MISCANTHUS – POSSIBILITY OF GREENHOUSE GAS EMISSION MITIGATION

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Abstract: One of the most important renewable energy source is the energy from phytomass. Recently, there has been significant development of growing energy crops as raw materials for biogas production in biogas plants (BGP). In the conditions of the Czech Republic, it is mainly maize. Maize cultivation itself and especially technical processes associated with it participate significantly in the anthropogenic emission production. One of the ways of reducing these emissions is the substitution of maize with another plant suitable for such purposes. This may be *Miscanthus x giganteus*. This article presents the results of monitoring of emission load resulting from the cultivation of maize (*Zea mays* L.) and *Miscanthus x giganteus* for energy purposes. The tool to determine the level of emission load (expressed in CO_2e where CO_2e = 1x CO_2 + 23x CH_4 + 298x N_2O) is the simplified Life Cycle Assessment (LCA) method, respectively its Climate Impact category. For the calculations, the SIMAPro software and the ReCiPe Midpoint (H) method is used. The results show that within the cultivation of *Miscanthus x giganteus* for energy purposes, the CO_2e production decreases during the second year of cultivation by nearly 40% per 1 kg of dry matter. While in comparison with maize, it is almost half production of CO_2e per the production unit depending on the yields and energy inputs.

Key Words: maize, *Miscanthus x giganteus*, greenhouse gas emissions, Life Cycle Assessment

INTRODUCTION

Climate-change-wise environmental impacts are the key issue of these days. Since the population growth continues very rapidly and also the energy consumption in agriculture increases, we cannot expect that in the foreseeable future, a spontaneous reversion of the trend of increasing environmental load will come (Schau, Fet 2008). Emissions from agriculture account for roughly 12% of the total produced emissions of greenhouse gases (CO_2e) on the Earth (representing 5.1 to 6.1 billion tonnes of CO_2e) (Niggli et al. 2009), within the EU-27, the share of emissions produced by agriculture to the total production of CO_2e is estimated at 10–11% (O'Brien 2014). It is necessary to constantly monitor the production of greenhouse gases (GHG) within agriculture and, at the same time, look for ways to reduce their most important sources (Franks, Hadingham 2012). For example, Smith et al. (2008) provides a variety of options of mitigation of greenhouse gas emissions in crop production. One of the ways can be the attempt to look for savings of greenhouse gases with most commonly grown crops. The very often grown crop, not only in conditions of the Czech Republic, is maize (Graebig et al. 2010). It is widely used as raw material for the BGP (Ahlgren et al. 2010) as an important renewable energy source (Poeschl et al. 2012). However in general terms, it is perceived as a plant representing a considerable burden for the environment (Vogel et al. 2015). In this respect, maize can be partially substituted with another plant also suitable for this usage. It can be *Miscanthus x giganteus* (Lewandowski et al. 2000) that can contribute to potential reduction of environmental impacts in the form of greenhouse gases (GHG) with its yield potential and the perennial plant character (Boehmel et al. 2008). For the monitoring of specific emission loads in different farming systems, we can use the LCA (Life Cycle Assessment) study (Contreras et al. 2009) evaluating environmental impacts of a product based on the assessment of the impact of material and energy flows that the monitored system exchanges with the environment (Haas et al. 2000). Flows of greenhouse gases produced within agriculture are highly complex and heterogeneous but proper management of agricultural systems offers opportunities for mitigation (Smith et al. 2008). It is a transparent scientific tool (Weinzettel 2008) which evaluates the environmental impact on the basis of inputs and outputs within the production system (O'Brien et al. 2014). On the basis of this study, it is possible to make a model of set production systems, identify the strongest sources of emissions from various energy flows and compare the emission load within the maize and *Miscanthus x giganteus* growing during the first three years of cultivation.

