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The comparison of single and double cut harvests on biomass yield, quality and biogas production of *Miscanthus* × *giganteus*

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Abstract: The aim of the research was to determine the impact of double-cut harvest system on yield, as well as on suitability of *Miscanthus* × *giganteus* biomass for ensiling and biogas production. Biomass was harvested at the end of June (harvest I) and at the beginning of October (harvest II, regrowth). A single-cut regime at the end of October was also conducted. Biomass from harvests I and II was ensiled and subjected to anaerobic fermentation. The total dry matter (DM) yield from double-cut harvest system was similar to the DM yield from one-cut harvest, but two harvests per year had a positive effect on chemical composition of the biomass. C/N ratio and lignin content in the biomass from harvest I was lower compared to the single-cut biomass. Double harvest biomass was susceptible to ensiling, however, the biomass from harvest I characterized by low dry matter and water soluble sugars content resulted in poorer quality of the obtained silage (butyric acid was present). There were no significant differences between the methane yields obtained from ensiled biomass from harvests I and II.

Keywords: lignocellulose biomass; lignocellulosic material; energy production; energy crop; weather condition

Lignocellulosic biomass is considered as the largest renewable carbon source used for energy production (Kumar et al. 2008). Recently, intensive research and industrial solutions go to the conversion of lignocellulosic materials. They are not food and feed products and constitute alternative plants to maize as the predominant substrate for biogas production. The suitability of lignocellulosic biomass for energy production is characterized by high biomass yield, which can be obtained under low inputs of energy, water, fertilizers and pesticides (McKendry 2002). Lignocellulosic biomass, such as *Miscanthus* × *giganteus* and other perennial grasses with C4 photosynthetic pathway, includes high content of cellulose, hemicellulose and lignin in the proportion of 35–50, 20–35 and 10–25%, respectively (Liu et al. 2008). This kind of biomass is used mainly for combustion processes (Jones and Walsch 2015). Perennial grasses can also be used for biogas production during anaerobic digestion (AD); as a result, biogas (energy-rich CH_4 gas) is produced (Vasco-Correa and Li 2015). However, interactions between fibre components cause plant lignocellulosic complex to be not fully decomposed during hydrolysis, and thus its biogas potential rate is limited (Peng et al. 2012). Many different methods are known to be used for increasing the digestibility of lignocellulose complex and, as a consequence, production of biofuels (Frydental-Nielsen et al. 2016). However, every kind of biomass pretreatment consumes energy and additional financial expenses, so that innovative solutions of biomass pretreatment should be investigated.

In the case of energy crops, quality of biomass providing high biogas yield could be achieved by harvesting plants at the appropriate stage of their maturity, which could lead to limiting of intense biomass pretreatments (Wang et al. 2018). Perennial grasses intended for combustion are typically harvested at their maturity stage (in late autumn or spring), when the moisture content is low (Jones

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and Walsch 2015). For biogas production, biomass from a green harvest would be preferable, because time of harvesting has an effect on e.g. crude fibre content in biomass (Prochnow et al. 2009).

One of the grass species identified as a promising energy crop that can be harvested green or matured is *Miscanthus* × *giganteus* (Kiesel and Lewandowski 2016). This grass species originates from South-East Asia and produces high biomass yield even under temperate climates. For instance the yield of 15 t/ha (dry mass) was reached in northern regions of Europe (Denmark, Sweden) after only four or five years of planting (Lewandowski et al. 2000). Despite such benefits as low fertilizers and pesticides requirements, effective use of water and beneficial impact on soil carbon, biodiversity etc., *Miscanthus* cultivation is still not widespread in Europe and is mainly used for combustion process (Kiesel and Lewandowski 2016, Lewandowski et al. 2016). The reason is that there are no stable markets for *Miscanthus* biomass and relevant applications are low-value (Lewandowski et al. 2016). However, the usefulness of *Miscanthus* × *giganteus* for biogas production as well as for ensiling was evaluated (Piątek et al. 2016, Whittaker et al. 2016). On the other hand there are some reports suggesting that green harvest of miscanthus intended for biogas production should be avoided because of lower biomass yields in the succeeding year (Kiesel and Lewandowski 2016).

