Theoretical Estimation of Biomethane Production from *Miscanthus × giganteus* in Croatia

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Summary

Although grass *Miscanthus × giganteus* biomass is currently used mostly as a raw material for direct combustion, an increasing consideration is now given to its potential use in production of biogas, namely biomethane. The aim of this paper is to determine the yield of dry-matter (DM) and organic dry matter (oDM) from the crop *Miscanthus × giganteus* in three different harvest times and at three different locations, and, based on these values, to calculate the biomethane yield on the abandoned agricultural surfaces in Croatia. The investigations which were conducted for this purpose determined the average values of dry matter yield (24.77 t/ha) and organic dry matter yield (24.11 oDM/ha) as well as the biomethane yield of 5976 Nm^3/ha. In relation to total natural gas consumption and percentage of the abandoned agricultural land, Croatia could replace between 1.6% to 4.8% of the consumed natural gas by introducing *Miscanthus × giganteus* grass on 5% to 15% of the abandoned agricultural lands in three of its counties (Sisačko-moslavačka, Karlovačka and Ličko-senjska).

Key words

biogas, biomass, energy crop, energy production, potential

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Introduction

Biogas production is one of the most promising technologies to produce sustainable energy and energy carriers such as methane. If applied properly, anaerobic digestion (AD) can significantly contribute to minimize dissipation of fossil energy resources and greenhouse gas emissions (Verstraete et al. 2005). In general, biogas is composed of 45–70% methane, 35–45% carbon dioxide and 2% trace elements. Methane (CH_4) gas consists of one carbon and four hydrogen atoms and is the main component of natural gas (Rasi, 2009). The dry-matter (DM) content, also known as total solids (TS), is a widely used parameter for the characterization of substrates and digestates. Dry matter consists of organic dry material (oDM) known as the volatile solids (VS) and inorganic material known as ash. The oDM represents the part of DM, which can be converted into biogas and is often expressed as a percentage of the DM content (Vahlberg, 2013).

Biogas can be produced from a wide range of crops, organic wastes and from the most commonly used animal manure (Truong and Abatzoglou, 2005), but maize is the dominant substrate due to its high biogas yield (Pokój, 2014). Although biogas production from maize is the most efficient and technically advanced option, it could result in severe competition between energy and food supplies, which is probably not favourable in the long term. For this reason, a great deal of interest in energy crops has been aroused in recent years. This interest has focused on the use of agricultural wasteland and perennial crops (Klimiuk, 2010). An abandoned or nutritionally depleted agricultural land can be used for the production of lignocellulosic (non-food) bio-energy crops to produce energy from cellulose (Campbell et al., 2008; DeBolt et al., 2009).

Lignocellulosic biomass is a renewable and carbon-neutral resource that can be found abundantly and low in cost. However, the characteristics of the materials itself are the major barrier for efficient conversion of cellulose and hemicelluloses into monosaccharide that can be subsequently fermented into biogas (Nizami, 2010). Agricultural energy crops can be a good source for bioenergy production, and one of such crops is the perennial energy crop *Miscanthus × giganteus*. Currently, the primary energy utilization of the mentioned crop is direct combustion, but certainly it should be emphasized that it has very significant potential in the production of second generation biofuels (Bilandžija et al., 2015).

