COMPARATIVE ANALYSIS OF BIO-RAW MATERIALS AND BIOFUELS

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Abstract. The biofuels made of bio-materials have no adverse environmental impact. In terms of the raw material energy characteristics the biomass from energy crops is similar to the classic fuel wood. The biofuels produce more ash and some chemical elements but this fact does not diminish their important role as fuels of good prospects. From an energy point of view the biofuels have net calorific value of about 16-17 $MJ \cdot kg^{-1}$and their emissions are usually within the values allowed by relevant standards. This article refers to testing several interesting energy crop energy potential. The experiments aimed at determination of calorific values of plant raw materials were conducted by using the calorimeter MS-10A LAGET in accordance with the European standards. As the result the main factors affecting the calorific value of any plant raw material were chosen; they particularly are as follows: chemical composition and moisture content.

Keywords: biomass, calorific value, moisture content, energy yield, energy crops.

Introduction

The key issue for sustainable development of the society is the production and use of renewable energy sources. Limited possibilities of non-renewable energy sources, environmental consequences, and dependence on countries with highly volatile economics have been leading developed countries to solve the issue of energy sources by renewable sectors [1; 2]. Biomass (both - cultivated and waste) appears to be one of the largest potentials. Their common feature is the high content of organic matter and water [3; 4]. The use of this renewable energy source is an important part of sustainable development, and it also reduces a number of problems, which include: mitigation of CO_2 emissions and therefore greenhouse gas emissions and the greenhouse effect; substitution of fossil fuels; efficient and sustainable use of land resulting from the restrictions of limited food production in the EU and related overproduction of food crops; the development of rural areas and reduce of unemployment in them; increase energy self-sufficiency using indigenous energy resources [1-3].

High yielding annual and perennial energy plants like Miscanthus spp., Reynoutria x bohemicac, Arundo donax, Cannabis sativa and Sorghum bicolor seem to be a promising source of renewable energy in appropriate areas.

Experimental cultivation and testing of all above mentioned energy crops under the conditions of the Czech Republic was carried out in the framework of this study.

Brief description of energy crops of the present study in accordance to literature review and previous studies based on discussions with research workers from the Crop Research Institute (Prague and Chomutov) and the Research Institute of Agricultural Engineering, Prague is as follow:

Miscanthus (Miscanthus), a genus with C4 photosynthesis and a native of East Asia, has good potential as a biomass energy crop [1]. It is perennial grass which can grow up to 3-4 m high. Two kinds of Miscanthus - M. sinensis and M. x giganteus (sterile triploid hybrid between diploid M. sinensis and tetraploid M. sacchariflorus) were selected for experimental purposes. In accordance to [5] in terms of zoning, M. sinensis is the most suitable for the Northern Europe, M. giganteus for the Central Europe. The high yield and low input demand are the main factors why recent analyses conclude that Miscanthus (especially M. giganteus) in the (warm) temperate zone is the bioenergy crop that seems able to deliver the highest net GHG mitigation [2].

Knotweed (Reynoutria) is perennial C3 grass, which was introduced in Europe and North America from the Asian temperate zone. It is shrub-like grass that reaches a height of 2-4 m [6]. On the one hand, according to [4] the knotweed species are now considered to be among the most aggressive invasive weeds in temperate terrestrial ecosystems and their liquidation is very costly, on the other hand, by [7] knotweed species belong among the most effective crops in the Central Europe as regards the phytomass yield. To solve this situation, knotweed could be successfully utilized for energy purposes. Reynoutria x bohemica (hybrid between Reynoutria japonica and Reynoutria sachalinensis), which has the highest yield comparing to other species of knotweed in the conditions of the Czech Republic in accordance to [7], was selected in the framework of the present study.

Giant reed (*Arundo donax* L.) is tall, perennial C3 grass and it is one of the largest herbaceous grasses that can reach a height up to 8–9 m under optimal growth conditions. Arundo donax is thought to have originated from Asia but is also considered as a native species in the countries surrounding the Mediterranean Sea. Nowadays it has become widely dispersed into all of the subtropical and warm-temperate areas of the world [8]. Due to its high biomass production and great adaptability to marginal land, Arundo donax is being seen as one of the most promising energy crops [9].

