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CULTIVATION OF TALL WHEATGRASS AND REED CANARY GRASS FOR ENERGY PURPOSES IN TERMS OF ENVIRONMENTAL IMPACTS

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Abstract

Cultivation of energy crops for the production of thermal energy through direct combustion has become one of the trends within the ecological energetics. A number of perennial plants is grown in the conditions of the Czech Republic, too, for this purposes. One of them is reed canary grass (RCG). This species might gradually be replaced by another grass, better-performing tall wheatgrass (*Elymus elongatus* subsp. *ponticus* cv. Szarvasi-1). Greenhouse gas emission savings may be achieved due to the higher yield potential and energy yield when growing it. This article presents the results of emission load monitoring resulting from the RCG and Szarvasi-1cultivation for energy purposes. The simplified LCA method, respectively its Climate change impact category is used as a tool for emission load measuring. The results show that the emission savings of up to 45% per 1 GJ can be achieved when growing Szarvasi-1 for energy purposes in comparison with RCG.

Key words: energy grasses, greenhouse gases emissions, Life Cycle Assessment.

INTRODUCTION

Global energy demand increases in the context of demographic transition (Ho and Show, 2015). Fossil fuels represent a major source (Vostracký et al., 2009). However, their combustion contributes to environmental pollution (Nicoletti et al., 2015) and is responsible for a significant share of greenhouse gas emissions (GHG) (Moutinho et al., 2015). Moreover, they are not renewable (Mastný et al., 2011) and thus their use is not sustainable (Libra and Poulek, 2007). The importance of renewable energy sources (RES) increases in relation to the finite nature of fossil fuels (Gürdil et al., 2009). RES are considered as "clean" sources of energy (Panwar et al., 2011). The most important renewable energy source is biomass (Jasinskas and Šateikis, 2009) and the combustion of biomass, in particular (Malaťák et al., 2008). The production of biogas is also widespread (Jasinskas et al., 2008). Switching to biomass offers a range of economic, social and environmental benefits (Saidur et al., 2011), including the reduction in carbon dioxide emissions within the energy sector (Lind et al., 2016). The importance of the emission reduction, as well as fight against the climate change has been widely acknowledged (Hoel, 2011).

Many agricultural products may be used, inter alia, for energy purposes (Robbins et al., 2012). However, some plants are grown specifically for this purpose (Lewandowski et al., 2003). Their suitability has been examined to the present day (Mast et al., 2014) and, in the context of a changing climate, the special emphasis has been placed on the drought tolerance (Konvalina et al., 2010). Perennial plants appear to be more suitable from an environmental point of view (Kopecký et al., 2015). Grasslands perform a range of non-productive functions (Skládanka, 2007) and may also be recommended for the areas with high erosion risk (Dumbrovský et al., 2014). In addition, fewer fertilisers are required (Lewandowski et al., 2003) and grasslands have lower requirements for the pest and disease management (Lewandowski et al., 2000) in comparison with annual plants. For instance, RCG (*Phalaris arundinacea* L.) (Tahir et al., 2011) or *Elymus elongatus* subsp. ponticus cv. Szarvasi-1 (Csete et al., 2011) may be included into energy crops.

Although energy plants offer many advantages compared to fossil fuels, it is necessary to determine the impacts on all components of the environment that may be affected by their production (Saidur et al., 2011) or operation of the facilities using biomass for energy production (Malaťák and Vaculík, 2008). Combustion of biomass in the combustion chambers intended for fossil fuels is technically possible, but very inefficient and high emissions of carcinogenic substances and aromatic hydrocarbons are produced. This also applies under unfavorable combustion conditions, as may be the low temperature combustion (Ochodek et al., 2006). Many authors (i.e. Das et al., 2010; Ochodek et al., 2006) point out that energy plants compete with food crops for arable land. Therefore, it is recommended to grow energy crops on marginal lands (LEWANDOWSKI ET AL., 2003) or degraded lands (VASSILEV ET AL., 2012).

For the quantification of specific emission loads in different farming systems, the LCA (Life Cycle Assessment) study (KOČÍ, 2009) or the simplified LCA (HOCHSCHORNER AND FINNVEDEN, 2003), 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 (BISWAS ET AL., 2010), may be used. LCA 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).

The aim of this study was to draw up models of technological processes during the practical cultivation of RCG (the Chrastava variety) and Szarvasi-1 and determine their emission load impact on the environment.

