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Evaluation of productivity of cereals and Jerusalem artichoke to be used for biogas depending on the level of nitrogen fertilization

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Abstract. Development of renewable energy can multiply the demand for agricultural raw materials used for energy purposes. Independent estimates indicate that biogas produced from agricultural substrates would be one of the major energy carriers. Therefore, the paper presents the results of the research on the assessment of yield and productivity of biogas from rye, triticale and Jerusalem artichoke cultivated on sandy soil at different levels of nitrogen fertilization. The field experiment was conducted in 2008–2010 at the Experimental Station IUNG-PIB (N: 51°27′59.98″ E: 21°39′44.28″) in a randomized complete block design "split-plot", in four replications. The results indicate that the largest biogas and methane yield from 1 kg of dry organic matter was characteristic for the silage from the first swath of Jerusalem artichoke and rye, while the smallest was found in the silage of the second swath of Jerusalem artichoke. The largest biogas and methane production from one hectare can be obtained from rye harvested at milky-wax maturity. In the next years the highest biogas and methane production was obtained from the cultivation of Jerusalem artichoke in two swaths. The lowest production of biogas and methane were obtained from the cultivation of triticale.

keywords: productivity, biogas, rye, triticale, Jerusalem artichoke

INTRODUCTION

An intensive development of the global economy contributes to the rapid growth of consumption of conventional energy. According to various scenarios, it is anticipated that after 2020, there will be a reduction in the share of conventional fuels due to the depletion of resources and the related increase in energy prices (Cornelissen et al., 2012; Matyka, 2008; Tsavkelova and Netrusow, 2012). The adopted EU climate-energy package assumes that by 2020, member countries will have achieved a 20% market share of renewables in energy consumption and a 10% share of liquid biofuels. In addition, an approximately 20% reduction in emissions of greenhouse gases and an increase in energy efficiency are expected as well. Implementation of these objectives is presumed to multiply the demand for raw agricultural products intended for energy (Kuś and Faber, 2009; Oniszk-Popławska et al., 2014). The biogas produced from agriculture constitutes a very small share of the country's energy balance, and according to independent estimates, its production in the 10-year time will grow rapidly at the rate of tens of percent a year and it will be one of the largest in the so called. "green cart of energy" (Curkowski et al., 2011). Biogas can be produced from organic fertilizers (reduction of emissions of CH_4 to the atmosphere), organic waste and biomass of many plant species. The most important parameter when selecting plant species for cultivation for the production of biogas is their efficiency of net energy per 1 hectare, which is determined mainly by the yield of biomass and productivity of methane (Chodowska-Miszczuk and Szymańska, 2013; Kacprzak et al., 2010; Negri et al., 2014). Species rich in easily fermentable carbohydrates and protein substances and low in hemicellulose and lignin, characterized by low biodegradability, are the most useful for its production (Dandikas et al., 2014; El Bassam, 1998). In addition, such material should be easy for storage and thus available throughout the year. So far, there has been some research done on the choice of species in Central Europe, but there is little data assessing the potential of biogas production from plant species cultivated in Eastern Europe (Księżak et al., 2012; Weiland, 2003).

It was assumed that on light soils, common in Eastern Europe, cultivation of rye, triticale and Jerusalem artichoke may be an alternative solution to gain a satisfactory level of biomass yield, while cultivation of other species is unreliable (Jones et al., 2012; Tuck et al., 2006).

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The aim of this study was to evaluate the yield and productivity of biogas and methane obtained from rye, triticale and Jerusalem artichoke grown on sandy soil at different levels of nitrogen fertilization.

MATERIALS AND METHODS

The field experiment was carried out in the period of 2008–2010 in the experimental station IUNG-PIB in Osiny (N: 51°27′59.98″ E: 21°39′44.28″) in the split-plot system in 4 replicates. In the design of the experiment, factor I were the crops: winter rye 'Diament', triticale 'Krakowiak', and Jerusalem artichokes 'Albik', and factor II – the level of nitrogen fertilization (kg ha^{-1}): N_1 – 40; N_2 – 80; N_3 – 120.