Industrial hemp (Cannabis sativa) is an annual fibre plant originated from Western Asia and India which can be grown at higher altitudes as well. Hemp has been grown over the world for its fibre and seed for centuries. According to the restrictions of the EU politics the hemp cultivations went on decline [10]. Due to the great benefit of this plant which considers in its ability to create over 24 tons of biomass per hectare (equal to 10 t. ha^{-1} of *DM*) during 140 days [11], use of hemp for energy purposes can be an interesting alternative.

Sweet Sorghum (*Sorghum bicolor* L.) is an annual herbaceous C4 plant originated from Africa, but also used in America and Asia, some specific types of Sorghum are also cultivated in Europe. In the case of Sweet Sorghum, biomass synthesis is done with relatively low energy, chemicals and water inputs, characteristics which are typical for C4 [12]. Vestigial waste biomass could be usefully utilized in a form of solid biofuels.

The above mentioned energy crops were selected and subjected to experiments during which the biomass yield (*BY*), moisture content (*MC*), gross calorific value (*GCV*), and maximum potential (theoretical) energy yield were determined. The objective of the research was testing of interesting energy crops with promising potential to determine and compare the maximum (theoretical) energy yield.

Materials and methods

The main part of this study is based on field trials of the above mentioned energy crops. The samples were used for determination of the biomass yield, moisture content, heating value and energy yield. The data were subjected to statistical analyses according to ANOVA.

Field trials. The cultivated crops were harvested in the Prague area (Suchdol) in 2010-2012 in order to obtain biomass for the energy yield evaluation from the harvests. The energy crops were grown on trial plots of 50-100 m^2 and the energy yields of the small- scale samples (determined by collecting and weighing all plants) were extrapolated to an energy yield per hectare.

Sample analyses. The plants used for sampling were harvested on a 0.5 m × 0.5 m square and hand-cut down to ground level. The samples for *MC* analysis were dried at temperature of 105 ºC for 8 hours in an automatic hot air oven MEMMERT model 100-800.

The *MC* (the quantity of water in raw material) in percent was determined by formula 1:

$$MC = (m_v - m_0) / m_v \cdot 100 \tag{1}$$

where m_v – mass of moist sample, g;
m_0 – mass of dry sample, g.

The determination of gross calorific value of pure raw materials used for briquetting was performed according to the standard ČSN EN 14918.

The principle of calorific value determination: the calorific value is determined by a bomb calorimeter. A sample of air dried biomass with a known mass is burnt in atmosphere of oxygen in a stainless steel high pressure vessel, known as a bomb. This bomb is placed in a calorimeter which is a highly polished outer vessel containing a known amount of water with a known temperature. The combustion products CO_2 and H_2O are allowed to cool to the standard temperature. The resulting heat of combustion is measured from the accurate measurement of the rise in the temperature of water in the calorimeter, the calorimeter itself and the bomb. The calorific value so estimated is the gross calorific value [13]. Automatic calorimeter LAGET MS-10A with accessories was used for the calorific value determination.

Calorific value – gross calorific value of the material (q_{gr}) in $J \cdot g^{-1}$ is calculated as:

$$Q_{gr} = q_{gr} = (dT_k \cdot T_k - (c_1 + c_2)) / m, \tag{2}$$

where dT_k – temperature jump, ºC;
T_k –heat capacity of calorimeter=9161 J·ºC^{-1};
c_1 – repair of benzoic acid = 20 J;
c_2 – repair of the heat released by burning spark fine wire = 70 J;
m – weight of material sample, g.

The value of the temperature jump is automatically calculated by the calorimeter and is shown on a display of the calorimeter after every single measurement.

Gross biomass energy yield calculation. With use of the *MC* values the dry matter yield (*DM*) in t·ha^{-1} was calculated by use of the following formula (3):

$$DM = (100 - MC / 100) \cdot BY, \tag{3}$$

where MC – moisture content, %;
BY – biomass yield, t·ha^{-1}.