The aim of the current study was to estimate how time of *Miscanthus* × *giganteus* harvesting interacts with biomass yield, chemical composition, quality of silages and biogas production.

MATERIAL AND METHODS

Site description and materials. Biomass of *Miscanthus* × *giganteus* J.M. Greef & M. Deuter (hereafter 'miscanthus') came from the collection of energy crops located in the Experimental Station in Skierniewice (central Poland) belonging to the Warsaw University of Life Sciences (51°57'N, 20°09'E). Weather conditions in the field during the experimental period are presented in Table 1.

The stock of miscanthus was 10 000/ha and the cultivation of the grass was carried out on Luvisols (FAO 2014) loamy sand with the following fractions in the 0–25 cm layer: > 0.05 mm 87%; 0.002–0.05 mm 5%; < 0.002 mm 7%. During the four years of the research mechanical weeding was applied and there were no measures to control diseases and pests (there was no need). In early spring, N-P-K fertilization was applied into the soil at a dose of 40-90-150 kg/ha. The plot area for the harvest of individual replication varied from 50 to 100 m^2. Each year, the same area was used for a single harvest and another for two cuts per year. Each harvest was conducted in 4 repetitions. Each year, the double-cut was conducted at the end of June (harvest I) and at the beginning of October regrowth was harvested (harvest II); late single-cut was also conducted at the end of October. The dry matter (DM) yield was calculated based on the fresh matter yield and the DM content. The biomass from harvests I and II was cut into 1 cm pieces and ensiled in 30 L barrels (in triplicate). Approximately 10 kg of biomass were compacted in a barrel (no headspace was left), then the barrel was tightly closed. After

Table 1. Weather conditions in the field during the experimental period based on data from the research station in Skierniewice (Poland)

Year	Month												Total
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
	average precipitation (mm)												
2011	30.7	25.6	15.1	80.5	38.9	106.1	203.3	88.7	11.9	13.5	0.6	39.0	653.9
2012	47.4	28.3	23.2	52.8	21.4	57.7	69.2	65.6	35.2	48.9	28.6	22.6	500.9
2013	58.5	28.9	44.5	49.6	127.5	149.4	17.7	38.0	60.2	32.5	22.7	22.9	652.4
2014	47.8	18.6	28.0	49.8	92.6	60.2	82.8	81.1	32.7	7.6	27.2	54.2	582.6
	average temperature (°C)												annual average
2011	–0.2	–4.1	3.0	10.5	14.4	18.6	18.1	18.5	15.0	8.7	2.8	2.7	9.0
2012	–0.8	–6.1	5.0	9.4	15.6	17.4	20.6	19.0	14.4	8.0	5.7	–2.9	8.8
2013	–3.5	–1.0	–3.0	7.6	14.6	18.1	19.9	19.0	11.8	9.7	5.4	2.4	8.4
2014	–1.6	–1.7	6.4	10.3	14.1	16.4	20.9	17.9	14.4	9.2	5.1	0.6	9.6

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three months, barrels were opened and chemical composition of obtained silage was analysed.