The experiment was conducted on the soil of the good rye complex. The content (mg in 100 g of soil) of available phosphorus was: 17.6, potassium 19.9, magnesium 9.3; the content of the humus 1.46 and pH slightly acid – 5.05. Were used 26.2 kg ha^{-1} of phosphorus and 74.7 kg ha^{-1} of potassium. Seeds were sown with a point drill from 18 to 29 September, at a rate of 3 million grains per hectare. Jerusalem artichoke was planted on 23 April 2008, at spacing 75x35 cm. Before sowing, seeds were treated with insecticides and fungicides. Weed control in rye and triticale was performed with the use of Marathon 375 SC at the dose of 4.0 l ha^{-1} and Mustang at the dose of 0.6 l ha^{-1}.

The evaluated species were grown for silage. Harvest of rye was performed on 15–18 June, triticale 23 June – 6 July, and first swath of Jerusalem artichoke in the first decade of July, the second swath in the second decade of October.

The yields of green and dry matter were determined, as well as the content of dry matter, protein, fat, fibre, ash and digestibility (by the enzymatic method). In addition, the contents of the main macroelements including P, K, Mg and Ca were determined by methods commonly used in such research. Before the harvest, the height of the plants was determined on 10 randomly selected plants from each sub-plot. Silage was prepared from the plants fertilized at the nitrogen rate of 80 kg ha^{-1}, and was analysed for the content of the before mentioned elements and efficiency of biogas. Laboratory analyses were made only for the years 2008 and 2009. Fermented silage samples were weighed prior to biogas assessment so that an initial burden amounted to approximately to 5 kg VS (m^3)$^{-1}$. The portion of the silage with the anaerobic sludge was then placed in a tightly closed fermentation vessel with the capacity of 500 ml. Fermentators were then placed in a water bath at the temperature of 37°C. The obtained biogas was discharged into the cylinder, a calibrated gas collector filled with acidified water. The accumulated gas pushed out water from the collector to the overflow tank. The level of gas in the collector was read every 24 hours, and its composition was analyzed using a gas composition analyzer GAS DATA. Fermentation was carried to the point where there were no significant increases in the volume of biogas. At the beginning and the end of batch fermentation of the bioreactor content, pH, dry matter content, and the content of dry organic matter (PN-75 C-04616/01), Chemical oxygen demand (COD) were determined by dichromatic method using reagents and a DR/5000 spectrophotometer by Hach-Lange's company (method 435). Starved and unadapted anaerobic sludge obtained by incubation of bovine manure properly prepared in mezophile temperature range was used as an inoculum.

Significant differences as to the influence of the studied factors on the observed features were evaluated by the analysis of variance, setting Tukey's confidence half-intervals at significance level $\alpha = 0.05$.

RESULTS AND DISCUSSION

The level of dry matter yields of the evaluated species was significantly influenced by weather conditions during the vegetation period, while significantly less affected by the level of nitrogen fertilization (Table 1, Table 2).

A significantly higher dry matter yield of Jerusalem artichoke was recorded in comparison with cereals. Moreover, the triticale yielded better than the rye, regardless of

Table 1. Weather conditions of experimental on the background of long-term average.

Year	January–March	April	May	June	July	August	September	October–December	Average for year
Temperature [°C]									
2008	2.5	9.4	13.5	18.2	18.8	18.6	12.5	5.5	9.6
2009	-0.4	11.0	13.7	16.6	20.1	18.4	14.8	3.7	8.7
2010	-2.3	9.3	14.0	17.7	21.7	20.3	12.3	2.5	8.1
Rainfall [mm]									
2008	96	43	83	42	94	72	61	97	589
2009	113	2	63	96	69	98	22	161	624
2010	67	22	133	66	54	120	111	82	655

Table 2. The yield of green and dry matter depending on the dose of nitrogen fertilization