The biomass gross energy yield (*BEY*) in GJ per hectare describes the total mass of energy stored in biomass (potential energy yield). It was calculated by multiplying the dry matter (*DM*) yield by the corresponding gross calorific value (GCV) in MJ·kg^{-1}, i.e.:

$$BEY = GCV \cdot DM. \tag{4}$$

Results and discussion

Table 1 (below) shows the results of laboratory measurements, field results and calculations.

Table 1

Gross calorific value, Biomass yield, maximum energy yield

Biomass	Gross calorific value, MJ·kg^{-1}	Standard deviation, MJ·kg^{-1}	Biomass yield, t·ha^{-1}	Maximum energy yield, GJ·ha^{-1}
Miscanthus giganteus	20.3	0.43	26.2	531.9
Miscanthus sinensis	19.3	0.14	18.8	362.8
Giant knotweed	19.6	0.33	19.8	387.7
Giant reed	19.5	0.51	23.1	451.6
Hemp	19.6	0.37	10.9	213.6
Sweet sorghum	19.1	0.61	18.1	345.7

It is evident from Table 1 that the gross calorific value of the biomass raw material ranges from 19.1 MJ·kg^{-1} (biomass of sweet sorghum) to 20.3 MJ·kg^{-1} (biomass of miscanthus giganteus).

For more probability of the results the standard deviations were found. They vary from 0.14 MJ·kg^{-1} to 0.61 MJ·kg^{-1}.

Raw biomass was produced from 10.9 t·ha^{-1} to 26.2 t·ha^{-1} of dry matter. The gross calorific value and biomass yield determined that the maximum potential energy yield (theoretical) of dry matter was from 213.6 GJ·ha^{-1} to 531.9 GJ·ha^{-1}.

The energy output from miscanthus giganteus was significantly the highest among the tested energy plant species.

All of the above mentioned plants were grown under natural conditions without additional inputs (in the form of fertilizers, irrigation, etc.). A hypothesis can be formulated that the yield could have been increased through some inputs, which would have had also to increase the maximum potential energy yield.

In this study theoretical maximum yields were taken into account. Losses (post-harvest and combustion losses) were not taken into account – they can vary between 30 - 50 % [10].

In the study annual as well as perennial crops were subject to testing. Figure 1 shows that the annual energy yield of annual crops (case of hemp and sweet sorghum) must be classified as the worst one from among the tested energy crops while the perennial crops (case of miscanthus giganteus and giant reed or giant knotweed) had significantly higher energy yield.

It is to mention that some advantages can be identified as linked to harvesting the above annual energy crops. According to the reference [3] there is no need of special investments (particularly into harvesting machinery and technologies); another priority is that the land remains in good condition for an eventual return to grow food crops.

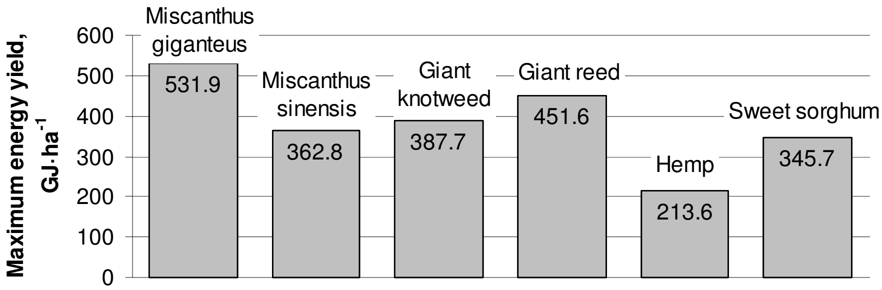

Fig. 1. **Maximum energy potential yield of biomass**

Conclusion

Evaluation of long-term experiments with growing plants for energy purposes clearly demonstrates preference of perennial plant species to annual energy crops. The highest biomass yields and maximum (theoretical) potential energy yield were found at miscanthus giganteus growing as followed by giant reed and giant knotweed. This is in line with available references [5; 7; 8].

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