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YIELD OF THE ABOVEGROUND PARTS AND TUBERS OF JERUSALEM ARTICHOKE (*Helianthus tuberosus* L.) DEPENDING ON PLANT DENSITY

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Abstract. In the years 2010-2012 the effect of plant density was studied on the yield of the aboveground parts and tubers of Polish cultivars of Jerusalem artichoke, Albik and Rubik. The experiment was carried out on a light soil of a good rye complex in a randomized block design. The experimental factors included: I) Jerusalem artichoke cultivars: Albik, Rubik, II) plant density: 2, 4, 6, 8 plants·m^{-2}. Cvs. Albik and Rubik, on average over the three years of research, did not differ in the dry matter yield of the aboveground parts and tubers. In the year with a higher rainfall total during growing season, cv. Albik gave higher yields, while in the year with a dry spell from July to September, cv. Rubik yielded higher. With a density of 6 and 8 plants·m^{-2} the dry matter yield of the aboveground parts was significantly higher compared with a density of 2 plants·m^{-2}. The lowest tuber yield was obtained at a density of 2 plants·m^{-2}, a significantly higher one at a density of 4 plants·m^{-2}. Increasing plant density from 4 to 6 or 8 plants·m^{-2} did not result in an increase in the tuber yield. Increasing density from 2 or 4 plants·m^{-2} to 6 or 8 plants·m^{-2} caused a decrease in the number and weight of tubers per plant as well as in the average weight of a single tuber.

Key words: tuber number, tuber weight, cultivar, structure of the aboveground biomass

INTRODUCTION

Jerusalem artichoke (*Helianthus tuberosus* L.) is a species of a great production potential and extensive use [Sawicka 1999, 2004], which also indicates high tolerance to adapting to climatic conditions [Kiru and Nasenko 2010, Baldini *et al*. 2006, Lingyun *et al*. 2007]. The aboveground part of Jerusalem artichoke may be used for the production of biomethane, for direct combustion of the granulated mass or briquettes and pellets [Stolarski 2004, Stolarski *et al*. 2008, Sawicka 2009]. Beside the yield of the

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aboveground biomass, Jerusalem artichoke also produces a high tuber yield [Sawicka 1999, Góral 2000] which may be used universally. Jerusalem artichoke's tubers are characterized by a high content of inulin, dietary fiber, protein, ash and phenolic compounds [Florkiewicz *et al*. 2007, Kapusta *et al*. 2013], and may be used in food industry, brewing or pharmaceutical industry [Sawicka 1999, Cieślik and Filipiak--Florkiewicz 2000]. Inulin contained in tubers indicates hypoglycemic and hypocholesterolemic properties [Cieślik and Kopeć 2002], therefore the tubers are recommended in the diabetic diet [Barta *et al*. 1990, Sawicka *et al*. 2009]. They may also be used in the production of bioethanol or biogas [Majtkowski 2007, Stolarski 2004, Stolarski et al. 2008, Sawicka and Skiba 2009].

Despite many advantages, Jerusalem artichoke is not very popular in agricultural practice. According to Majtkowski [2007], arguments in favor of expanding its cultivation in Poland are its high yielding potential, ease of cultivation as well as high adaptability to soil conditions. Jerusalem artichoke may well be cultivated on various soil types [Kuś *et al*. 2008, Sawicka *et al*. 2009, Prośba-Białczyk 2007].

In literature, there are reports on the subject of the feeding value of Jerusalem artichoke, the effect of fertilization, cultivar and date of harvest on the yield, and chemical composition of tubers [Sawicka 1998, Prośba-Białczyk 2007]. In Polish literature, however, there is little information on the subject of an optimal plant density [Tabin and Pawłowski 1956]. The research hypothesis assumed that plant density determines height of the yield of tubers and the aboveground parts and its structure.

The aim of the study was evaluation of the effect of plant density on the yield of the aboveground parts and tubers of Polish cultivars of Jerusalem artichoke, Albik and Rubik.

MATERIAL AND METHODS

The research was carried out in the years 2010-2012 in Górno near Sokołów (50°15' N; 22°10' E), on a light soil of a granulometric composition of loamy sand, good rye complex, bonitation class IVb. The soil was characterized by an acidic reaction (pH = 5.29). The content of available forms of phosphorus was very high, potassium – average, and magnesium – low.