Dose [kg N ha-1]	Green mass yield [t ha-1]				Dry mass yield [t ha-1]			
	2008	2009	2010	X̄	2008	2009	2010	X̄
rye								
40	46.1	26.9	22.8	31.9	7.5	10.4	8.4	8.8
80	48.8	28.1	26.0	34.3	7.9	10.5	9.1	9.2
120	51.1	29.2	26.9	35.7	8.4	10.3	9.0	9.2
X̄	48.7	28.1	25.2		7.9	10.4	8.8	
triticale								
40	52.0	29.0	18.9	33.3	8.8	10.3	8.4	9.2
80	52.3	31.8	22.7	35.6	8.8	10.6	9.9	9.8
120	56.6	34.4	26.0	39.0	10.5	11.3	10.4	10.7
X̄	53.6	31.7	22.5		9.4	10.7	9.6	
Jerusalem artichoke I swath								
40	32.5	84.4	74.6	63.8	11.4	16.2	15.9	14.5
80	33.1	91.2	78.7	67.7	10.9	16.4	16.3	14.5
120	35.0	98.6	81.4	71.7	11.2	16.7	14.8	14.2
X̄	33.5	91.4	78.2		11.2	16.4	15.7	
Jerusalem artichoke II swath								
40	-	29.3	25.2	27.2	-	5.4	5.3	5.3
80	-	31.1	26.2	26.6	-	5.6	5.3	5.4
120	-	33.2	28.7	30.9	-	5.6	5.6	5.6
X̄	-	31.2	26.7		-	5.5	5.4	
Jerusalem artichoke total yield								
40	32.5	113.7	99.8	82.0	11.4	21.6	21.2	18.1
80	33.1	122.3	104.9	86.8	10.9	22.0	21.6	18.2
120	35.0	131.8	110.1	92.3	11.2	22.3	20.4	18.0
X̄	33.5	122.6	104.9		11.2	22.0	21.1	
HSD*								
for species					0.51	0.64	0.36	
for fertilization					0.51	0.48	0.58	

* $\alpha = 0.05$

Source: own study.

weather conditions during the vegetation period. Dry matter yield of Jerusalem artichoke in the first regrowth was approximately 3-fold higher than in the second regrowth. Increasing levels of nitrogen fertilization has a positive impact on the yield of cereals, while a far lower impact on Jerusalem artichoke. In the year 2010, in the first regrowth, Jerusalem artichoke fertilized with the highest dose (120 kg N ha^{-1}), as a result of lodging plants, yielded significantly lower than its plants fertilized with smaller doses. Buxton et al. (1999), after application of 140 kg N·ha^{-1}, achieved a slight increase in dry matter yield of rye (0.8 t ha^{-1}) compared with about half of this dose, a further increase in fertilisation rate led to a reduction in yield.

In the period under study the largest height was achieved by Jerusalem artichoke, while the lowest by triticale (Table 3).

Taller plants of Jerusalem artichoke, under the influence of increased nitrogen fertilization, were reported in 2008 and 2009 (I regrowth), while in other years, nitrogen rate had little effect on the height of these species as well as cereals.

In 2009 and 2010, a higher content of dry matter was found at cereals compared to Jerusalem artichoke both the first and second regrowth, while in the year of planting Jerusalem artichoke, was observed an inverse relationship. The favorable distribution of rainfall and higher than average air temperature in 2008 year resulted in a much higher yield of cereal green mass, but with a lower dry matter content compared to the subsequent years of research. Increasing the level of nitrogen fertilization applied to triticale, rye (2009 and 2010 year) and to Jerusalem artichoke at both regrowths in all growing seasons resulted in reducing the dry matter content in those crops. Diversification of the doses of N fertilization had little influence on the concentration of dry mass in the crops of rye in 2008 (Table 3). The content of dry matter in silage of all assessed species was very similar to the content of green forage.

Table 3. The content of dry mass and height of crops in depending on nitrogen fertilization level.

Dose [kg N ha^{-1}]	Content of dry mass [%]				Height of plants [cm]			
	2008	2009	2010	$\bar{X}$	2008	2009	2010	$\bar{X}$
				Rye				
40	16.3	38.6	36.8	30.6	154	138	154	149
80	16.2	37.3	35.2	29.6	149	136	152	146
120	16.4	35.5	33.3	28.4	147	140	153	147
$\bar{X}$	16.3	37.1	35.1		150	138	153	
				Triticale				
40	16.9	35.6	44.3	32.3	123	103	115	114
80	16.8	33.4	43.2	31.1	131	104	128	121
120	18.5	32.8	40.2	30.5	130	104	123	119
$\bar{X}$	17.4	33.9	42.6		128	104	122	
				Jerusalem artichoke I swath				
40	35.2	19.2	21.3	25.2	278	174	209	220
80	33.1	18.0	20.7	23.9	305	189	200	231
120	32.1	16.9	18.2	22.4	311	201	210	241
$\bar{X}$	34.5	18.0	20.1		298	188	206	
				Jerusalem artichoke II swath				
40	-	18.6	21.0	19.8	-	139	119	129
80	-	17.9	20.3	19.1	-	144	115	129
120	-	16.8	19.4	18.1	-	147	124	135
$\bar{X}$	-	17.8	20.2		-	143	119	

Source: own study.