Miscanthus × giganteus takes three to five years of cultivation before the plant reaches its maximum yield (Schwarz et al., 1995), with 15–20 year lifetime. The main characteristics of *Miscanthus × giganteus* as sterile C_4 grass are: exceptional adaptability to different climate and pedological conditions, feasibility for cultivation on poor quality soils, high dry matter yields by unit of surface, extraordinary disease and pest resistance (application of pesticides is not necessary), low fertilization and herbicides requirements (Lewandowski et al., 2003; Davis et al., 2010; Bilandžija, 2015). Given the fact that *Miscanthus × giganteus* can be harvested from October/November (after early frosts) until the beginning of the following vegetation cycle (March/April), in each climate region an optimal harvest time can be chosen taking into account the agro-ecological conditions, current yield, moisture content and other energy properties of the crop. Generally, early harvesting will maximize the yield per hectare while late harvest will lower it (Lewandowski et al., 2003; Zub et al., 2011). When optimizing the dates of harvesting *Miscanthus × giganteus* it is essential to know the technology of converting biomass into final energy product, i.e. the type of desired green energy. For example, postponing the harvest from autumn to spring will have a positive impact on biomass composition when biomass is used for direct combustion (Bilandžija, 2015). But, this is not the case if *Miscanthus × giganteus* biomass is used for biogas production. Kiesal and Lewanowski (2014) investigated the production of biomethane in relation to different harvest times. These investigations determined the biomethane yields of 293.1 Nm^3/t oDM (July), 261.1 Nm^3/t oDM (August), and 244.5 Nm^3/t oDM (October). A challenge with using *Miscanthus* in AD is that the crop undergoes considerable changes in yield, moisture content and composition during the growing season (Brosse et al., 2012). The stalky dry biomass has a low quality for biogas production and a high risk of forming floating layers in wet fermentation biogas plants. An early harvest of green biomass would seem to be more favourable for biogas production, but first investigations with *Miscanthus × giganteus* showed that the yield of the following year is reduced by an early harvest in August (Fritz, Formowitz, 2010). Cellulose is typically found to be most abundant (30–70%), while hemicellulose and lignin represent 15–30% and 10–25% of the biomass, respectively (Monlau et al., 2013).

In relation to the lignocellulose system and biogas production by use of the similar grass, *Miscanthus × sacchariflorus*, Aralul et al. (2011) found the drop in biogas production of an average 7.49 CH_4/kg DM with 1% increase of lignin content. Bilandžija et al. (2015) investigated hemicellulose composition of the grass *Miscanthus × giganteus* in different agro-ecological conditions in Croatia. The investigations established the average contents of lignin (29.25%), cellulose (49.25%) and hemicellulose (19.27%), which means that *Miscanthus × giganteus* can be characterised as a satisfactory raw material for biogas production.

As mentioned before, in cultivation of lignocellulosic crops the focus should be put on utilisation of the abandoned agricultural land. According to the digital CLC database (2012), total abandoned agricultural land in Croatia amounts to 541,930 hectares, which represents a large potential for introducing energy crops without interfering with the current agricultural production. Figure 1 shows surfaces of the abandoned lands in the Republic of Croatia by the counties.

The objective of this work is to determine yields of dry matter (DM) and organic dry matter (oDM) of *Miscanthus × giganteus* biomass on three different harvest dates (17 October, 3 and 17 November) and three different locations (Medvednica, Donja Bistra and Ličko Petrovo Selo). Based on the determined biomethane yields, the yields data quoted in the literature and the data on abandoned agricultural land (5%, 10% and 15%) in Croatia, the principal aim of this work is to determine the potential to obtain biomethane from *Miscanthus × giganteus* biomass.

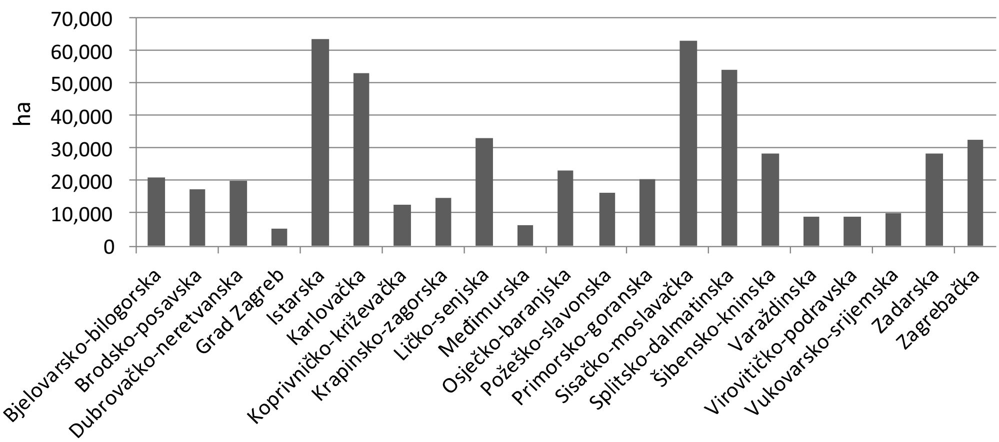

Figure 1.
Abandoned agricultural land in the Republic of Croatia by counties (ha)

Materials and methods

The experimental field under the crop *Miscanthus* × *giganteus* was set up at three locations in Croatia. They are:

— Medvednica (N 45°55′37.2″, E 15°58′24.4″, altitude 655 m);

— Donja Bistra (N 45°55′06.2″, E 15°50′32.5″, altitude 144 m);

— Ličko Petrovo Selo (E 15°43′29.4″, N 44°52′01.8″, altitude 352 m).