The research was conducted as a two-way experiment in a randomized block design, with 3 replications, on plots of an area of 45.0 m^2. The factors included:

I – cultivar: Albik, Rubik,
II – plant density ($plant \cdot m^{-2}$): 2, 4, 6, 8.

No mineral fertilization was applied in the experiment. Jerusalem artichoke tubers were planted with a spacing of 62.5 cm on the following dates: 27th April 2010, 19th April 2011 and 29th March 2012, while the harvest was conducted on: 25th October 2010, 25th October 2011 and 8th November 2012. Before harvest, 10 plants were randomly collected from each plot in order to determine the number and weight of tubers per plant as well as the average weight of 1 tuber (the tubers were dug out to a depth of about 25-30 cm).

The results were subjected to statistical analysis according to the experimental design. Calculations were made in the program ANALWAR-53 FR. Significance of differences between the means was indicated with the use of Tukey test, with a significance level of $\alpha = 0.05$.

The data concerning weather conditions come from the Meteorological Station of the University of Rzeszów in Rzeszów. The characteristics of the average thermal and rainfall conditions is described with Sielianinov's hydrothermal coefficient [Molga 1972].

The course of weather over the years of research was diversified (Table 1). The lowest rainfall in the growing season of Jerusalem artichoke (April-October) was observed in 2012 (lower by 26% compared with average records for this period), with at the same time the highest air temperature in the research period (on average by 1.2°C higher compared with the long-term period). That year the drought period occurred in August and September, and a dry spell in April and July. In the years 2010 and 2011, air temperatures did not differ significantly from average records, while only in 2010, lack of a drought period was observed. The highest rainfall total in the growing season of these plants (higher by 58.3% compared with the long-term period) was observed in 2010.

Table 1. Weather conditions in the years 2010-2012 compared with the long-term period

Year	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
Rainfall, mm												
2010	38.9	48.8	22.3	49.9	177	126	200	98.6	97.5	17.8	38.4	47.1
2011	39.2	27.6	20.0	50.0	49.2	88.5	234	28.6	8.6	29.5	0.4	28.2
2012	18.1	36.4	29.5	30.9	64.6	102	46.9	20.3	8.9	84.5	15.9	20.7
Mean from 1980-2009	30.6	28.0	36.9	48.3	75.3	83.3	92.4	69.5	68.1	47.7	37.6	37.2
Air temperature, °C												
2010	-6.9	-3.3	2.7	8.9	14.3	17.9	20.8	19.5	12.2	5.2	7.1	-5.4
2011	-0.3	-4.2	2.8	10.3	10.6	18.2	18.6	19.0	15.2	7.6	2.0	4.0
2012	-1.8	-7.8	4.8	10.2	14.6	18.1	20.8	18.8	14.9	9.2	6.7	-1.8
Mean from 1980-2009	-2.4	-1.2	2.6	8.3	13.8	16.8	18.7	18.0	13.4	8.8	3.2	-0.9
Sielianinov's hydrothermal coefficients												
2010	–	–	–	1.81	4.01	2.27	3.11	1.63	2.59	1.10	1.74	–
2011	–	–	–	1.57	1.50	1.57	4.05	0.49	0.18	1.25	–	–
2012	–	–	–	0.97	1.43	1.82	0.73	0.35	0.19	2.96	0.76	–

Sielianinov's coefficient value: <0,5 – severe drought, 0,51-0,69 – drought, 0,70-0,99 – mild drought, ≥1 –lack of drought

RESULTS

In the 3-year period of research, the yield of the dry matter of the aboveground parts of Jerusalem artichoke cultivars did not differ significantly. However, a different reaction of these cultivars was found to atmospheric conditions in particular years of research (Table 2). In the year with the highest rainfall total (2010) cv. Albik gave a significantly higher (by 134%) dry matter yield of the aboveground parts, and in the year with the lowest rainfall total (2012) a significantly lower one (by 16.5%) compared with cv. Rubik. The dry matter yield of the aboveground parts of Jerusalem artichoke also depended on plant density per unit of area. A significantly higher yield of the aboveground parts was obtained at a density of 8 and 6 plants·m^{-2}, compared with a density of 2 and 4 plants·m^{-2}.