The highest protein content was found in Jerusalem artichoke in the second and third year of production, while the lowest in Jerusalem artichokes in the first year (year of planting). The other species were characterized by a similar content of this component (Table 4). Increasing the nitrogen fertilization rate from 80 to 120 kg ha^{-1} increased the protein content in crops of all the evaluated species. The results indicate that the protein content in the silage made from the plants of these species in 2008 was higher than that in the green forage, and in 2009, it was slightly lower (Table 5). The low pH of the silage (from 3.3 to 4.1) and favourable ratio of lactic acid to total organic acids (LA/TA) (from 0.804 to 0.568) and acetic acid to lactic acid (AA/LA) (from 0.241 to 0.741) indicate that the ensiling process ran properly and was performed by lactic acid bacteria which means that a small protein degradation occurs. The protein content in the silage recorded by Tillmann (2002) is similar to that in our study, while Linn and Martin (1989) report that the protein constitutes up to 17% of dry matter of silage. Also, Jung and Lal (2011) reported increased protein content due to the use of higher doses of nitrogen fertilizer.

Rye in the second and third years of research contained considerably more crude fiber than triticale. Most of crude fiber was found at Jerusalem artichoke in the year of planting (Table 4). Differentiated nitrogen fertilization and weather conditions during the growing season in the studied period had little effect on the accumulation of this component in rye and triticale crops, and resulted in its increase in both regrowths of Jerusalem artichoke. Determination of fiber content in silage shows that its concentration in rye and Jerusalem artichoke is generally smaller, and higher in every year only in the silage made from triticale compared to concentration in dry mass (Table 5).

The evaluated species were characterized by a very similar average fat content in dry matter (Table 4).

Differentiation in the concentration of this component in each year was negligible too. In contrast, an increased fertilization limited the accumulation of this component. Determination of fat content in silage shows that its concentration was similar or higher by from 0.1 to 0.9% than in the dry matter of forage (Table 5).

The highest ash level was found at the plants of Jerusalem artichoke (Table 4). The application of highest doses of nitrogen fertilization to the crops of triticale and Jerusalem artichoke caused a greater accumulation of ash. The silage of triticale accumulated more ash than green forage, whereas in the plants of Jerusalem artichoke, less ash was found in silage (Table 5).

Digestibility of triticale dry matter was higher than in rye and Jerusalem artichoke which is very closely associated with a lower content of fiber in the plants of these

Table 4. The content of nutrients in dry mass depending on nitrogen fertilization level [%].

Dose [kg N ha^{-1}]	Protein			Fat			Ash			Fiber			Digestibility		
	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010
Rye															
40	6.6	6.8	5.6	2.4	2.4	2.4	4.2	4.3	4.5	31.2	32.6	34.8	48.0	47.2	47.0
80	7.2	7.1	6.9	2.3	2.3	2.0	4.3	4.4	4.5	32.0	33.0	34.3	47.2	47.3	47.0
120	7.5	8.1	6.9	2.1	2.0	1.9	4.3	4.4	4.5	32.9	33.7	35.2	46.7	45.7	46.8
Triticale															
40	6.6	7.1	5.8	3.3	3.5	2.3	6.0	4.3	4.0	30.7	25.0	26.1	55.4	58.8	60.5
80	7.3	7.7	6.8	2.9	2.9	2.0	6.1	4.3	4.2	30.7	25.8	26.0	55.4	57.4	59.7
120	7.7	8.0	7.2	2.5	2.6	2.1	6.2	5.0	4.6	31.5	25.4	24.7	53.6	56.7	60.4
Jerusalem artichoke I swath															
40	2.7	8.6	10.2	2.5	2.4	1.9	7.2	8.9	9.9	43.6	28.8	33.4	48.4	59.6	47.9
80	3.5	11.7	10.6	2.5	2.4	1.9	7.6	10.8	10.5	45.7	32.4	37.1	46.2	56.1	47.5
120	3.4	11.9	11.3	2.2	2.3	1.6	7.8	11.4	10.7	48.2	34.0	36.7	44.3	54.5	48.9
Jerusalem artichoke II swath															
40	-	10.2	14.8	-	2.7	1.8	-	11.8	12.0	-	31.9	22.8	-	59.3	59.0
80	-	9.9	15.1	-	2.6	1.9	-	11.8	12.2	-	32.7	21.9	-	58.6	58.4
120	-	14.0	15.9	-	2.3	1.7	-	12.7	11.7	-	34.5	27.0	-	57.2	55.7