MATERIALS AND METHODS

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 as an indicator of carbon dioxide equivalent (CO_2e). The SIMA Pro software and the ReCiPe Midpoint (H) method was used for the calculations. The functional unit of the system was 1 kg of the final product - dry matter (hereinafter referred to as DM) and 1 GJ obtained through combustion of the final product. Technological processes of the cultivation of RCG and Szarvasi-1 intended for the direct combustion was 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 - 2016 and the secondary data between 2000 - 2015. The data selected for modelling are based on the average of commonly applied intensive farming technologies (KAVKA, 2006; WROBEL, 2009; CSETE ET AL., 2011; STRAŠIL, 2012). 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 and transport were included into the model system. Infrastructure was not included into the system processes.

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 (DE KLEIN ET AL., 2008).

Furthermore, the CHNS analysis (elemental composition of phytomass) was carried out using the Vario EL CUBE within the BBOT Standard. The heat of combustion was calculated using the Mendeleev's Formula $Q_s^r = [81\cdot C+300\cdot H–26\cdot(0–S)]\cdot 4.187$ (kJ·kg^{-1}), as well as calorific value from the formula $Q_u = Q_v–5.85\cdot(W+8.94\cdot H)\cdot 4.186$ (kJ·kg^{-1}), where Q_v is the heat of combustion in kcal·kg^{-1} (HUBÁČEK ET AL., 1962).

RESULTS AND DISCUSSION

This paper evaluates the results of the 3-year cultivation of RCG and *Elymus elongatus* subsp. ponticus cv. Szarvasi-1 for the direct combustion purposes using the intensive farming technologies under one cut treatment. Based on the methodology and acquired data (DM yields, inputs and outputs of the growing cycle, heat of combustion and calorific value calculated from the elemental composition), it was possible to compile the life cycle of chosen energy plants and quantify their impact on the environment. As already mentioned, the results of the study were related to the *Climate Change Impact Category* expressed in the carbon dioxide equivalent where CO_2e = 1x CO_2; 23x CH_4; 298x N_2O, based on the difference in the effectiveness of these greenhouse gases (FORSTER ET AL., 2007; SOLOMON, 2007).

Fig. 1 shows the amount of phytomass harvested during each season The grasslands always underwent a one-phase harvest in late winter or early spring. In this period, the plants contain the highest amount of DM (Ø>75%) (STRAŠIL ET AL., 2011) which is favourable for the direct combustion.process. In this case, the harvest took place from 17.3. - 1.4. , when RCG contained on average 80.6% of DM and Srazvasi-1 78% of DM. The CHNS analysis (elemental composition) was carried out and the heat of combustion (Q_s^r) and calorific value (Q_u) was calculated in DM samples. Values are reported in Fig. 2.

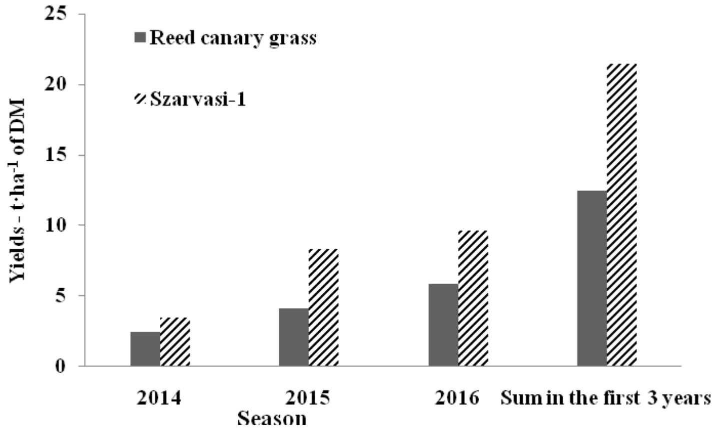

Fig. 1. – DM yields in particular years

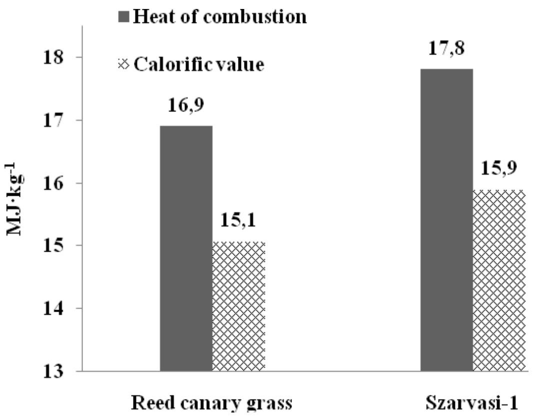

Fig. 2. – Heat of combustion and calorific value of chosen grasses calculated from the elemental analysis (MJ·kg^{-1})