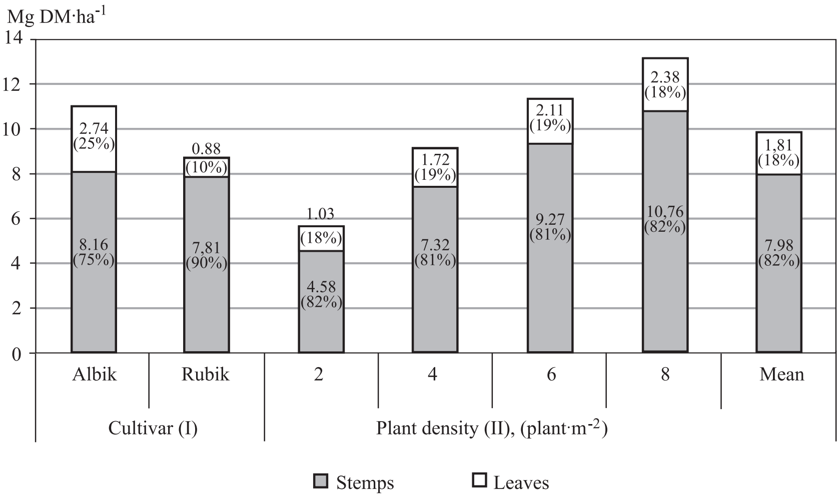
Table 2. Dry matter yield of the aboveground parts of Jerusalem artichoke, Mg·ha^{-1}

Cultivar (I)	Plant density plant·m^{-2} (II)	Year 2010	2011	2012	Mean
Albik	2	7.6	4.0	5.5	5.71
	4	14.5	6.7	9.9	10.37
	6	17.0	8.0	11.4	12.13
	8	21.8	10.2	14.2	15.38
Rubik	2	4.0	5.1	7.4	5.52
	4	5.8	6.7	10.7	7.71
	6	8.0	9.2	14.7	10.63
	8	8.2	9.5	15.0	10.89
$LSD_{0.05}$	II/I	5.35	ns	ns	ns
	I/II	3.82	ns	ns	ns
Means for variables					
Albik		15.2	7.2	10.3	10.90
Rubik		6.5	7.6	11.9	8.69
$LSD_{0.05}$		1.91	ns	1.29	ns
	2	5.8	4.6	6.5	5.61
	4	10.1	6.7	10.3	9.04
	6	12.5	8.6	13.0	11.38
	8	15.0	9.8	14.6	13.13
	$LSD_{0.05}$	3.78	1.15	2.48	5.52
Mean		10.8	7.4	11.1	9.79
$LSD_{0.05}$			ns		–

ns – difference not significant at $\alpha \leq 0.05$

The dry matter yield of the aboveground parts of Jerusalem artichoke was determined mainly by the weight of stems, which constituted on average 81.5% of the total yield weight (Fig. 1). In the 3-year research period, cv. Albik gave a higher average yield of the dry weight of stems and leaves compared with cv Rubik, however this correlation was statistically confirmed only with reference to the leaf yield. In cv. Albik leaf yield constituted 25.1%, while in cv. Rubik 10.1% of the total yield. Increasing plant density per unit of area resulted in an increase in the yield of stems and leaves. With a density of 8 plants·m^{-2} the yield of stems and leaves was significantly higher, by 6.17 and 1.35 Mg·ha^{-1}, respectively, compared with a density of 2 plants·m^{-2}. Also at a density of 6 plants·m^{-2} the plants produced a significantly higher leaf yield, by 1.08 Mg·ha^{-1}, compared with the lowest plant density.

Plant density per unit of area, as well as meteorological conditions over the years of research, had a significant effect on the yield height of tubers, while cvs. Albik and Rubik did not differ significantly in this respect (Table 3). Significantly the highest tuber yield was obtained in the year with the highest rainfall total (2010), higher by 64.8% compared with the yield in 2012, with the lowest rainfall total and the highest average air temperature, in which plants gave the lowest yields. On average, in the 3-year research period, Jerusalem artichoke cultivars did not differ from each other significantly in the tuber yield, however these cultivars' reaction to the course of meteorological conditions in particular years was diversified. In the year with the highest rainfall total (2010) cv. Albik significantly exceeded cv. Rubik with its tuber yield by 18.8%, while in the year with rainfall deficiency (2012) it gave a yield lower by 8.6%.



