form, useful for spring plant fertilization. In the opinion of Kozłowski et al. [2006], the higher the soil in higher culture and the higher the temperature of the soil as well as the number of bacteria, the faster the urea works. It also causes the lowest soil salinity: 2–4 times lower than other nitrogen fertilizers.

The course of growth and development of *Helianthus tuberosus* was conditioned to a large extent by the length and variability of the growing season, genetic properties of cultivars, fertilization, as well as environmental conditions. In the conducted studies, a significant influence of the genotype on plant growth has been proved. The highest growth of plants distinguished the French cultivar 'Violet de Rennes', and the lowest – 'Rubik'. The fastest, initial rate of growth of plants characterized the 'Albik', later the growth rate of 'Violet de Rennes' was higher. In the middle of the growing season, the growth rate of 'Albik' decreased significantly, while plants of 'Rubik' and 'Violet de Rennes' grew more intensively. Rodrigues et al. [2007], Chołuj et al. [2008], Żołnierz et al. [2011], Paungbut et al. [2015] and Puchalski et al. [2017] also observed the influence of the genotype on the length of ground shoots. Prośba-Białczyk [2007] showed that ‘Albik’ plants are significantly higher than Rubik in medium soil conditions. The basic factor limiting the dynamics of the normal growth of Jerusalem artichoke biomass was nitrogen deficiency, the absorption of which by the plant from the soil was determined by the remaining nutrients. Cultivars ‘Albik’ and ‘Violet de Rennes’ reacted best on a dose of 150 kg of N·ha^{-1} in the amide form, against the background of phosphorus-potassium fertilization, and ‘Rubik’ – to 100 kg·ha^{-1} in the form of nitrate-ammonium without additional PK fertilization. In the case of the ‘Rubik’ cultivar, the plant height after application of phosphorus-potassium fertilization and after application of combined fertilization of PK and 50 kg of N·ha^{-1} in the form of nitrate-ammonium was significantly lower than in the object without mineral fertilization. Klimont [2012] in turn showed that nitrogen fertilization, against the background of soil enrichment with sewage sludge, significantly affects the growth of height and mass of Jerusalem artichoke plants. Hassan and Hassan [2013] observed that Jerusalem artichoke plants under fertilization 50 kg of N·ha^{-1} in the form of ammonium nitrate (20.6% N) were significantly higher than those, for which a half dose of this component was applied. In turn, Gao et al. [2011] noted that increasing the dose of nitrogen to 50 kg N·ha^{-1} gives a positive effect, but only in the case of combined use with irrigation. Żołnierz et al. [2011] found that the highest growth rate of *Helianthus tuberosus* occurs in June, while in August, it is already inhibited when plants are going into the generative phase. In the conducted research, the rate of plant growth in particular years of research varied. This is confirmed by Puchalski et al. [2017], who observed that in one year of research, mineral fertilization caused a reduction in the height of shoots by about 16 cm, while in the following year, fertilization did not affect this feature. They also found that increasing the dose of fertilizers from 0 to 8.6 t·ha^{-1} gives beneficial effects, while further increase in the fertilizer index had no effect on the height of Jerusalem artichoke plants. According to Žaldarienė et al. [2012], sufficient amount of potassium and available phosphorus for Jerusalem artichoke seeds is over 150 mg·kg^{-1} of soil. Too low potassium content in the soil causes the leaves of plants to curl and deform, yellow spots appear and the plants start to fade out.

Plant growth in 2013, due to the drought, was more intensive only after 80 days from planting, in 2014 – in the initial stage of development, and in 2015 – just one month after sunrise. It was probably related to the weather conditions. Paungbut et al. [2015] proved that the amount of rainfall and air temperature has a significant impact on the development of the aboveground parts of Jerusalem artichoke.

CONCLUSIONS

1. Genetic features determined significantly the growth of plants. The ‘Violet de Rennes’ was characterized by the highest, while ‘Rubik’ – the lowest plant growth.

2. For the growth rate of plants, the most optimal was the use of 100 kg of N·ha^{-1} in the form of nitrate-ammonium, without phosphate-potassium fertilization, but based on

the full dose of manure. Phosphorus-potassium fertilization resulted in significant shortening of the height of Jerusalem artichoke plants.

3. Warm and optimal weather, in terms of the amount of rainfall, contributed to the highest growth of plants, while extremely warm and dry weather during the growing season limited the growth of Jerusalem artichoke plants.

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Streszczenie. Badania oparto na doświadczeniu polowym przeprowadzonym w latach 2013–2015 w Stacji Doświadczalnej Uniwersytetu Przyrodniczego w Parczewie (51°38'24"N; 22°54'02"E), na glebie płowej. Eksperyment założono metodą podwójnie rozszczepionych jednostek eksperymentalnych (split-split-plot) w trzech powtórzeniach. Czynnikami I rzędu były trzy odmiany: 'Albik', 'Rubik' i 'Violet de Rennes'. Czynnik II rzędu stanowiło zaś nawożenie mineralne ($N_0P_0K_0$ – jako obiekt standardowy oraz P_{43}, K_{124}, N_{100}, $P_{43}K_{124}$, $N_{50}P_{43}K_{124}$, $N_{100}P_{43}K_{124}$, $N_{150}P_{43}K_{124}$), w przeliczeniu na formę pierwiastkową nawozów. Jako podstawowe nawożenie stosowano obornik bydlęcy w ilości 30 $t \cdot ha^{-1}$. Celem badań było opracowanie podstaw do zarządzania nawożeniem słonecznika bulwiastego, które umożliwi uzyskanie maksymalnego przyrostu części nadziemnej tego gatunku. Stwierdzono, iż dla tempa wzrostu roślin najbardziej optymalne okazało się podstawowe nawożenie obornikiem oraz nawożenie mineralne w ilości 100 kg $N \cdot ha^{-1}$ w formie azotanowo-amonowej. Samo nawożenie fosforowo-potasowe, mimo stosowania obornika, istotnie obniżało wysokość roślin w porównaniu z obiektem standardowym.

Słowa kluczowe: słonecznik bulwiasty, nawożenie mineralne, tempo wzrostu, odmiany

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