Source: own study.

species (Table 4). Increased nitrogen fertilization of cereals and Jerusalem artichoke limited digestibility of dry matter of these species. Varied weather conditions during the growing season had a relatively low impact on digestibility of the organic matter of the compared species. Digestibility of silage of the tested species was a few percent higher than the digestibility of the raw material from which it was prepared (Table 5).

The highest concentrations of K, Ca and Mg were found in Jerusalem artichoke in the second and third year of cultivation regardless of the time of harvest (Table 6).

An increase in the dose of nitrogen fertilization did not have an important effect on the levels of Mg, Ca and P, but caused an increase in the concentration of potassium in the plants of the evaluated species. Varied weather conditions during the growing season had an insignificant effect on the accumulation of these compounds. Silage prepared from the crops of the tested species contained generally similar amounts of Mg and P, but less Ca and K than forage (Table 7).

The parameters of silage fermentation of the evaluated species are shown in Table 8. The longest periods of both fermentation and obtaining 90% biogas was characteristic for silage made from the first swath of Jerusalem artichoke. This was mainly due to higher fiber content and lower digestibility.

The highest efficiency of biogas and methane from 1 kg of dry organic matter was obtained from the silage from the first swath of Jerusalem artichoke and rye, while the lowest from the silage from the second swath of Jerusalem artichoke (Table 9).

Lewandowski (2002) reports that from a properly conducted fermentation of 1 kg of dry matter, about 0.4 m^3 of biogas can be obtained, which has a calorific value of 16.8–23 MJ m^{-3}, and after the separation of CO_2, its calorific value increases to 35.7 MJ m^{-3}. According to Lemmer

Table 5. The content of nutrients in silage [%].

Dose kg N ha^{-1}	Protein		Fat		Ash		Fiber		Digestibility	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Rye										
80	8.0	7.1	3.1	3.2	4.2	4.2	33.0	30.2	52.7	55.2
Triticale										
80	7.3	7.5	2.9	2.8	6.4	4.7	34.9	30.0	55.8	62.4
Jerusalem artichoke I swath										
80	5.1	11.0	2.4	2.8	7.6	10.0	41.6	32.1	48.8	61.5
Jerusalem artichoke II swath										
80	-	9.5	-	2.8	-	10.7	-	29.5	-	60.2

Source: own study.

Table 6. The content of macro nutrients in the dry mass depending on of nitrogen fertilization level [%].

Dose [kg N·ha^{-1}]	P			K			Ca			Mg		
	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010
Rye												
40	0.22	0.21	0.24	1.73	1.25	1.33	0.28	0.27	0.23	0.10	0.10	0.10
80	0.22	0.23	0.25	1.79	1.22	1.44	0.26	0.22	0.20	0.11	0.10	0.09
120	0.23	0.24	0.24	1.86	1.29	1.42	0.27	0.22	0.23	0.11	0.11	0.10
Triticale												
40	0.24	0.25	0.24	1.76	1.13	0.96	0.28	0.19	0.17	0.10	0.11	0.10
80	0.23	0.24	0.27	1.87	1.32	1.04	0.28	0.19	0.16	0.11	0.11	0.10
120	0.26	026	0.25	1.95	1.33	1.17	0.26	0.21	0.21	0.112	0.12	0.10
Jerusalem artichoke I swath												
40	0.26	0.20	0.25	1.00	2.56	2.64	0.97	1.31	1.34	0.27	0.29	0.32
80	0.22	0.28	0.25	1.10	3.35	3.14	1.10	1.50	1.35	0.31	0.35	0.30
120	0.22	0.28	0.23	1.16	3.60	3.39	1.17	1.48	1.30	0.28	0.36	0.31
Jerusalem artichoke II swath												
40	-	0.16	0.28	-	2.03	2.47	-	1.67	1.70	-	0.51	0.46
80	-	0.16	0.26	-	1.92	2.98	-	1.76	1.69	-	0.55	0.50
120	-	0.21	0.27	-	2.80	3.29	-	1.93	1.75	-	0.58	0.53

Source: own study.