Analytical methods. Dry matter content in the fresh and ensiled materials was determined by oven-drying in a laboratory dryer (SUP500, Wamed, Warsaw, Poland) at 105°C until constant weight. Dry matter content in the fresh and ensilaged biomass was corrected for the loss of volatiles, as reported by Porter and Murray (2001). Organic dry matter (ODM) was measured by determining the loss of mass after combusting of dried biomass in a muffle furnace (CARBOLITE RWF 1200, Derbyshire, UK) at 550°C for five hours relative to wet mass. For chemical analyses, the air-dried subsamples of fresh or ensilaged biomass were crushed in a laboratory mill (SJ500, 1-CUBE, Havlíčkův Brod, Czech Republic) and then sieved using a 1-mm sieve. Nitrogen needed for the content of total protein calculation was estimated by the Kjeldahl method (Kjeltec™2200, FOSS, Hillerod, Denmark). Particular fibre, such as neutral-detergent fiber (NDF), acid-detergent fiber (ADF) and acid-detergent lignin (ADL) needed for the content of cellulose and hemicellulose calculation were determined according to PN-EN ISO 16472, 2007P and PN-EN ISO 13906, 2009P, respectively (Fibertec™ 8000, FOSS, Hillerod, Denmark). NDF was determined as the weight of the residue after boiling the sample in a solution containing sodium lauryl sulphate followed by filtering and washing with water and acetone. ADF was obtained by extracting the sample in sulfuric acid containing cetylmethylammonium bromide detergent followed by filtering and washing. ADL fibres were determined by soaking the residue after ADF determination in 72% sulfuric acid, which hydrolyses the polysaccharides. The lignin residue was then filtered, dried and weighed. Cellulose was calculated as a difference between the content of ADF and ADL fibre, hemicellulose as a difference between NDF and ADF fibre. Phosphorus (P) was determined by atomic emission spectrometry method with inductively coupled plasma induction (ICP-AES) with argon as a carrier gas (Thermo Scientific iCAAP 6500, Walham, USA). Carbon was measured using the infrared detection (IR) (total organic carbon analyser TOC-5000A with SSM-5000 A Solid Sample Module, Shimazu, Kyoto, Japan). Organic acids in silages (lactic, acetic and butyric) were extracted with demineralized water. Extracts were then deproteinized and filtered through a 0.45 µm polyvinyl difluoride (PVDF) syringe filter (Macherey-Nagel, Düren, Germany) prior to injection onto the chromatographic column. HPLC method with photometric detection at the wavelength of 210 nm (Waters HPLC system, 2996 Photodiode Array Detector, Milford, USA) and Aminex HPX-87H column (Bio-Rad, Hercules, USA) was used. The column was maintained at 35°C and eluted with a mobile phase (4 mmol sulphuric acid) at a flow rate of 0.6 mL/min. Water soluble sugars (WSC) were determined in water extracts of silages by the Luff-Schoorl method.

Anaerobic digestion. AD tests were performed in 1.3 L grass fermenters. Inoculum (the source of methanogenic bacteria) was obtained from the digester of agricultural biogas plant operating in central Poland at mesophilic conditions and using maize silage and apple pomace as the main feedstock for biogas production. 5 g of the substrate (ensiled biomass) and 100 mL of the inoculum were added to each fermenter (in triplicate). Fermenters were encapped with measuring heads of OxiTop® Control (WTW, Weilheim, Germany) pressure monitoring system. Assays with inoculum but without substrate addition were prepared as control assays. Fermenters were flushed with N_2 to remove air from the headspace. Fermenters were placed in a thermostatic cabinet (at 39°C) on the inductive stirring platforms (WTW) used to mix the contents of the fermenters. During anaerobic digestion the increase of biogas pressure was monitored and measured every day by manometry sensors in measuring OxiTop® heads. AD was conducted for at least 30 days until *plateau* was achieved. At the end of the fermentation process data was wirelessly transmitted (infrared) from the measuring heads to the OxiTop® OC 110 controller (WTW, Germany) and then transferred to a PC and processed in Excel program. Volume of the gas pressure was converted into the amount of biogas (in moles) using the ideal gas equation:

$$pV = nRT \quad (1)$$

Where: p – pressure (Pa); V – reactor capacity (m^3); T – temperature (K); R – universal gas constant 8.31 (J × (mol/K)); n – number of moles.

The biogas production was calculated as dry gas (water vapour pressure was considered). The amount of biogas was then converted into the volume of biogas referring to normal conditions (1013.25 hPa, 273.15 K). All measurements were corrected for methane production from the inoculum. For this purpose the amount of biogas produced from the inoculum itself (control assays) was subtracted from the amount of

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biogas obtained from the tested substrates and the inoculum.

