ENERGY BALANCE OF BRIQUETTES MADE OF HEMP (*CANNABIS SATIVA* L.) CULTIVARS (FERIMON, BIALOBRZESKIE) FROM AUTUMN HARVEST TO PRODUCE HEAT FOR HOUSEHOLD USE

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Abstract. Searching for renewable energy sources in the form of energy crops becomes a perspective solution for sustainable development of many countries. This paper discusses the energy balance and energy efficiency of briquettes made of different hemp (*Cannabis sativa* L.) cultivars. The hemp plants, the well-known variety of Polish origin Bialobrzeskie and the modern promising variety of French origin Ferimon, were experimentally cultivated and harvested. The objective was obtaining biomass for energy yield evaluation from its harvests and comparing differences between the cultivars. The harvest samples were subjected to experiments, during which the moisture content (MC) and gross calorific value (GCV) were measured, according to which the dry matter content (DM), biomass yield (BY) and net calorific value (NCV) were determined. An integral part of the energy balance determination was consideration and calculation of energy inputs the individual technological operations contribute to the overall sum of the consumed energy. The energy expenditures for hemp were calculated including direct energy inputs by fuels and human labour, and indirect energy inputs in fertilizers, seeds and energy embedded in machines. Regardless of the higher net energy yield for Ferimon cultivar compared with Bialobrzeskie, it was found that the difference between their Energy Return On Energy Invested (*EROEI*) is not significant.

Keywords: energy input, energy output, Energy Return On Energy Invested, calorific value, energy efficiency.

Introduction

Biomass from energy crops is partly able to displace fossil fuels. This is one of the reasons for researchers to focus on their evaluation of: economic profitability, energy balance as well as environmental impact (mainly mitigation of the global warming potential). Energy balance can be calculated that accounts for the energy outputs minus the direct and indirect energy inputs in cultivation, harvest, transport and conversion [1]. This kind of evaluation was done for the first generation biofuels, e.g., maize and wheat for bioethanol production as well as rape seed used as biodiesel [2; 3]. There are still missing some crops with promising energy potential for calculation.

Hemp (*Cannabis sativa* L.) is a plant that has been prohibited for years in relation to the psychoactive effect of some of its secondary metabolites – terpenoids [4]. However, it has been experiencing a worldwide revival in the last 10 years [4]. Hemp can also be used as a feedstock for the production of solid biofuels - briquettes and pellets [1] as well as a source of biomass for biogas generators [2]. Furthermore, because of the high concentration of cellulosic fibers as glucose, hemp could be a suitable second generation crop for the production of cellulosic ethanol [3]. Hemp seeds can also be used for energy production since the oil they contain could be converted into biodiesel [4]. Industrial hemp is well known for its high productivity as well as gross calorific value, which can be compared to wood [4]. The uniqueness of this plant lies in its ability to yield more than 24 tons of green biomass per hectare (corresponding to 10.9 $t \cdot ha^{-1}$ of dry biomass) within 120 days. The high energy potential of hemp and lack of information about its cultivation, harvest and environmental suitability has led to further research to obtain new information.

Materials and methods

A variety of hemp of the Polish origin Bialobrzeskie and French Ferimon were harvested in the Prague area (Suchdol) in 2012 in order to obtain biomass for the energy yield evaluation from its harvests to compare the differences between the cultivars. Its row spacing was 12.5 cm, seeding rate 60 $kg \cdot ha^{-1}$ and sowing depth 3 cm. The growing season (14th May – 10th October) lasting 150 days had precipitation 255 mm during the vegetation period and an average temperature of 17.4 ºC. Hemp was grown on a trial plot of 100 m^2 (50 m^2 each) 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 the ground level. The samples for *MC* analysis were dried at temperature of 105 ºC for eight 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 laboratory measurement of the gross calorific values (GCV) in $MJ \cdot kg^{-1}$ was carried out in an adiabatic calorimeter type MS 10A from LAGET, Ltd. All calorimetric measurements were repeated 10 times and the results were statistically processed using ANOVA statistical analysis software.

Gross biomass energy yield calculation

With use of the *MC* values the dry matter yield in $t \cdot ha^{-1}$ (*DM*) was calculated by use of the following formula:

$$DM = (100 - MC / 100) \cdot BY, \tag{2}$$

where w – moisture content, %;
BY – biomass yield, $t \cdot ha^{-1}$.

The biomass gross energy yield in $GJ \cdot ha^{-1}$ (*BEY*) 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*), i.e.:

$$BEY = GCV \cdot DM. \tag{3}$$

Harvestable biomass

To account for losses during harvest, hemp *DM* yields were reduced by 10% for harvesting in the autumn.