Table 7. The content of macronutrients in silage [%].

Dose [kg N ha^{-1}]	P		K		Ca		Mg	
	2008	2009	2008	2009	2008	2009	2008	2009
Rye								
80	0.24	0.21	1.8	1.10	0.29	0.22	0.111	0.096
Triticale								
80	0.22	0.24	1.87	1.38	0.24	0.22	0.103	0.113
Jerusalem artichoke I swath								
80	0.18	0.23	1.47	2.67	1.13	1.39	0.340	0.294
Jerusalem artichoke II swath								
80	-	0.14	-	1.47	-	1.57	-	0.234

Source: own study.

Table 8. Parameters of fermentation in 2008 year.

Species	Fermented mass [g]	Fermented dry organic mass [kg VS·(m^3)$^{-1}$]	Time of fermentation [days]	Time of production of 90% biogas [days]
Rye	9.0	5.0	82	67
Triticale	28.71	14.84	55	38
Jerusalem artichoke I swath	17.54	5.02	105	70
Jerusalem artichoke II swath	13.54	4.75	37	16

Source: own study.

Table 9. Productivity of biogas and methane.

Species	biogas			methane		
	Nl kg^{-1} g.m.	Nl kg^{-1} d.m.	Nl kg^{-1} VS	Nl CH_4 kg^{-1} g.m.	Nl CH_4 kg^{-1} d.m.	Nl CH_4 kg^{-1} VS
Rye	213	721	768	119	402	428
Triticale	112	406	435	74	266	285
Jerusalem artichoke I swath	116	722	812	89	551	619
Jerusalem artichoke II swath	43	206	243	32	153	180

Nl – normal liter, g.m. – green mass, d.m. – dry mass, VS – dry organic mass
Source: own study.

and Oechsner (2001), from 1 ton of biomass from grasslands, 100 m^3 of biogas can be obtained, and from corn harvested at wax maturity – 180 m^3. According to Weiland (2007), corn is a more homogeneous material and can be processed in 90%, while grasses in 50%. Lower concentrations of CH_4 were characteristic of silage from rye. Silage from the first and second swath of Jerusalem artichoke were characterized by high efficiency. Goliński and Jokś (2007) also report that methane is an essential component of biogas, the share of which in the total weight is usually in the range of 50–55% and even 75%. According to Amon et al. (2007), biogas production is positively correlated with the content of crude fiber, non-nitrogen compounds and carbohydrates soluble in water, but it negatively affects the content of protein and ash. According to the above-mentioned authors, raw material in the advanced stages of development is more suitable for biogas production than sward at the stadium of grassland maturity. The yield of biogas and methane obtained in these authors' study is similar to the range obtained by other authors (Cantale et al., 2016; Herrmann et al., 2011; Hűbner et al., 2011; Igos et al., 2016; Negri et al., 2014).

The largest biogas and methane production from one hectare in first year of vegetation could be obtained when rye was harvested at milky-wax maturity (Fig. 1). In the next years the highest biogas and methane production was obtained from the cultivation of Jerusalem artichoke crop in two swaths (Fig. 2, Fig. 3). But even a single swath was able to achieve higher production of biogas than did the cultivation of rye or triticale. The lowest production of biogas and methane were obtained from the cultivation of triticale.

The results showed that the Jerusalem artichokes as a perennial crop achieved its full potential of yielding from the second year of vegetation onwards. Among the compared crops Jerusalem artichoke cultivation allows the highest production of biogas and methane. This plant does not require to be tilled every year, which may lead to lower costs of biogas.