$LSD_{0.05}$ for comparison:

cultivar	yield of stems	ns
	yield of leaves	0.41
plant density, plant·m^{-2}	yield of stems	4.83
	yield of leaves	0.78

ns – difference not significant

Fig. 1. The structure of the yield of the aboveground parts of plants

Regardless of the cultivar and research years, significantly the lowest tuber yield was obtained at a density of 2 plants·m^{-2}. Increasing plant density to 4 plants·m^{-2} caused an increase in the tuber yield by 39.4%, compared with the density of 2 plants·m^{-2}, while further increasing of plant density resulted in a decrease in the tuber yield.

A significant interaction between the experimental factors in determining tuber yield of Jerusalem artichoke was indicated only in the year with the highest rainfall total (2010). Under such meteorological conditions, the highest tuber yield in cv. Albik was obtained at a density of 6 plants·m^{-2}, and it was significantly higher compared with the yield at a density of 2, 4 and 8 plants·m^{-2} by 87.4%, 18.8% and 26.6%, respectively. On the other hand, cv. Rubik yielded significantly the highest at a density of 4 plants·m^{-2}, and higher compared with a density of 2, 6 and 8 plants·m^{-2}, by 81.6%, 30.1% and 57.4%, respectively. It was also observed that the tuber yield in cv. Albik, cultivated at a density of 6 and 8 plants·m^{-2}, was significantly higher compared with cv. Rubik.

The number and weight of tubers per plant as well as the average weight of a single Jerusalem artichoke tuber were significantly modified by plant density per unit of area and climatic conditions, though they did not depend on the plant's genotype (Table 4). At a density of 2 and 4 plants·m^{-2}, the plants developed a significantly higher number of tubers compared with a density of 6 and 8 plants·m^{-2}, whereas tuber weight per plant and weight of a single tuber decreased significantly with an increasing plant density per 1m^2. Significantly, the highest numerical values of the evaluated traits were obtained in the year with the highest rainfall total (2010).

Table 3. Tuber yield of Jerusalem artichoke, $Mg \cdot ha^{-1}$

Cultivar (I)	Plant density plant·m^{-2} (II)	Year 2010	2011	2012	Mean
Albik	2	17.5	12.9	8.9	13.1
	4	27.6	20.9	16.1	21.5
	6	32.8	19.7	15.2	22.6
	8	25.9	17.3	15.3	19.5
Rubik	2	16.3	13.0	11.1	13.5
	4	29.6	21.1	16.4	22.4
	6	22.6	20.1	16.6	19.7
	8	18.8	19.4	16.2	18.1
$LSD_{0.05}$	II / I	4.71	ns	ns	ns
	I / II	3.48	ns	ns	ns
Means for variables					
Albik		25.9	17.7	13.9	19.2
Rubik		21.8	18.4	15.1	18.4
$LSD_{0.05}$		1.74	ns	0.77	ns
	2	16.9	13.0	10.0	13.3
	4	28.6	21.0	16.3	21.9
	6	27.7	19.9	15.9	21.2
	8	22.3	18.3	15.8	18.8
	$LSD_{0.05}$	3.33	2.78	1.47	4.50
Mean		23.9	18.1	14.5	18.8
$LSD_{0.05}$		1.84		–	

ns – difference not significant

Table 4. Traits of tuber yield

Plant density plant·m^{-2} (II)	Number of tubers per plant			Weight of tubers per plant, g			Average weight of 1 tuber, g		
	cultivar (I)		mean	cultivar (I)		mean	cultivar (I)		mean
	Albik	Rubik		Albik	Rubik		Albik	Rubik	
2	29.5	32.7	31.1	655	674	665	20.9	20.5	20.7
4	25.6	28.7	27.1	538	560	549	19.8	19.3	19.6
6	21.0	18.3	19.6	377	329	353	16.7	18.0	17.3
8	17.6	13.6	15.6	244	227	235	14.1	16.8	15.5
Mean	23.4	23.3	23.4	453	447	450	17.9	18.6	18.3
Year 2010			27.2			575			20.6
Year 2011			23.7			433			17.9
Year 2012			19.2			343			16.4
$LSD_{0.05}$ I			ns			ns			ns
$LSD_{0.05}$ II			5.91			114.6			1.53
$LSD_{0.05}$ II/I			ns			ns			2.16
$LSD_{0.05}$ I/II			ns			ns			1.60
$LSD_{0.05}$ years			1.26			42.6			1.05

ns – difference not significant

In case of the weight of a single tuber, an interaction was indicated between the experimental factors. The average weight of 1 tuber in both cultivars growing at a density of 2, 4 and 6 plants·m^{-2} did not differ significantly, while with an increasing density to 8 plants·m^{-2}, the weight of tubers of cv. Rubik was significantly lower (by 2.6 g) compared with cv. Albik.