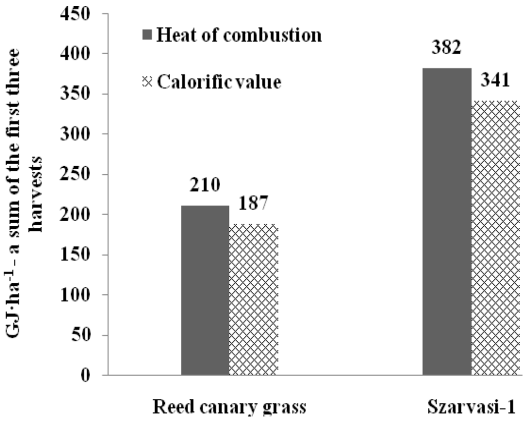

Fig. 3. – Net energy gain (a sum of the first three harvests) (GJ·kg^{-1})

The heat of combustion values of RCG (Q_s^r) are in accordance with ŠTINDL ET AL. (2006). He notes that the value is 16.6 ±0.20 (MJ·kg^{-1}) (calculated according to the Mendeleev's Formula). The heat of combustion of Szarvasi-1 is, according to the obtained data, on Ø 7% higher [Q_s^r = 17.8 (MJ·kg^{-1})], as well as the calorific value (Q_u Szarvasi-1 > Q_u RCG) in comparison with RCG (see Fig. 2). Q_u value is variable depending on the current moisture content of harvested phytomass. Fig. 3 presents the values of the total net energy gain (GJ·ha^{-1}) for the first three years. Szarvasi-1 can be regarded as more energy efficient due to the higher energy yield per production unit and higher production of phytomass per area unit. The total net energy gain of Szarvasi-1 (GJ·ha^{-1}) is almost $^{1}/_{2}$ higher in comparison with RCG on the basis of three-year monitoring. Based on these values, the emission load (in the form of CO_2e) per 1 kg DM and 1 GJ of the phytomass intended for direct combustion was then quantified (see Fig. 4).

Due to the identical farming technologies used for both species, the total net energy gain and yield is crucial in order to determine the difference between the emission loads at a profit of 1 GJ . As shown in Fig. 4, the difference in the total emission load in Szarvasi-1 cultivation (11.1 kg CO_2e·GJ^{-1}) and RCG cultivation (20.2 kg CO_2e·GJ^{-1}) is about 45%. A share of particular inputs and outputs of the growing cycle, making up the total emission load, is shown in Fig. 5.

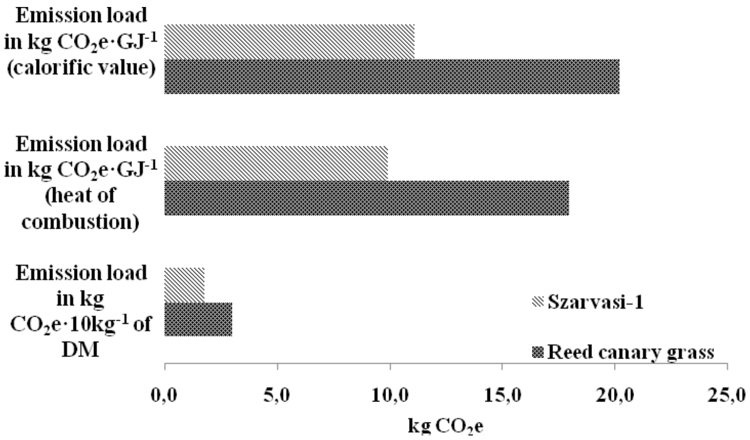

Fig. 4 - Emission load (kg CO_2e) per the production unit (1 GJ and 10 kg of DM)

