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Life cycle assessment (LCA) of crops for energy production

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Abstract

The replacement of fossil fuels by biomass in the power generation process is an important strategy promoted by the European Union (EU). This is aimed at reducing the effects of climate change along with increased security of supply and diversification of energy sources. Life cycle assessment (LCA) is an increasingly popular method for research due to the difficulties associated with environmental impact assessment. This technique is aimed at analysing and evaluating the environmental impact of materials, products or services through the entire cycle of production. The paper presents the application of an LCA study to assess the impact of energy crops on the environment. The aim of the study was to compare the environmental impact of various crops used for biofuel production. We have estimated the potential global warming, acidification and eutrophication for crops from the lignocelluloses group (willow, Miscanthus) and traditional plants for Polish agriculture (wheat, rapeseed, potato).

Key words: Life cycle assessment (LCA), biomass, biofuel.

Introduction

Life cycle assessment (LCA) is a management tool used for comprehensive assessments of environmental impacts, covering all stages of the production processes. Guidelines and principles for conducting LCA studies are included in the standard quality and environmental management (ISO 14040) introduced by the International Commission for Standardization (ISO). The replacement of fossil fuels in power generation with biomass is an important strategy promoted by the European Union (EU) to reduce the impact of climate change and increase the security of supply and diversification of energy sources [1]. Big expectations for alternative energy sources and the fact that most EU governments due to increased use of energy crops, presuppose the need to conduct more detailed analysis (Biomass Action Plan[2]) coursed that the European Parliament issued a directive on the effort to reduce greenhouse gas emissions. This will become mandatory to demonstrate the LCA method to reduce CO_2 emissions by 35% until 2017, by 50% by 2018 and to 60% after 2018 (Directive 2009/28/EC)[3]. According to a study by the IEA [4], regarding the reduction of greenhouse gas (GHG) emissions, due to the use of biofuels in relation to petrol and diesel, only ethanol produced from lignocellulose plants can reduce GHG emissions by the required 60%. Tests carried out by the OECD [5] show a very large divergence of results from research carried out with LCA. Ethanol produced from wheat can reduce GHG emissions 30- 60% and biodiesel with vegetable oil 40-55%. However, according to Crutzen [6], emissions of N_2O resulting in the production of biofuels does not lead to a reduction of global warming. Relative rates of climate warming, caused by emissions of N_2O from the production of rapeseed and wheat, suggests that the use of liquid biofuel production will negatively affect global warming.

The aim of study was a preliminary attempt to compare the environmental impact of various crops for biofuel production using life cycle analysis.

Materials and Methods

A simple analysis of LCA was undertaken with the use of previously published indicators. GHG emissions for *Miscanthus* were calculated on the basis of energy balance using the indicators published by Bullard and Metcalfe [7] and Fernando and Oliveira [8]. GHG emissions for willow were calculated with indicators described by Börjesson [9]. In the case of wheat, rape and potato indicators published by Williams [10] were used.

The net energy efficiency was calculated as the ratio between energy produced from biomass and energy used during its production. Energy inputs to production were the sum of the energy used to produce seeds, fertilisers, pesticides, agro-production, use of machinery, storage of biomass, as well as transportation.

The produced energy was calculated as the quotient of dry matter yield (t ha^{-1}) and gross caloric value of biomass. The net energy produced was calculated as an energy that was reduced by 10% of yield losses.

To conduct studies on willow and *Miscanthus*, the results from field experiments conducted in the Experimental Station of the Institute of Soil Science and Plant Cultivation in Osiny, Poland, in 2006 (Table 1) were used. In the case of wheat, oilseed rape, and potatoes, the average yields (Table 1) taken from the Central Statistical Office [11] were used.

Results and Discussion

Rape was characterised with the highest greenhouse gas emissions (Fig. 1) and associated with high demands of fertilisers. High GHG emissions were also calculated for the cultivation of *Miscanthus* (Fig. 1). Styles *et al.* [12] estimated the greenhouse gas emissions of 1.2 - 2.7 t eq. CO_2 ha^{-1}. Willow cultivation requires low energy inputs, and therefore has low GHG emissions. Styles *et al.* [12], estimated it at 0.8 - 1.8 t eq. CO_2 ha^{-1}, whereas Heller [13] estimated emissions from willow cultivation at 7.28 t eq. CO_2 ha^{-1}.