Table 1 shows soil nutrient content and soil reaction of the experimental sites. Rhizomes of *Miscanthus* × *giganteus* were planted by end of April 2011. The planting distance was 1 metre, with identical gaps between the rows. The trial was set at a random block arrangement pattern. The harvest of the analysed samples was carried out in the year 3 of the plantation.

The yield was measured at three harvest times (17 October 2014, 3 November 2014 and 16 November 2014) by manual cutting off the plants on eight randomly selected lots of 10 m^2 each, at the height of 5 cm above the soil. After that, the procedure included weighting the harvested biomass, drying sub-samples of 1000 grams of chipped mass (for 48 h at 60°C), and repeated weighting and recalculating in t/ha. After drying, the samples were ground in a laboratory grinder (IKA Analysentechnik GmbH, Germany).

The analytical investigation was conducted at the Faculty of Agriculture University of Zagreb. The ash content was determined by the standard method (CEN/TS 14775:2009). The organic dry matter was calculated by subtracting the raw ash content from the total solids (Menardo, 2012). In order to determine the average chemical composition of the analysed biomass harvested at three different dates, the samples were separated after drying and ground in order to obtain a representative homogenous sample for further analysis. The samples were coalesced and then separated in the separator through two separations, each consisting of eight sub-separations. The samples were analysed three times in order to provide reproducibility of the analyses. The biomethane yield is the product of multiplication of the average determined oDM, specific biomethane yield and 5%, 10% and 15% potentially available agricultural surface. The results were processed in the statistical programme *SAS* (SAS Institute, 1999) by use of the MIXED procedure.

Results and discussion

Dry and organic matter. In order to calculate the biomethane yield it is necessary to determine dry i.e., organic matter in biomass. Organic matter is determined by subtracting ash from dry matter. Table 2 shows dry matter, organic dry matter and ash in relation to the planting locations and harvest dates of the observed crop.

The statistical analysis discovered significant differences in the dry matter and organic dry matter contents in all the observed locations with regard to the time of harvesting, while none of the investigated variables had any significant influence on the ash content in the investigated biomass. The dry matter content in *Miscanthus* × *giganteus* biomass primarily depends on harvest time. Where harvesting is postponed from autumn to spring, natural drying process results in higher dry matter. Investigating the dry matter content in *Miscanthus* × *giganteus*

Table 1. Soil nutrient content and soil reaction of the experimental sites

Location	pH	%		mg /100 g[1] of dry soil	
	KCl	Humus	N	P_2O_5	K_2O
Medvednica	4.52	2.93	0.23	11.85	56.0
Donja Bistra	5.38	2.10	0.16	1.30	11.0
Ličko Petrovo Selo	6.36	6.67	0.34	1.80	19.20

Table 2. Dry matter, organic dry matter and ash in biomass of *Miscanthus* × *giganteus*

Harvest time	DM %			Ash %			oDM %		
	Medvednica	Donja Bistra	Ličko Petrovo Selo	Medvednica	Donja Bistra	Ličko Petrovo Selo	Medvednica	Donja Bistra	Ličko Petrovo Selo
October 16-17	44.32a	44.23a	45.28a	1.34a	1.24a	1.53a	42.98a	42.99a	43.75a
November 10-11	45.12b	44.83b	46.38b	1.36a	1.23a	1.49a	43.76b	43.60b	44.89b
November 29-30	46.42c	45.73c	47.98c	1.35a	1.25a	1.50a	45.07c	44.48c	46.48c
$\overline{x}$	45.29	44.93	46.55	1.35	1.24	1.50	43.93	43.69	45.04