Lower heating value on dry basis calculation

$$LHV_{D.B.} = GCV_{D.B.} - ED \cdot (MC / 100 - MC) - ED \cdot (HC / 100) \cdot MMR, \tag{4}$$

where ED – enthalpy difference between gaseous and liquid water at 25 ºC, $MJ \cdot kg^{-1}$;
HC – content of hydrogen in the biomass, %;
MMR – molar mass ratio between water (H_2O) and hydrogen (H_2).

Production scenario

This way of utilization describes the production of heat from combustion of autumn-harvested, stored under roof for moisture loosening and briquetted hemp. This scenario illustrates combustion in small-scale boilers for heating of private homes.

Energy input calculation

The amount of energy inputs in $GJ \cdot ha^{-1}$ (*EI*) was determined as the conversion of the spent labour and materials (hours of human labour, kWh, kg, etc.) in the energy equivalent or the conversion coefficient.

There were included the following items (all per hectare and year), superphosphate 0.25 t, potassium salt 0.1 t, farmyard manure 4.5 t, ammonium sulphate 0.3 t, limestone 0.2 t, stubble treatment, ploughing, seedbed preparation, sowing, rolling, chopping, compressing, loading (2 times), transport to processing. The briquetting lines consisted of a separator and a crusher.

The chronological sequences of the technological operations (fertilization, soil preparation, sowing, harvesting, and transport and field treatment after harvest) as well as the repeatability of the operations and material inputs were based on average conditions and the intensity of production [5]. Machines and equipment recommended for hemp cultivation were taken into consideration according to the Crop Research Institute [6]. The briquettes were assumed to be burned in small-scale domestic boilers (80 % thermal efficiency) for heating purposes (useful heat).

The energy equivalents as well as the conversion coefficients were taken from the listed references (see Table 1).

Table 1

Energy conversion equivalents

Item	Unit	Energy equivalent	Source
Human labour	1 h	2.3 $MJ \cdot h^{-1}$	[7]
Diesel	1EQF	35.8 $MJ \cdot l^{-1}$	[8]
Electricity	1 kWh	3.6 MJ $(kWh)^{-1}$	[9]
Steel	1 kg	25 $MJ \cdot kg^{-1}$	[10]
Seeds	1 kg	22.9 $MJ \cdot kg^{-1}$	[6]
Fertilizers			
Superphosphate (19 % of P2O5)	1 t	1024.9 $MJ \cdot t^{-1}$	Own calculation
Limestone (87.5 % of CaO)	1 t	2449.6 $MJ \cdot t^{-1}$	Own calculation
Ammonium sulphate (21 % of N)	1 t	17 325 $MJ \cdot t^{-1}$	Own calculation
Potassium salt (60 % of K2O)	1 t	7260 $MJ \cdot t^{-1}$	Own calculation
Tractors		95.7 $MJ \cdot kg^{-1}$	[8]
Ploughing machines and equipment		99.2 $MJ \cdot kg^{-1}$	
Sowing machines and equipment		95.4 $MJ \cdot kg^{-1}$	
Spreaders		95.4 $MJ \cdot kg^{-1}$	
Harvesters, mowing machinery		83.5 $MJ \cdot kg^{-1}$	

Note: *EQF* – unit is equal to 1.17 litres of fuel where 0.17 corresponds to the energy for mining, refining and transport of one litre of fuel.

Direct energy inputs (in $GJ \cdot ha^{-1}$) include that of human labour (E_1) and energy in fuels (E_2). Indirect energy inputs consist of the energy embedded in machines (E_3), in seeds (E_4), and in fertilizers (E_5).

$$EI = E_1 + E_2 + E_3 + E_4 + E_5, \quad (5)$$

$$E_1 = S_{hl} \cdot e_{hl}, \quad (6)$$

where S_{hl} – spent human labour per hectare, $h \cdot ha^{-1}$;
e_{hl} – energy equivalent of human labour, $MJ \cdot h^{-1}$.

$$E_2 = S_f \cdot e_{ff} + S_e \cdot e_e, \quad (7)$$

where S_f – fuel consumption, $l \cdot ha^{-1}$;
e_{ff} – energy equivalent of fuels, $MJ \cdot l^{-1}$;
S_e – consumed electricity per hectare, $kWh \cdot ha^{-1}$;
e_e – energy equivalent of electricity, $MJ \cdot kWh^{-1}$.

$$E_3 = W \cdot K_e \cdot T_s \cdot K_{rm} / T_{wh}, \quad (8)$$

where W – weight (mass) of machines, kg;
K_e – conversion equivalent, $MJ \cdot kg^{-1}$;
T_s – time spent on operation, h;
K_{rm} – repairing and maintenance coefficient;
T_{wh} – total number of working hours per machine service life, h.

$$E_4 = S_s \cdot e_s, \quad (9)$$

where S_s – seeding rate, kg·ha^{-1};
e_s – energy equivalent, MJ·kg^{-1}.

$$E_5 = S_{fe} \cdot e_{fe}, \tag{10}$$

where S_{fe} – fertilizing rate, kg·ha^{-1};
e_{fe} – energy equivalents, MJ·kg^{-1}.