Table 1. Plant yields and the biomass caloric value.

Plant	Yield (t ha^{-1})	Biomass caloric value (GJ)
Miscanthus	17.8	19.3
Willow	14	19.5
Winter wheat	3.4*, 3.4**	18.6*, 17.7**
Rape	2.65*, 2.65**	23.8*, 15**
Potato	15	17.2

* grain, ** straw.

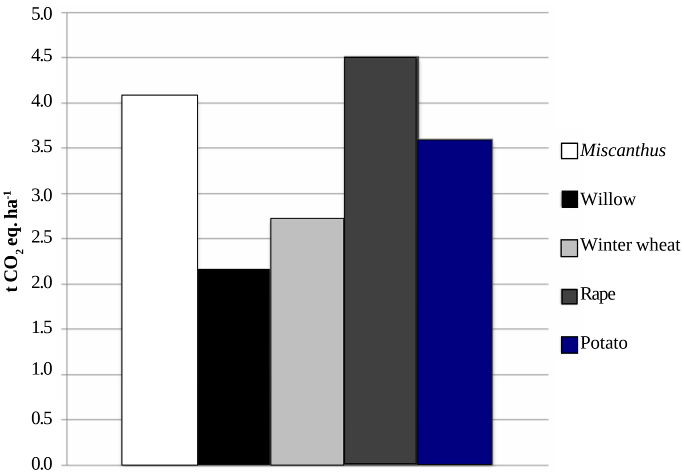

Figure 1. Greenhouse gas emissions (t CO_2 eq. ha^{-1}).

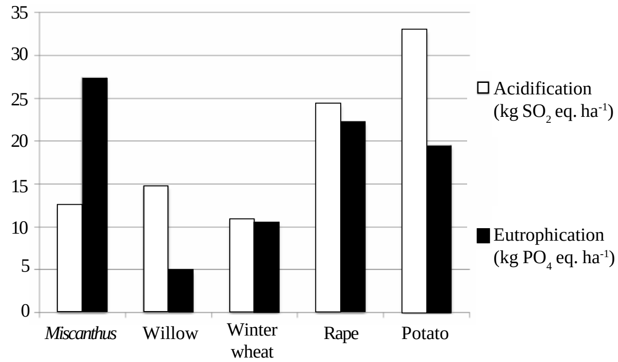

Figure 2. The emissions of gases affecting acidification and eutrophication of the environment.

In Poland, soils acidification for decades was one of the major problems of agriculture. According to the soil fertility index, this factor has a large influence in limiting agricultural production [14]. According to calculations, the biggest impact on acidification was potato cultivation (Fig. 2). This was due to the high fertilisation rate and the fact that the soil under cultivation of this plant is susceptible to increased leaching of basic cations, especially calcium and magnesium. The largest nitrogen excess was in the area occupied by roots [15]. A lower influence of acidification was in the cultivation of oilseed rape (Fig. 2) despite its high fertilisation, a densely standing cultivation reduces leaching of nutrients to the soil. Wheat cultivation (Fig. 2) was characterised with the lowest impact on acidification.

Growing *Miscanthus* had the greatest impact on eutrophication (Fig. 2) which is enriching water with nutrients, mainly phosphorus and nitrogen compounds, while cultivation of willow (Fig. 2) has a low impact on eutrophication due to the low fertilisation and efficient use of nutrients.