Biogas composition was analysed at the end of the AD process using a gas analyser attached with rubber hoses to fermenter tubes (Combimass®GA-m, Binder Group, Buchbunneweld, Germany).

The analysis of variance (ANOVA, Tukey's test) was performed, after checking if the data meet the assumption of ANOVA (normality of distribution and equality of variance). For all results, the level of significance was set at 0.05. The analysis was performed using Statistica 8.0 (Statsoft, Tulsa, USA).

RESULTS AND DISCUSSION

Dry matter yield. Perennial energy crops used as alternative feedstock for biogas production should ideally be high-yielding. *Miscanthus* × *giganteus* has been identified as a promising energy crop in many studies (Lewandowski et al. 2000, Stępień et al. 2014, Kiesel and Lewandowski 2016). In the years of this study, the DM yield of miscanthus from a single-cut, early harvest I and harvest II (regrowth) ranged between 21–26.5; 12.5–22.5 and 4.5–6.5 t/ha, respectively (Figure 1). Lewandowski et al. (2000) reported that in Europe, average dry matter yield of *Miscanthus* × *giganteus* harvested in spring amounted to 25 t/ha. In southern Europe with warm weather conditions the average dry matter yield of miscanthus amounted to 30 t/ha (when irrigation was used); in central Europe the yield reported to be typical amounted to 10–25 t/ha (without irrigation).

In 2011, the DM yield from the one-cut harvest system was higher (but not significantly) than that from the double-cut regime (total yield from harvests I and II). In remaining years the DM yield from the one-cut harvest was lower than from the double-cut harvest but not significantly ($P < 0.05$) (Figure 1). It was noticed that the DM yield was influenced by the weather conditions in a given year of the study. For instance, the lowest sum of precipitation between harvests I and II was observed in 2013 year compared to the remaining years of the research (Table 1). The consequence of small rainfall between June and October in 2013 was the lowest DM yield of miscanthus from harvest II compared to the remaining years (Figure 1). This observation agrees with the statement, that not only harvesting time, but also weather conditions during vegetation season determine the maximum annual DM yield (Kaiser et al. 2011).

In the years of the study, the DM yield decrease was not observed in the case of a single-cut regime and early harvest I, despite the fact that a green harvest of miscanthus is not recommended in literature. Some authors indicated that too early harvest carries a risk of lower biomass yields in the succeeding year due to the insufficient translocation of nutrients and starch to the rhizomes before harvest (Frydental-Nielsen et al. 2016). Kiesel and Lewandowski (2016) observed yield reduction in two years of the study in the double-cut (July/October) and one early single cut (August) harvest system of approx. 40% and 60%, respectively. These authors recommended that the best harvest system of *Miscanthus* × *giganteus* ensuring high annual yield of an average 26 t/ha of dry mass is single-cut in October.

Biomass composition. The chemical composition of biomass from particular growing seasons over the years of the research was very similar and therefore Table 2 presents mean values of individual parameters determined in the biomass from four years of the research.

In the case of chemical composition of biomass obtained from harvests I and II, there were no significant differences between DM, ODM, content of cellulose, hemicellulose and digestibility of DM. DM in the biomass from harvests I and II was low, under favourable range for ensiling process, which needs DM between the range of 28–35%. When DM of biomass is over 35%, it is difficult to adequately compact the plant material to get rid of the air from the space between the layers of the plant material, which can lead to obtain silage with poor quality