Energy balance calculations

The energy balance calculations count the energy outputs (gross potential energy yield – *BEY*) and energy inputs (*EI*), both of them in GJ·ha^{-1}.

Net energy yields

The energy balance was calculated as the difference between the energy outputs (*BEY*) and energy inputs (*EI*).

Energy return on energy invested (EROEI)

The parameter EROEI or energy efficiency is the ratio of energy yield and energy inputs:

$$EROEI = \text{energy yield } (E_y) \text{ / energy inputs } (EI). \tag{11}$$

Results and discussion

Table 2 (below) shows the results of laboratory measurements, field results and calculations.

Table 2

Moisture content, biomass yield, GCV, NCV, energy output

Variety	Yield, t·ha^{-1}	Moisture content, %	*GCV*, GJ·t^{-1}	*DM*, t·ha^{-1}	Harvestable biomass, t·ha^{-1}	*NCV*, GJ·t^{-1}	En.output, GJ·t^{-1}	Useful heat, GJ·t^{-1}
Bialobrzeskie	22.1	56.8	19.3	9.6	8.6	17.3	148.8	119
Ferimon	26.5	59.8	18.6	10.7	9.6	15.8	151.7	121.4

Energy inputs calculated as a sum of partial energy items

The consumed energy for the spring harvest was 16 849 MJ·ha^{-1} of which fuels (5663 MJ·ha^{-1}), energy in fertilizers (8753 MJ·ha^{-1}), seeds (1371 MJ·ha^{-1}), machinery (960 MJ·ha^{-1}) and human labour (104 MJ·ha^{-1}) respectively representing, 33.6 %, 52 %, 8.1 %, 5.7 %, and 0.6 %. The spring harvest consumed 2994 MJ·ha^{-1} of electricity and 2669 MJ·ha^{-1} of fossil fuels (mainly diesel) for engines.

Energy yields and energy return on energy invested

The difference between the energy output and energy inputs has been calculated as 102.2 GJ·ha1 for Bialobrzeskie variety and 104.6 GJ·ha^{-1} for Ferimon variety. The *EROEI* was determined to be 7.1 for Bialobrzeskie and 7.2 for Ferimon. It was found that, for the given conditions, the difference between the cultivars is not significant.

The biomass yield and gross calorific value for industrial hemp are the most important output factors affecting the overall better efficiency. The yield can be influenced by several factors including the weather conditions (precipitation and temperature), sowing rate, period of sowing, time of harvest and soil fertility. Several authors have found that *GCV* could also be influenced by the time of harvest [2; 11].

The *EROEI* is a method for the evaluation of energy efficiency that could be applied to energy production. The output/input energy ratio is proposed as the most comprehensive factor permitting to assess sustainability. The EROEI compared to other energy crops cultivated under similar conditions based on the high level of mechanization, average conditions, the intensity of production and system of crop rotation are as follows: *Miscanthus* -20.1 [11], Rapeseed (*Brassica napus* L.) -6.7 [11], *Camelina sativa* L. -8.9 [11]. The lower *EROEI* is mainly caused by the lower yields and the higher energy inputs for different kinds of utilization in the case of biodiesel (rapeseed, camelina). Higher *EROEI* – *Miscanthus*, which can be processed into briquettes as well, does not require annual energy inputs. For that reason, we can state that industrial hemp can be placed among the energy crops with slightly above-average energy crops. Furthermore, hemp is a relatively new energy crop with great potential for yield improvements.

Conclusion

The energy balance and energy efficiency are crucial to solving many problems – they indicate how much energy is produced by the crop per unit of energy input; the energy balance can reveal the existing reserves and optimize the energy inputs in the manufacturing process. The inventory analysis serves well as a measure of the economic balance as well as the environmental impact evaluation (*LCA*) and possibility of CO_2 (greenhouse gases) reduction. Hemp has high biomass *DM* and good net energy yields per hectare. Furthermore, hemp has good energy output-to-input ratios and is therefore an above-average energy crop.

Advantages over other energy crops are also found outside the energy balance, e.g., low pesticide requirements, good weed competition.

Targeted scientific research in yield improvement may determine this crop as among the best energy crops in the Czech Republic.

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