The production of each crop entails some cost, in the case of analysed plants potato cultivation was characterised with the highest cost (Table 2). Dobek [16] estimated the energy consumption of potato cultivation at 21-39 GJ ha^{-1}, depending on the cultivation system. Energy consumption in the cultivation of rape and *Miscanthus* (Table 2) was at a similar level (14-16 GJ ha^{-1}), for a comparison Skrobacki [17] and Dobek [18], estimated the energy consumption of rapeseed cultivation at 12-29 GJ ha^{-1}, while Jonathan [19] estimated it at 19.3 GJ ha^{-1} for rape and 9.2 GJ ha^{-1} for *Miscanthus*. Energy inputs for willows cultivation ranged from 6 to 22.5 GJ ha^{-1} at harvest every year [18] or when the harvest was every three years to 42 GJ ha^{-1} [20]. Inputs to wheat production also depend on the cultivation system: standard cultivation 15.6 GJ ha^{-1} and intensive one 17.5 GJ ha^{-1} [21]. Kuesters and Lammel [22] estimated the contribution of the energy at 7.5 GJ ha^{-1} in the absence of fertilization and 17.5 GJ ha^{-1} with high fertilization, while Jonathan [18] estimated it at 21 GJ ha^{-1}.

The highest net energy produced was in *Miscanthus* and willow cultivation (Table 2) which resulted in a high yield from those crops. The size of net energy production in the cultivation of *Miscanthus* was higher than calculated by Fernando and Oliveira [8] in their studies. Lewandowski [23] measured net energy production in the range of 115-590 GJ ha^{-1} y^{-1} while Jonathan [18] estimated it at 300 GJ ha^{-1}. The second largest energy yield was willow (Table 2); Jonathan [18] estimated the size at 180 GJ ha^{-1}. Kuesters and Lammel[21] estimated that in the range of 40-160 GJ ha^{-1} while Jonathan [18] estimated that at 189 GJ ha^{-1} (grain).

The energy efficiency of crops was expressed as a ratio between yield energy value and investment for cultivation. This value is largely due to the intensity of production and plant growth conditions [21]. Willow cultivation was characterised with the highest energy efficiency (Table 2). This is due to a relatively high yield and low energy inputs for yield production. This ratio depends on the yield of crops and the cost in obtaining this yield, but the yield is significantly varied depending on soil conditions and thus the value of this ratio ranged from 27 to 4.54 [24]. Börjesson [9] obtained for willow the energy efficiency at 21, Jonathan [18] at 30, while Szczukowski and Budny [19] identified it in the range from 22 to 41 when it was harvested annually and in a three-year rotation. The three-year rotation of the willow was characterised with the lowest energy consumption for one ton of dry wood chips production, and the highest rate of energy efficiency. Despite the high inputs of *Miscanthus* production, this plant was characterised with a high rate of energy efficiency 22.6. Jonathan [18] estimated it at 32.5. The energy efficiency of wheat was estimated at 14.59 (Table 2). Kwapisz [20] estimated it at 8 for the standard cultivation and 9.37 for the intensive, when both grain yield and straw were taken into account. Kuesters and Lammel [21] estimated the rate at 6-13 depending on the fertilization while Jonathan [18] estimated that at 8.8 (grain). The energy efficiency of potato was estimated at 10.06 (Table 2) and is higher than the literature data. Klikocka [25] estimated between 2.36 and 3.35 while Dobek [17] calculated

Table 2. Energy balance and greenhouse gas emission reductions in the production of plants.

		Miscanthus	Willow	Winter Wheat	Rape	Potato
Energy use	GJ/ha	16.14	7.30	7.82	14.31	21.00
Energy produced	GJ/ha	424.21	273.00	135.46	102.82	258.00
Net energy produced	GJ/ha	365.65	238.40	114.09	78.023	211.20
Net energy efficiency		22.66	32.66	14.59	5.47	10.06

it between 1.49 and 3.43 depending on the cultivation type. Rape was characterised with the lowest energy efficiency (5.5) due to very high production costs. Jonathan [18] estimated that at 3.8 while the comparable results at 5.5 (including) straw obtained by Bassam [26].

Conclusions

The life cycle analyses of crops for energy production presented in this work are preliminary attempts to use the method for a comparison of the environmental impact of various crops.

1. The cultivation of oilseed rape was characterised with the highest emissions of greenhouse gases.
2. The cultivation of potatoes and oilseed rape has the greatest influence on acidification among the analysed plants.
3. *Miscanthus* cultivation has the highest potential for net energy production between investigated plants.
4. Willow cultivation was characterised with the highest energy efficiency of net production.

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