DISCUSSION

The high yielding potential of Jerusalem artichoke, low moisture in the obtained biomass as well as possibility to obtain aboveground parts of plants and tubers, are significant traits from the point of view of energetic utilization [Kacprzak et al. 2012]. Jerusalem artichoke is a plant with a significant yielding potential reaching 38-75 $Mg \cdot ha^{-1}$ of green matter. According to Góral [1999], on a fertile and sufficiently humidified soil, even 200 Mg of the aboveground biomass and 90 Mg tubers may be obtained from 1 hectare, while on soils of class III or IV with periodic dry spells, production of the aboveground biomass may reach 40-75 Mg, while tuber yield 23-34 $Mg \cdot ha^{-1}$. Piskier [2006] states that even in the first year of cultivation, the biomass yield of Jerusalem artichoke ranges from 25 to 60 $Mg \cdot ha^{-1}$, and in the second year from 40 to 80 $Mg \cdot ha^{-1}$. Kays and Nottingham [2008] state that the dry matter yield of the aboveground parts of Jerusalem artichoke ranges from 4 to 30 $Mg \cdot ha^{-1}$, depending on the genotype, climatic conditions, soil type and plantation age, whereas the dry matter yield of tubers ranges from 4 to 15 $t \cdot ha^{-1}$. The yield of the total dry matter (including tubers) ranges from 6-9 Mg $DM \cdot ha^{-1}$ under unfavorable conditions, to 20-30 $Mg \cdot ha^{-1}$ under conditions close to the optimum. Prośba-Białczyk [2007] proved that a high level of yielding in Jerusalem artichoke is possible even on soils with a very acidic reaction. In our research carried out on a soil of a good rye complex, class IVb, characterized by an acidic reaction, over the 3-year research period, the dry matter yield of the aboveground parts of Jerusalem artichoke (stems and leaves) was on average 9.79 $Mg \cdot ha^{-1}$, and was higher from the one obtained by Sawicka and Skiba [2009] on a soil of a good rye complex (8.58 $Mg \cdot ha^{-1}$), and close to the one given by other authors. Kuś *et al*. [2008] on a light soil obtained on average 9.5 $Mg \cdot ha^{-1}$ of dry matter of the aboveground part (stems), while in the experiment of Kowalczyk-Juśko [2010] the yield of the aboveground parts of Jerusalem artichoke fertilized with sludge ranged from 9.10-12.91 $Mg \cdot ha^{-1}$. The yield of the aboveground parts was determined mainly by stem biomass, which is confirmed by Chołuj *et al*. [2008]. In our studies, the proportion of dry matter of stems in the aboveground biomass of plants oscillated on average around 81.5%.

Prośba-Białczyk [2007] indicated that on medium- and heavy soil, Jerusalem artichoke cultivated without fertilization and chemical protection is characterized by a yielding potential on the level of around 40 Mg tubers from hectare. In our research conducted on a light soil, the yield of the fresh weight of tubers on average for the years 2010-2012 was 18.8 $Mg \cdot ha^{-1}$. Kuś *et al*. [2008] under similar soil conditions, obtained a lower yield of the fresh weight of tubers (8-10 $Mg \cdot ha^{-1}$).

Over the 3-year period of research on Jerusalem artichoke, cvs. Albik and Rubik did not differ significantly in the yield height of their tubers or the aboveground parts. Plant yield, however, was significantly modified by meteorological conditions over the years of research and by plant density. Sawicka and Michałek [2005] state that the rate of an increase in the tuber weight is determined by the time of tuber formation, while length of the period of its growth, depends on the condition of the photosynthetically active leaves. In our studies the main factor determining tuber yield height in Jerusalem artichoke was the amount of water in the soil, which is also indicated by Klimont [2012]. The highest tuber yield was observed in the year with the lowest mean air temperature in the growing season but with a high rainfall (2010), while in the year with the highest air temperature and rainfall deficiency (2012) the yield was lower by 64.8%.

Various reaction of cultivars to environmental conditions and tolerance to hydrothermal stress is reported by Kays and Nottingham [2008]. In our research, under better hydrothermal conditions (2010), cv. Albik was characterized by a higher productivity compared with cv. Rubik, however under less favorable conditions, an inverse correlation was observed. A similar effect of weather conditions on the yield of cvs. Albik and Rubik is also indicated by Prośba-Białczyk [2007].