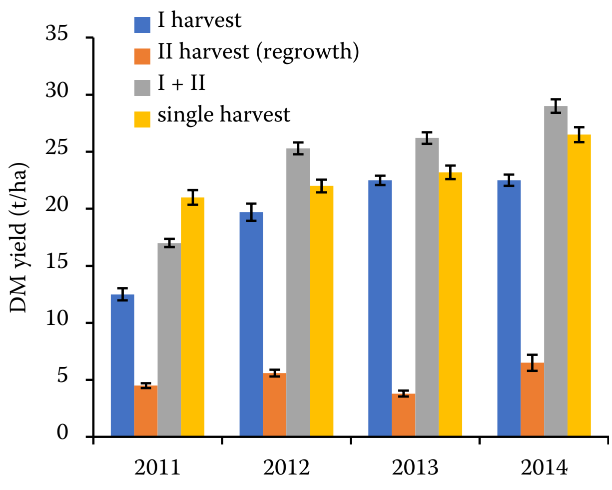

Figure 1. Dry matter (DM) yield of *Miscanthus* × *giganteus* depending on the time and frequency of harvesting

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Table 2. Characteristics of miscanthus biomass depending on the harvest system

Harvest	DM (%)	ODM (% DM)	C/N	Total protein	Cellulose	Hemi-cellulose	Lignin[1]	Digestibility of DM[2] (%)	P	WSC
				(% DM)					(% DM)	
I	24.3 ± 5.17[a]	93.0 ± 0.66[a]	30.0 ± 5.59[a]	9.1 ± 1.68[c]	37.3 ± 0.84[a]	22.2[a] ±1.67	5.5 ± 0.29[a]	55.2 ± 0.49[b]	0.74 ± 0.08[c]	2.8 ± 0.80[a]
II	26.0 ± 5.13[a]	94.9 ± 1.30[a]	52.4 ± 17.18[b]	6.7 ± 3.03[b]	36.2 ± 1.27[a]	22.6[a] ±1.03	6.5 ± 0.42[b]	55.7 ± 1.25[b]	0.49 ± 0.02[b]	4.1 ± 1.27[a]
Single-cut	40.1 ± 0.11[b]	97.1 ± 0.10[b]	68.4 ± 1.69[c]	3.6 ± 0.06[a]	38.4 ± 0.03[a]	25.7[b] ±0.11	6.8 ± 0.02[b]	53.6 ± 0.02[a]	0.17 ± 0.01[a]	3.8 ± 0.05[a]

[a,b,c]mean values marked with different letters (in columns) indicate significant differences ($P \leq 0.05$). WSC – water soluble carbohydrates; [1]as the content of ADL (acid-detergent lignin); [2]digestibility of DM calculated according to the formula 88.9–0.779 × ADF (Understanding Relative Feed Value (RFV) and Relative Forage Quality (RFQ). ExEx8149, August 2004. http://agbiopubs.sdstate.edu/articles/ExEx8149.pdf)

(McDonald et al. 1991). For this reason the biomass from a single-cut, which is characterized by 40.1% of DM (Table 2) was considered unsuitable for ensiling and silages from this biomass were not prepared.

The biomass from harvest I contained a higher amount of protein, phosphorus and lower content of lignin compared to the biomass from harvest II (Table 2). These results confirmed the observations of other authors who claimed that the later harvest, the less protein in the biomass of grasses (Prochnow et al. 2009).

The biomass of miscanthus from single-cut harvest characterized by the highest DM and hemicellulose content compared to the biomass from harvests I and II. Moreover, one-cut biomass had the lowest content of the total protein and phosphorus. The main difference in the chemical composition between biomass from harvests I, II and a single-cut harvest was observed in the case of carbon to nitrogen ratio (C/N). The biomass from a single-cut harvest had the highest C/N ratio (68.4), while C/N ratio of the biomass from harvest II was higher than in the biomass from harvest I (Table 2). The difference between C/N ratio in the biomass from harvests I and II resulted from the difference in the content of nitrogen compounds. High C/N ratio in the biomass from a single-cut was also influenced by the increased content of carbohydrates in the biomass compared to the biomass from double-cut harvest system.