Table 3. Biomethane yields and theoretical production

Harvest time	DMY t/ha			oDMY t/ha			EBMY Nm³/ha		
	Medvednica	Donja Bistra	Ličko Petrovo Selo	Medvednica	Donja Bistra	Ličko Petrovo Selo	Medvednica	Donja Bistra	Ličko Petrovo Selo
October 16-17	25.32a	31.03a	21.41a	24.99a	30.65a	19.32a	6.11a	7.49a	5.15a
November 10-11	24.58b	30.04b	19.58b	24.25b	29.67b	18.49b	5.93b	7.25b	4.716b
November 29-30	23.62c	29.13c	18.23c	23.31c	28.77c	17.75c	5.70c	7.03c	4.39c
$\overline{x}$	24.51	30.06	19.74	24.18	29.70	18.52	5.91	7.26	4.75

DMY – dry matter yield; oDMY – organic dry matter yield, EBMY – estimated biomethane yield

biomass from the autumn harvest, Borkowska and Molas (2013) and Lewandowski and Heinz (2003) found the average values of 40.1% to 50.5%, respectively. If these values are compared to the average 45.59% content, as obtained in this investigation, the compatibility between these data can be noticed. However, some wider divergences can be expected, given the fact that dry matter content is mostly influenced by climate factors of the given location and harvest times.

Desirable is a lower ash content regardless of the of final biogas type to be produced. The average ash content in this investigation is 1.36% and is significantly below the literature values, which are between 1.9% and 9.6% (Visser and Pignatelli, 2007; Garcia et al., 2012). It can be assumed that favourable agro-ecological conditions of the planting locations resulted in a lower ash content in the investigated biomass.

In order to find out how suitable the raw material is for biomethane production from anaerobic digestion, it is essential to determine the percentage of organic dry matter. Based on the conducted analysis, this work determined the average percentage share of oDM at 44.22%. Investigating *Miscanthus* × *giganteus* biomass, Wittaker et al. (2016) and Kiesel and Leandowski (2014) analysed the oDM levels of 32.7% and 43.7%, respectively. A somewhat higher oDM content is the result of a better dry matter to ash ratio found in investigation when compared to the literature values.

Dry matter, organic dry matter and methane yield. As one of the main characteristics of all energy crops, including *Miscanthus* × *giganteus*, is the production of large quantities of dry matter or dry organic matter by unit of surface, which, with the specific production of biomethane, is the basic parameter for calculation of the biomethane potential. Table 3 presents the yields and theoretical production of biomethane in the given agro-ecological conditions.

Statistically significant differences in the biomass yields were found with postponing the harvest from October to mid-November. Analogue to the percentage content of dry matter and organic dry matter, significant differences were to be expected given the fact that the yield decreases when harvest is postponed from autumn to a winter or springtime date. The fall in yield is mainly connected to the loss of foliage biomass, caused by unfavourable meteorological conditions during the autumn or winter periods.

In the third and the following years, maximum yields are found to be between 18–20 t/ha of dry matter at various locations in Germany to about 20 tonnes of DM/ha in Austria and Switzerland (Schwarz, 1993; 1994; Schwarz et al., 1995). Investigating the fertility of four genotypes of *Miscanthus* × *giganteus* in different European countries, Clifton-Brown et al. (2001) determined the following autumn yields in the third year of cultivation: 37.8 t/ha DM in Portugal (with irrigation); 29.1 t/ha DM in Germany and 18.7 t/ha DM in England. Zub et al. (2011) found the autumn yield of *Miscanthus* × *giganteus* of 32.48 t/ha DM (with 1 × 0.5 m planting gaps) in France, while in Poland Borowska and Molas (2013) determined the autumn yield of 19.77 t/ha DM in the third year of the plantation's age. On the basis of the average yield of 24.77 t/ha DM, it can be concluded that in the investigated agro-ecological conditions in Croatia it is possible to achieve high yields of *Miscanthus* × *giganteus* biomass even without applying irrigating measures. In general, biomethane production per unit of surface primarily depends on the quantity of produced organic matter, chemical composition but also on specific production of biomethane.