MATERIAL AND METHODS

The aim of this study was to draw up models of technological processes during practical cultivation of maize and *Miscanthus x giganteus* and to determine the emission load impact on the environment using them. The simplified method of Life Cycle Assessment (LCA), defined by the international standards of ČSN EN ISO 14 040 (CNI 2006a) and ČSN EN ISO 14 044 (CNI 2006b), was used as a tool to calculate the emission load. The results of the study were related to *the Climate change* impact category expressed in the carbon dioxide equivalent *(CO_2e = 1x CO_2 + 23x CH_4 + 298x N_2O).* The SIMAPro software and the ReCiPe Midpoint (H) method were used for the calculations. The system functional unit represented 1 kg of the final product (1 kg of DM). Technological processes of the cultivation of maize and *Miscanthus x giganteus* intended for the production of biogas in BGP were compiled based on primary data (field experiments at ZF JU in České Budějovice), as well as secondary data (acquired from the *Ecoinvent 2010* database, literature search and normative data on agricultural production technologies). The database uses data geographically related to Central Europe. The primary data were collected between 2013 and 2015 and the secondary data between 2000 and 2015. Data selected for the modelling is based on the average of commonly applied technologies. Agrotechnical operations from seedbed preparation, the amount of seeds and seedlings, the use of plant protection products, production and application of fertilizers, etc., to harvesting the main product were included into the model system. Besides the emissions arising from the inputs mentioned above, so called field emissions (N_2O emissions) are also produced after the application of nitrogen fertilizers. The IPCC methodology (*Intergovernmental Panel on Climate Change*) is used to quantify them (O'Brien et al. 2014). The results presented in this paper are based on field experiments having been established since 2013 on the grounds of the University of South Bohemia in České Budějovice. Selected fertilization intensity and particular agrotechnical practices were set on the basis of the already used growing technologies for conditions of Central Europe (Lewandowski et al. 2000, Weger, Strašil 2009). The paper presents the results of 3-year growing of maize and *Miscanthus x giganteus* (hereinafter referred to as *M. x g.*) for biogas plants (BGP). *M. x g.* stands were harvested twice a year. Based on the chosen methodology and data acquired during their growing (yields of dry matter, inputs and outputs of the growing cycle), it was possible to compile their life cycle within the farm stage (from preliminary tillage to harvest and storage of the harvested material) and to determine the impact on the environment.

RESULTS AND DISCUSSION

As already stated, the results of the study were related to the *Climate change* impact category expressed in the carbon dioxide equivalent (CO_2e = 1x CO_2 + 23x CH_4 + 298x N_2O). CO_2, N_2O, CH_4 are characterized as greenhouse gases with a direct impact on the climate (Menichetti, Otto 2008) while each of them has different efficacy at the same concentration (Millar et al. 2010). Table 1 shows yields of dry matter and values of emission load resulting from the production of 1 kg of dry matter (hereinafter referred to as DM) in particular years. The highest yield of maize was achieved in 2014 (19.25 t · ha^{-1} DM) while 0.221 kg CO_2e corresponds to 1 kg of DM. On the contrary, the lowest yield was achieved in 2015 (7.29 t · ha^{-1} DM). This significant decline was primarily due to the extreme drought during the growing season. This year, the production of CO_2e per 0.583 kg $CO_2e \cdot kg^{-1}$ of DM has grown. The first harvest of *M. x g* was in 2014 (5.58 t · ha^{-1} DM) – the first production year. Normally, the newly established stands are not harvested in the year of establishment (Weger, Strašil 2009). For the calculation of emission load arising throughout the 3-year cultivation cycle (see Table 2), it is necessary to include the year of stand establishment in the calculation. Yields of *M. x g.* in the first three years of growing do not usually achieve the full yield potential (Christian et al. 2002) that can be up to 30 t · ha^{-1} DM (Weger, Strašil 2009). In the second year of cultivation (2015), the yield of DM 9.05 t · ha^{-1} was achieved (an increase of almost 40%).

Table 1 Dry matter (DM) crop and emission load per 1 kg of DM in particular years

	Year	Yield of DM (t · ha^{-1})	Emission load (kg $CO_2e \cdot kg^{-1}$ of DM)
Miscanthus x giganteus	2013	Without yield	Not assessed
	2014	5.58	0.263
	2015	9.05	0.162
Maize	2013	14.13	0.301
	2014	19.25	0.221
	2015	7.29	0.583

Legend: According to the conventional technological methods, Miscanthus x giganteus was not harvested in the year of establishment (2013)

Emission load (kg CO_2e) at the yield of 1 kg DM depends mainly on the final yields per one hectare. Therefore, it is natural that the emission load at the yield of 1 kg DM will decrease while maintaining the cultivation cycle of *M. x g.* and with the increasing yield per one hectare. This is noticeable already in 2015 when the emission load per 1 kg of DM at the yield of 9.05 t · ha^{-1} DM decreases by 38.4% as compared to 2014. At the expected yield of *M. x g.* at 15 t · ha^{-1} DM and maintaining the same growing process, the emission load per 1 kg of DM decreases by nearly 60% (as compared to 2014). *M. x g.*can be cultivated for even 16 years (Lewandowski et al. 2000) with reliable yields of 15–25 t · ha^{-1} DM. If we compare *M. x g.* and maize with an average yield of 15 t · ha^{-1} DM within a ten-year cycle at the preserved growing technology, we can conclude that the emission load from production of 1 kg of DM with *M. x g.* will be almost 50% lower than with maize.