The effect of plant density on the yield of Jerusalem artichoke is the subject of discussion. Tabin [1954] while conducting studies under conditions of Lublin Province, with spring harvest obtained significantly higher yields in a narrower spacing of 40 cm x 20 cm, while with autumn harvest no significant differences were indicated in the height of tuber yields between spacing of 40 cm × 20 cm and 40 cm × 40 cm. In other experiments, carried out on various soil types, Tabin and Pawłowski [1956] obtained the highest tuber yield and green matter yield when applying spacing of 40cm × 20cm, whereas Karsli *et al*. [2009] the highest yield of the aboveground parts observed with a spacing of 50 × 50 cm. Rodrigues et al. [2007] state that a lower plant density allows to obtain a higher tuber yield, while Rebora *et al*. [2011] as an optimal spacing consider 70-80 cm × 30-40 cm. From our research it follows that despite a higher number and weight of tubers per single plant obtained with a low density (2 plants·m^{-2}), tuber yield per hectare was lower compared with the yield from a higher plant density (6 and 8 plants·m^{-2}). Increasing plant density from 2 to 4 plants·m^{-2} caused a significant increase in the tuber yield, however further increasing of the plant density caused its systematic decrease. On the other hand, increasing plant density from 4 to 8 plants·m^{-2}, resulted in an increase in the yield of the aboveground parts, but this correlation was merely a tendency.

CONCLUSIONS

Cvs. Albik and Rubik did not differ significantly in the dry matter yield of the aboveground parts and tubers. In the years with a higher rainfall total, cv. Albik gave significantly higher yields, while in the years with dry spells cv. Rubik indicated a tendency to give higher yields.

Increasing plant density caused an increase in the yield of the aboveground parts. With a density of 6 and 8 plants·m^{-2}, the dry matter yield of the aboveground parts was significantly higher compared with a density of 2 and 4 plants·m^{-2}.

The studied cultivars of Jerusalem artichoke gave the lowest tuber yield at a density of 2 plants·m^{-2}. The highest tuber yield in cv. Rubik was obtained at a density of 4 plants·m^{-2}, and in cv. Albik with 6 plants·m^{-2}, whereas further increasing of plant density caused a decrease in the yield. Increasing plant density resulted in a decrease in the number and weight of tubers per plant as well as in the average weight of a single tuber.

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PLON MASY NADZIEMNEJ I BULW TOPINAMBURU (*Helianthus tuberosus* L.) W ZALEŻNOŚCI OD OBSADY ROŚLIN

Streszczenie. W latach 2010-2012 badano wpływ obsady roślin na plon masy nadziemnej i bulw polskich odmian topinamburu Albik i Rubik. Doświadczenie realizowano na glebie lekkiej kompleksu żytniego dobrego, w układzie losowanych bloków. Czynnikami w doświadczeniu były: I) odmiana topinamburu: Albik, Rubik, II) obsada roślin: 2, 4, 6, 8 szt.$\cdot$m^{-2}. Odmiany Albik i Rubik średnio z trzech lat badań nie różniły się plonem suchej masy nadziemnej i bulw. W roku o wyższej sumie opadów w okresie wegetacji wyżej plonowała odmiana Albik, natomiast w roku z okresem posusznym do lipca do września lepiej plonowała odmiana Rubik. Przy zagęszczeniu 6 i 8 szt.$\cdot$m^{-2} plon suchej masy nadziemnej był istotnie wyższy w porównaniu z obsadą 2 szt.$\cdot$m^{-2}. Najmniejszy plon bulw uzyskano w zagęszczeniu roślin 2 szt.$\cdot$m^{-2}, istotnie większy w obsadzie 4 szt.$\cdot$m^{-2}. Zwiększenie obsady roślin z 4 do 6 lub 8 szt.$\cdot$m^{-2} nie przyniosło zwyżki plonu bulw. Wzrost zagęszczenia roślin z 2 lub 4 szt.$\cdot$m^{-2} do 6 lub 8 szt.$\cdot$m^{-2} wpływał na zmniejszanie liczby i masy bulw z rośliny oraz średniej masy pojedynczej bulwy.

Słowa kluczowe: liczba bulw, masa bulwy, odmiana uprawna, struktura biomasy nadziemnej

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