Table 4. Biomethane production potential in relation to 5, 10 and 15 % abandoned agricultural land

County	Scenario 1		Scenario 2		Scenario 3	
	Area	EBMY	Area	EBMY	Area	EBMY
	ha	Nm^3 NH_4	ha	Nm^3 NH_4	ha	Nm^3 NH_4
Karlovačka	2,664	15,920,064	5,327	31,834,152	7,991	47,754,216
Sisačko-moslavačka	3,153	18,842,328	6,306	37,684,656	9,459	56,526,984
Ličko-senjska	1,665	9,950,040	3,330	19,900,080	4,995	29,850,120
Total	7,482	44,712,432	14,963	89,418,888	22,445	134,131,320

EBMY – estimated biomethane yield

Kiesel and Leandowski (2014) determined the specific production of biomethane in the autumn harvest time at 244.5 Nm^3/t oDM, and this data was used as a basic value for estimating the quantities of biomethane in this work.

The estimated average biomethane content in this investigation is 5,976 Nm^3/ha. Given the fact that corn silage, as the most commonly used lignocellulose raw material for anaerobic digestion, gives biomethane production of 1,660 to 12,150 Nm^3/ha (Murphy et al., 2011) it is possible to conclude that *Miscanthus* × *giganteus* demonstrates a satisfactory potential as a raw material for biogas production.

Biomethane potential in the Republic of Croatia. As previously mentioned, the Republic of Croatia has considerable surfaces of abandoned agricultural land (Figure 1). Leto et al. (2012) investigated the possibilities for growing the *Miscanthus* × *giganteus* on 11 locations in different areas of the country. Their investigations determined that the central and some parts of the continental Croatia are the most acceptable areas for cultivation of this crop without application of irrigation measures. The eastern part of the continental Croatia, as an area with exceptionally rich soil and the agro-ecological conditions highly favourable for food production, was not included in this investigation. Thus, Table 4 presents the biomethane potential, based on 5% (scenario 1), 10% (scenario 2) and 15% (scenario 3) of total available abandoned agricultural land in the counties: Karlovačka, Sisačko-moslavačka and Ličko-senjska. These counties were selected on the basis of the one fundamental criterion: the lowest possible competition to food production; also, their agricultural potential is reduced due to low population density and their satisfactory agro-ecological conditions for growing the *Miscanthus* × *giganteus* crop. These counties are characterised by a significant quantity of potentially available abandoned agricultural lands, which are suitable for growing energy crops.

According to the latest data available, in 2013 the consumption of natural gas in Croatia amounted to 2,809.9 million m^3 (EIHP, 2015), with domestic production covering 1,856.1 million m^3, while the remainder of 1270.4 million m^3 was imported. When comparing these values with those presented in Table 4, it can be concluded that, with introducing *Miscanthus* × *giganteus* on 5% of the abandoned agricultural lands, it would be possible to replace 1.6% of total natural gas consumption and to reduce the imports by 3.5%. Expanding the cultivation of *Miscanthus* × *giganteus* on 10% or 15% of the abandoned lands in the mentioned counties, the resulting biomethane production would replace 3.2% and 4.8% respectfully of total natural gas consumption. It would also reduce the imports by 7% or 10% respectfully. At the same time, the domestic production of natural gas would increase by 2.4, 4.8 and 7.3% respectfully, depending on scenario of production of biomass from *Miscanthus* × *giganteus*.

The data referred above allow to conclude that there is a significant potential to reduce the use of natural gas by introducing the cultivated energy crop and production of biological natural gas from the own sources.

Conclusion

The investigation of the grass *Miscanthus* × *giganteus* grown in several areas in Croatia (Medvednica, Donja Bistra, Ličko Petrovo Selo) confirms the crop's potential to produce significant quantities of good quality biomass. Although *Miscanthus* × *giganteus* is currently used mostly as a raw material in the direct combustion process, the conducted investigation indicates that this crop has a large potential in biomethane production as well. By introducing *Miscanthus* × *giganteus* on the abandoned agricultural lands, Croatia would ensure certain quantities of biomethane which would reduce the natural gas imports and enable utilisation of the unused agricultural surfaces.

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