Another situation occurs when comparing these two energy plants in the first three years of cultivation in total. In this evaluation, we must include also the first production year (year of stand establishment) of *M. x g.*, that is the most energy-intensive from the perspective of multiannual growing, in the calculation. This led to a significant increase of production of kg $CO_2e \cdot kg^{-1}$ of DM (Table 2) as compared to maize.

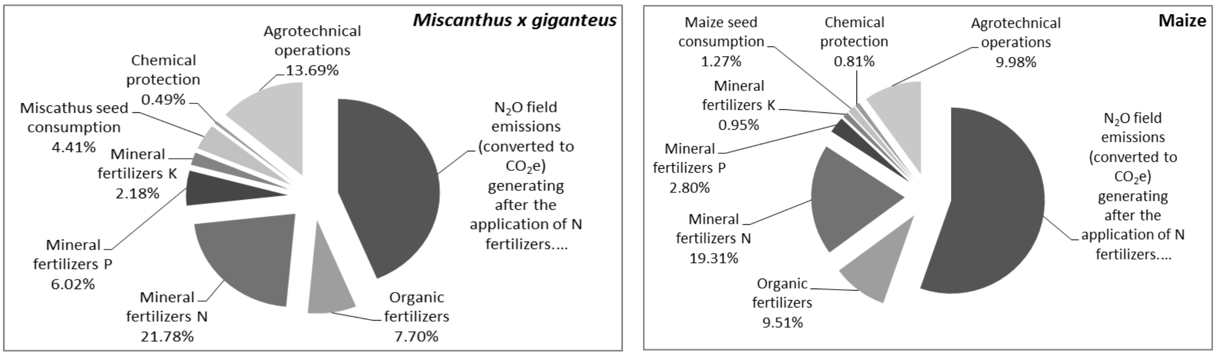
Table 2 Greenhouse gas emissions (kg $CO_2e \cdot kg^{-1}$ of DM); average in the first three years of cultivation

System subprocesses	Maize	*Miscanthus x giganteus*
Organic fertilizers	0.0298	0.0276
Mineral fertilizers N	0.0605	0.0781
Mineral fertilizers P	0.0088	0.0216
Mineral fertilizers K	0.0030	0.0078
Total fertilizers	0.1021	0.1351
Seed consumption	0.0040	0.0158
Chemical protection	0.0026	0.0018
Agrotechnical operations	0.0313	0.0491
N_2O field emissions (converted to CO_2e) generating after the application of N fertilizers.	0.1736	0.1568
Total production	0.3135	0.3586

Legend: All energy inputs in the first three years of cultivation and achieved yields of phytomass are included in system processes