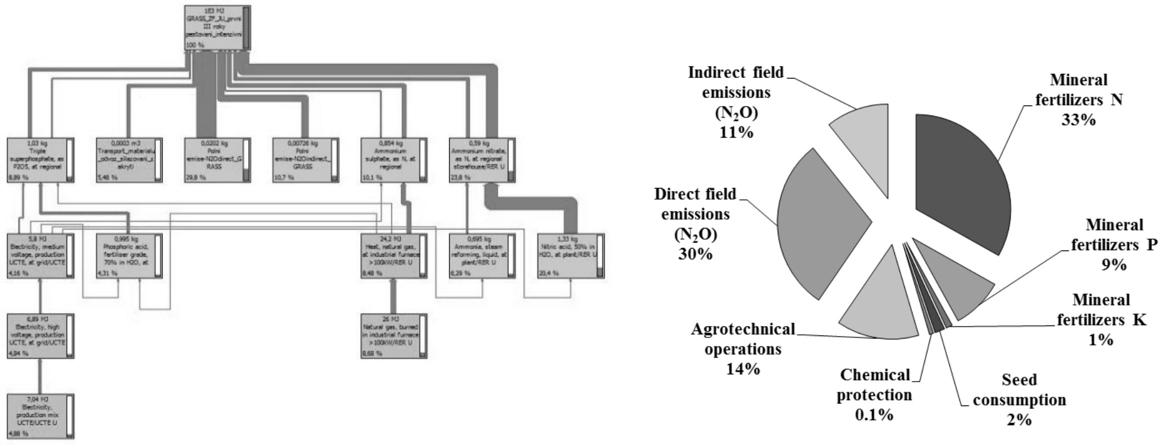

Fig. 5. – A share of particular inputs (in %) contributing to GHM emissions

Legend: Percentage of individual inputs is identical for both monitored grasses owing to the same farming technologies used.

The largest sources of GHG emissions from the crop production are fertilizers and their application (Gattinger et al., 2012). In this case, the emissions arising from the use of mineral nitrogen fertilisers (33%) and the emissions resulting from their application represent the largest share of total emissions. These are known as field emission and can be divided into two categories: direct (30%) and indirect (11%). Agrotechnical operations (14%), particularly characterized by the consumption of fossil fuels, have a significant impact on the emission load. However, their consumption in the agricultural sector is, according to Sauerbeck (2002), considered less significant in comparison with the overall fuel consumption (in agriculturally advanced countries it is only about 3-4.5%).

Speaking of reductions in CO_2e production within the chosen cultivation process, it is necessary to focus especially on two of the strongest sources (application of nitrogen fertilizers and field emissions arising after the application of nitrogen fertilizers). For example, Smith (2008) provides a variety of options of GHG mitigation within crop production In this regard, the issue of reduction in the dose of fertilizers or the total change of the agricultural system is often discussed (Paustian et al., 1998; Moudrý et al., 2013). Also, the amount of emissions from agriculture is influenced to a great extent by farming systems. Conventional farming systems use more inputs in the form of fertilizers (organic and mineral), which are key factors in the mitigation of N_2O a NO emissions from soil. N_2O may be considered as the main greenhouse gas and organic farming systems generally produce less N_2O, as well as CO_2emissions due to lower inputs (Bos et al., 2007) and more close production cycle (Konvalina et al. 2014a,b).

This paper points out the possibility of GHG mitigation per production unit (GJ) when growing different, more efficient energy grasses (Szarvasi-1) for direct combustion with the identical farming technologies. As the results show, Szarvasi-1 appears to produce more DM (21.4:12.4 t·ha^{-1} - (a sum of three harvests). It also has a higher heat of combustion (Q_s^r) (17.8:16.9 MJ·kg^{-1} of DM), as well as calorific value (Q_u) (15.9:15.1 (MJ·kg^{-1} of harvested material) and, in connection with this, a lower emission load per energy unit (11.1:20.2 kg CO2e·GJ-1). Therefore, Szarvasi-1 has a potential to gradually replace RCG, which has been grown for energy purposes last few years and, for example, has covered almost 70 thousand hectares in Finland (GHICA AND SAMFIRA, 2011).

CONCLUSIONS

The emission load per energy unit was quantified based on a three-year monitoring of selected energy grasses (RCG and *Elymus elongatus* subsp. ponticus cv.Szarvasi-1) grown for direct combustion. Based on the measured values, Szarvasi-1 appears to be more environmentally friendly alternative in comparison with RCG (11.1: 20.2 kg CO$_2$e·GJ^{-1}). According to the monitoring, the difference is 45% per kg CO$_2$e·GJ^{-1}. The article shows that GHG mitigation (related to a production unit) may be achieved through the replacement of existing plants by a more energy and yield efficient plant while maintaining the identical farming technologies. Further, mitigation could be initiated through the better management of mineral nitrogen fertilisers, extensive farming methods or a change of farming technology. Besides, cultivation of these perennial energy grasses brings extra benefits, such as the soil erosion protection, promotion of biodiversity and, when achieving appropriate yields of dry matter (> 12 t·ha^{-1} DM), economic efficiency.

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