Recommended C/N ratio of substrates used for biogas production should range between 20–30:1 (Agbor et al. 2011). Too high content of carbon in relation to nitrogen could adversely affect biogas production when carrying out the mono-fermentation process. In this situation the biomass from harvest I seemed to be the best substrate for biogas production, not only because of proper C/N ratio, but also the lowest content of lignin compared to the biomass from harvest II and single-cut harvest. For biogas production, high concentration of lignin is not desirable as it has a little value for biofuels production. It is a polymer, which limits the digestibility of lignocellulosic biomass through biological processes of degradation (Demirbaş 2003). Moreover, the process of biogas production from lignin might be prevented by soluble aromatic compounds, which arise from the disintegration of lignin and have an inhibitory effect on methanogenesis (Mulat and Horn 2018). When comparing the lignin content in the biomass from harvests I or II with data published in the literature that refer to the biomass of miscanthus with 12–25% lignin content and harvested once during growing season (in late autumn or early spring), it can be concluded, that two harvests per year are more recommended for biomass conducted for anaerobic digestion (Liu et al. 2008, Sawatdeenarunat et al. 2015).

Characteristics of silages and methane yield. For the continuity of biomass using as a substrate for biogas production, storage of plant material is inevitable from the current to the next harvesting season. Ensiling is the most often used and the cheapest method of biomass preservation and constitutes a promising technique of lignocellulosic biomass pretreatment (Ambye-Jensen et al. 2013).

The chemical composition of silages obtained from the biomass harvested during one vegetation season was presented in Table 3. 'Fresh' biomass means biomass after harvesting, before ensiling.

Ensiling process had a little impact on the chemical composition of miscanthus biomass compared to the fresh material. Cell wall components remained

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Table 3. Chemical composition of miscanthus biomass silage from the double-cut harvest system

Harvest	Material	DM (%)	ODM	Cellulose	Hemicellulose	Lignin	WSC
			(% DM)				
I	fresh	28.3 ± 0.25[b]	92.8 ± 0.30[a]	38.0 ± 0.29[b]	23.7 ± 0.45[a]	5.9 ± 0.02[a]	3.4 ± 0.16
	silage	24.8 ± 0.44 [a]	92.5 ± 0.51[a]	37.8 ± 0.31[a]	22.6 ± 1.49[a]	6.2 ± 0.01[a]	nd
II	fresh	31.9 ± 0.39[a]	96.7 ± 0.59[a]	37.9 ± 0.34[a]	23.6 ± 0.52[b]	7.0 ± 0.09[a]	5.8 ± 0.24
	silage	30.8 ± 0.85[a]	96.5 ± 0.65[a]	39.9 ± 1.12[a]	18.4 ± 1.83[a]	6.2 ± 0.07[a]	nd

nd – not detected (below the limit of the method quantification). [a,b]mean values marked with different letters (in columns for the same harvest) indicate significant differences ($P \leq 0.05$) ± standard deviation. DM – dry matter; ODM – organic dry matter; WSC – water soluble carbohydrates

substantially unchanged after ensiling, with the exception of hemicellulose in silages from the biomass from harvest II, which was reduced by about 5.2%. Moreover, in the case of the biomass from harvest I higher dry matter loss was observed as a consequence of the ensiling process (3.5%) compared to the biomass from harvest II (1.1%) (Table 3).

The quality factor of silage is primarily pH and proportions of individual organic acids, mainly lactic, acetic and butyric acid (McDonald et al. 1991). pH of the obtained silages was quite high (over 5.0), which is characteristic of plant material subjected to ensiling with high dry matter content achieved e.g. by field wilting or harvested at late stage of vegetation (Table 4). The maximum value of pH, which prevents from undesirable microorganisms development in silages, has been set at 4.2 (McDonald et al. 1991). pH of obtained silages could resulted from the low content of WSC in the biomass before ensiling – below 'the minimum sugar', which amounted to 50 g/kg (McDonald et al. 1991). Conversion of water-soluble carbohydrates into lactic acid is needed for the biomass preservation against spoilage losses. Nevertheless, in the silages no signs of moulds growth were observed. In the silages prepared from the harvest I biomass butyric acid was detected as a metabolite of the fermentation process caused by *Clostridium* bacteria. The growth of *Clostridium* bacteria in silages was favoured by low content of dry matter and water soluble carbohydrates (Borreani et al. 2018). Moreover, in the silages from the biomass from harvest I, higher amount of acetic acid than lactic acid was detected (Table 4).