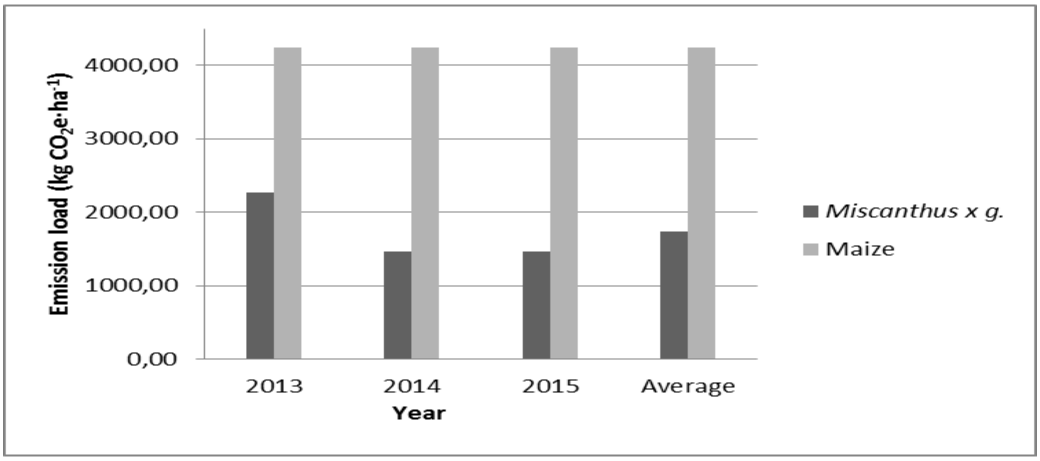
Figure 1 shows the share of particular system processes on the production of emissions (in %). It is known, that the most powerful sources of emissions released into the atmosphere come from the fertilizer use and their application to the soil (Zou et al. 2005, Mancinelli et al. 2013). Even in this case, we can say that the largest share of total production consists of the emissions generated by the use of fertilizers and so-called field emissions (N_2O emission converted to CO_2e) generated after the application of N fertilizers. The intensity of fertilization of both monitored plants was selected on the basis of established growing technologies (Lewandowski et al. 2000, Weger, Strašil 2009). The level of N fertilization was chosen similarly to Boehmel et al. (2008) who state that the optimum N fertilization level for maize is about 120 kg · ha^{-1} and for *M. x g.* 80 kg · ha^{-1}. At higher doses, the significant increase of phytomass is no longer detectable. Another monitored category was the production of greenhouse gas emissions per the unit of area (1 ha). This category includes all material and energy flows in a given year (within the farm stage). In this case, the calculation does not include the yields per hectare. Values are reported in the Figure 2.

Figure 1 Contribution of particular subprocesses (in %) to the creation of emission load



Legend: There was no harvest in 2013 (the year of the Miscanthus x g. stand establishment); this is why the emission load per the production unit was not calculated

Figure 2 Emission production (kg CO_2e) per the area unit (1 ha)



The aim of this chart is to show a significant difference in greenhouse gas production per the area unit (1 ha) between maize and *M. x g.* In the first year of cultivation, the difference was 46.5%, in the second and the third one 65.5% and on average for three years, it was 53.5%. In order to maintain uniform cultivation technologies for maize, the production of greenhouse gases per the area unit in each year is without differences. The same is true of *M. x g.* but from the second year of cultivation. In the first year of cultivation, the production of greenhouse gases (as against following years) is increased due to the relatively energy-intensive establishment of vegetation.

In general terms, this points to the possibility of reducing the production of greenhouse gases (CO_2e) by growing less energy-intensive perennial plants (Bellarby et al. 2008) even while maintaining yield potential comparable with maize. Another positive benefit of perennial plants (which *M. x g.* belongs to) is a permanent soil cover and deposition of carbon dioxide (Clifton-Brown et al. 2004, Deckmyn et al. 2004) but also the support of biodiversity (Hope, Johnson 2003). In terms of the possibility of mitigation of greenhouse gases within the cultivation of maize, questions regarding crop rotation, including intercrops in crop rotation and ploughless tillage systems are addressed (Al-Kaisi, Yin 2004). The advantage of growing *M. x g.*, besides a lower environmental impact and a high yield per hectare of phytomass, is also high energy production (Menardo et al. 2013).

CONCLUSION

The aim of this paper was to point out the possibilities for mitigation of greenhouse gas emissions CO_2e within growing *Miscanthus x giganteus*, as a plant suitable for use in the BGP and its mutual comparison with maize. The results show that with the cultivation of *M. x g.*, we can reduce greenhouse gas emissions per the unit of production (1 kg of DM) by about 50% and per the area unit (1 ha) by about 65% per year, as compared with maize. The determining factor in the calculation of emission load (CO_2e) within the farm stage through LCA is the chosen intensity of fertilization and the yield of phytomass. Additionally in the longer term, you can achieve yields per hectare of *M. x g.* that are comparable with maize and the total energy profit per the production unit. For the *Climate change* impact category, the highest emission load is associated with the application of nitrogen fertilizers, the field N_2O emissions arising from the application of nitrogen fertilizers and partially utilized agrotechnical operations. Any reduction in the amount of CO_2 produced within growing maize or *M. x g.* for BGP can be done by reducing the dose of fertilizer (probably at the cost of lower yields), by changing cultivation technology, and the inclusion of other environmentally friendly energy plants.

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