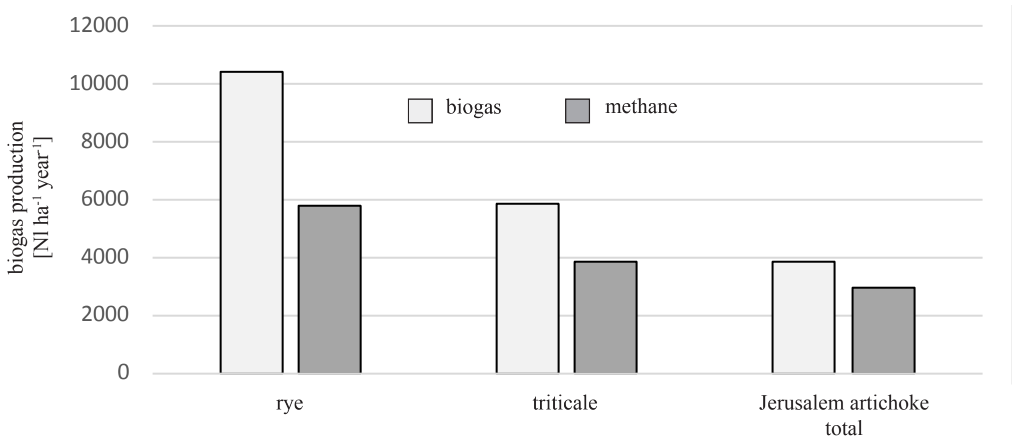

Figure 1. Production of biogas and methane from 1 ha in 2008 year.

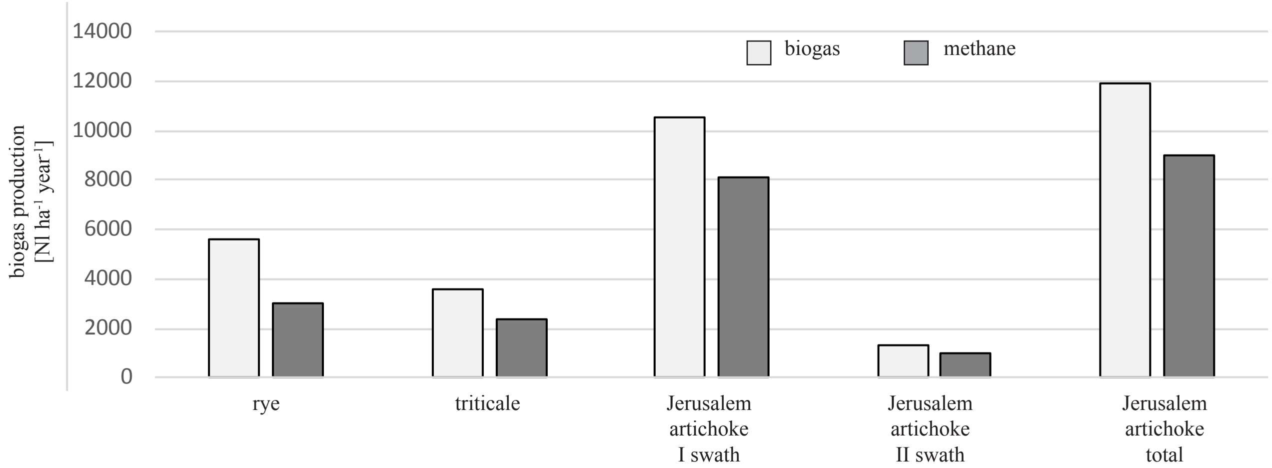

Figure 2. Production of biogas and methane from 1 ha in 2009 year.