Acetic acid is a natural preservative and inhibits moulds growth (Danner et al. 2003). Its presence probably resulted from the fermentation of pentosanes (e.g. xylose, arabinose) by heterofermentative lactic acid bacteria. Pentosanes are the monomers of e.g. xylan, which is a main part of hemicellulose (Peng et al. 2012). Acetate is directly reduced by methanogenic bacteria for methane production, thus increased amount of acetic acid is desirable in silages intended for biogas production (Kumar et al. 2008).

Results of this section showed the susceptibility of *Miscanthus* × *giganteus* biomass from double-cut harvest system to ensiling, however the biomass from harvest I is characterized by low DM content and thus poorer quality of obtained silages. Whittaker et al. (2016) found that *Miscanthus* × *giganteus* ensiled worse than maize (pH of obtained miscanthus silages was 5.2) and attributed this to the low content of sugars in biomass entering the silage silos. The authors suggested that silage additives consisting of lactic acid bacteria are necessary in order to miscanthus ensile more effectively. Baldini et al. (2017) observed some problematic aspects, such as high pH, high ammonium nitrogen and butyric acid in silages from miscanthus

Table 4. Organic acids and methane yield obtained from the miscanthus ensilaged biomass from the double-cut harvest system

Harvest	pH	Organic acids (g/kg DM)			Methane yield (m^3/t DM)
		lactic	acetic	butyric	
I	5.0 ± 0.06[a]	39.0 ± 19.35[a]	121.8 ± 23.05[b]	1.5 ± 0.30	333.1 ± 20.50[a]
II	5.3 ± 0.03[b]	44.0 ± 8.70[a]	4.0 ± 0.14[a]	nd	337.0 ± 12.50[a]

nd – not detected (below the limit of the method quantification) ± standard deviation. [a,b]mean values marked with different letters (in columns) indicate significant differences ($P > 0.05$). DM – dry matter

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harvested in July and October, which was probably due to low WSC concentration.

The content of methane in the biogas obtained from miscanthus silages at the end of AD process was 55.0% regardless the time of biomass harvesting. The methane yield obtained from the ensiled biomass from harvests I and II did not differ significantly and amounted to 333.1 and 337.0 m^3/t DM, respectively (Table 4). It is interesting that the methane yield obtained in this study from miscanthus silages was almost identical to the theoretical methane yield calculated for miscanthus harvested in July and October 2014 by Baldini et al. (2017). These authors achieved much lower experimental methane yield from the ensiled miscanthus, probably because of high concentration of propionic and butyric acids in obtained silages. Studies of other authors show small variations in the specific methane yield from miscanthus depending on the time of harvest. In the study of Kiesel and Lewandowski (2016) the methane yield decreased with later harvest dates and significantly the highest methane yield was measured in both cuts of the double cut-regime (July/October), about 300 m^3/t ODM. Compared to that, the methane yield obtained from maize silage under mesophilic conditions of AD was 380–388 m^3/t DM depending on the organic loading rate (Gołkowska and Greger 2013).

The results of this study have shown that the chemical composition of miscanthus biomass from a single-cut harvest excludes it from further use for biogas production in the form of silage; biomass from the double-cut harvest system is more suitable for this purpose. On the other hand, low dry matter content, as well as water-soluble carbohydrates in the biomass harvested in early summer could be a problem with regard to obtaining silage with good quality. In this case, a possible solution could be use of microbial or enzymatic silage additives in order to increase the amount of WSC or acids and consequently inhibit secondary fermentation in miscanthus silages. In addition, long-term effects of double-cut harvest system on the productivity of *Miscanthus* × *giganteus* need to be further assessed.

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