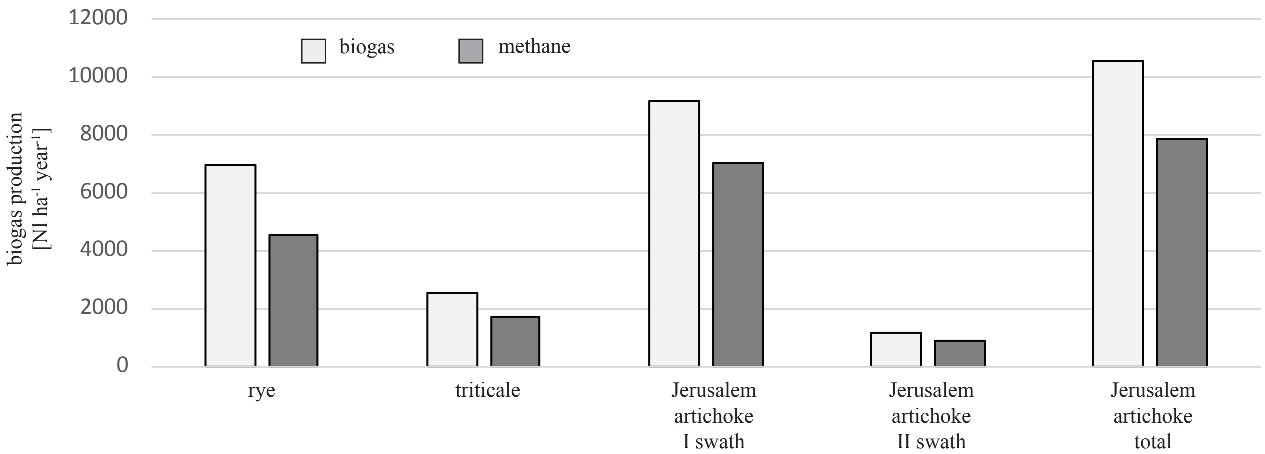

Figure 3. Production of biogas and methane from 1 ha in 2010 year.

CONCLUSIONS

1. On the light soil, a higher yield of dry matter can be obtained from Jerusalem artichoke cultivation compared to the cereals harvested at milky-wax maturity. Dry matter yield of Jerusalem artichoke harvested in the first regrowth was approximately 3-fold higher than in the second regrowth.

2. Increasing levels of nitrogen fertilization had little effect on Jerusalem artichoke, but a positive impact on the yield of cereals, increasing the protein content and potassium in the plants of all evaluated species, greater accumulation of ash by triticale and Jerusalem artichoke, and fiber in Jerusalem artichoke crops.

3. In the years 2009 and 2010, higher dry matter content were characteristic of cereals compared to Jerusalem artichoke (on average by about 13%). Increasing levels of nitrogen fertilization of triticale and rye (2009 and 2010) and Jerusalem artichoke caused a reduction in dry matter content of crops, but it had an insignificant effect on the concentration of this component in rye in 2008.

4. Digestibility dry matter in triticale was higher than that of rye and Jerusalem artichoke (full utilisation years), which is very closely associated with a higher content of fiber in the plants. Increased nitrogen fertilization of cereals and Jerusalem artichoke limited digestibility of dry matter and resulted in a lower accumulation of fat. Increased nitrogen fertilization did not have an important effect on the content of Mg, Ca and P, and accumulation of fiber in rye and triticale.

5. The largest protein content was recorded in Jerusalem artichoke in the second and third year of cultivation,

while the smallest in Jerusalem artichoke in the first year (year of planting). The other species were characterized with a similar content of this component

6. The highest content of fiber was found at Jerusalem artichoke harvested in the I and II swath. Rye generally contained much more of this nutrient than did triticale.

7. The evaluated species were characterized by a very similar average fat content in dry matter. The results indicate that the highest concentration of K, Ca, Mg and ash were found at Jerusalem artichoke in the second and third year of cultivation regardless of the time of harvest.

8. In 2008 year, the content of fat and protein (slightly lower in 2009 year) in the silage prepared from the plants of the evaluated species was similar or higher than in the green forage. The concentration of fiber and ash was higher only in the silage made from triticale, and digestibility of the all species was a few percent higher than the digestibility of raw material from which it prepared.

9. The content of dry matter, Mg and P in the silage of all the tested species was very similar to the material from which it was made, and the content of Ca and K in the silage of all the evaluated species, fiber in the silage of triticale, rye and Jerusalem artichoke, and ash from Jerusalem artichoke indicate that their concentration is lower than in green forage.

10. The largest biogas and methane yield from 1 kg of dry organic matter was characteristic of the silage from the first swath of Jerusalem artichoke and rye, while the smallest was found in the silage of the second swath of Jerusalem artichoke. Lower content of CH_4 was recorded in the silage of rye, while silage from the first and second swath of Jerusalem artichoke characterized by its far higher concentration. The largest biogas and methane production from one hectare in first year of vegetation can be obtained from rye harvested at milky-wax maturity. In the subsequent years the highest biogas and methane production was obtained from the cultivation of Jerusalem artichoke in two swaths. The lowest production rates of biogas and methane were obtained from the cultivation of triticale.

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