CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

Department of Sustainable Technologies

Economic evaluation of hemp (*Cannabis sativa*) grown for energy purposes (briquettes)

Master Thesis

Prague 2014

Supervisor:
Ing. Tatiana Ivanova, Ph.D.

Author:
Bc. Hana Pernikářová

Declaration

I hereby declare that the present Master Thesis entitled „Economic evaluation of hemp (*Cannabis sativa*) grown for energy purposes (briquettes)“ is my own work and all the sources have been quoted and acknowledged by means of complete references.

In Prague, 14th April 2014

……………………………………

Bc. Hana Pernikářová

Acknowledgement

I would like to express my gratitude to all people who supported me during the elaboration of this Thesis. I would like to sincerely thank to my supervisor Ing. Tatiana Ivanova, Ph.D. for her time, patience and valuable consultations, to Ing. Michel Kolaříková for cooperation in conducting a field trial, Ing. Vladimír Verner, Ph.D. for his assistance; Ing. Jindřich Špička from Research Institute of Economics and Information for advices and recommendations and to Václav Lapka who provided me with practical knowledge about hemp cultivation.

Abstract

Economic evaluation of hemp (*Cannabis sativa*) grown for energy purposes (briquettes)

Depletion of fossil fuels and their environmental risks have brought to the foreground energy crops as a possible source of bioenergy. Industrial hemp (*Cannabis sativa* L.) has been suggested for production of solid biofuels (briquettes) due to good physic – mechanical properties as well as positive energy and combustion characteristics. Production costs and revenue play significant role in decision of producer which crop to cultivate. As no similar publication has not been published yet, the main aim of present Thesis was to develop methodology for calculation of hemp briquettes economy intended for farmers, producers of solid biofuels and others interested in utilization of hemp. Moreover, this study determined economic potential of hemp briquettes production in the Czech Republic. A field trial was conducted in 2012 – 2013 in Prague in order to compare biomass yield (BY) of hemp varieties Bialobrzeskie (B) and Ferimon (F) harvested in autumn and spring period. Based on obtained results this study determined (i) production costs of hemp briquettes (CZK·t^{-1}), (ii) revenue (CZK·t^{-1}) and (iii) rate of return (%) for four scenarios (B, F harvested in autumn and B, F harvested in spring). Briquettes production costs ranged from 4,015 CZK·t^{-1} to 4,707 CZK·t^{-1} for B in spring and B in autumn, respectively, due to 30% lower biomass yield in spring harvest. Results indicated that hemp briquettes production was not profitable if the selling price was the same as the price of wood briquettes and with BY obtained in experiment (7.18 – 10.7 t·ha^{-1} of dry matter). Briquettes production in autumn made profit of 9% for B and 7% for F when subsidies for hemp cultivation were considered. The study revealed that profitability of hemp briquettes production was significantly influenced by BY (increase of 1 t improved the profitability on average by 4.4 percentage points) and by competitive market price of wood briquettes. In current conditions in the Czech Republic, utilization of hemp for briquettes production did not prove to be economically feasible.

Keywords: hemp, economic analysis, hemp briquettes, solid biofuels, production costs

Abstrakt

Ekonomické hodnocení pěstování konopí (*Cannabis sativa*) pro energetické účely (brikety)

Snižování zásob fosilních paliv a environmentální rizika, která jsou spojena s jejich spalováním, uvedla do popředí energetické plodiny jako možný zdroj pro výrobu biopaliv. Technické konopí (*Cannabis sativa* L.) bylo doporučeno pro výrobu pevných biopaliv (briket) vzhledem ke svým pozitivním mechanickým, energetickým a spalným vlastnostem. Důležitou roli při rozhodování pěstitele, kterou plodinu pěstovat, hrají náklady a výnosy dané produkce. Vzhledem k tomu, že žádná podobná publikace nebyla do současné doby vydána, hlavním cílem této práce bylo vytvořit metodiku kalkulace nákladů výroby konopných briket vhodnou pro zemědělce, výrobce briket i další potenciální zájemce o pěstování konopí. V této práci byla rovněž ekonomicky zhodnocena výroba konopných briket v podmínkách České republiky. V letech 2012 – 2013 byl v Praze založen experimentální pozemek za účelem porovnání výnosů biomasy odrůd Bialobrzeskie (B) a Ferimon (F) s obdobím sklizně na podzim a na jaře. Na základě zjištěných výsledků byla zhodnocena (i) nákladovost výroby konopných briket ($Kč \cdot t^{-1}$), (ii) výnos z produkce ($Kč \cdot t^{-1}$) a (iii) nákladová rentabilita (%) pro čtyři varianty (B, F sklízené na podzim a B, F sklízené na jaře). Náklady na výrobu briket se pohybovaly mezi 4,015 $Kč \cdot t^{-1}$ a 4,707 $Kč \cdot t^{-1}$ pro B sklízenou na podzim, respektive na jaře. Z výsledků vyplynulo, že pokud byla prodejní cena konopných briket stejná jako cena dřevěných briket a při výnosech z pokusného pozemku (7.18 – 10.7 $t \cdot ha^{-1}$), vykazovala produkce briket z konopného stonku ztráty. Po započtení dotací na pěstování konopí se nákladová rentabilita při podzimní sklizni zvýšila na 9 % pro B a 7% pro F. Studie prokázala, že rentabilita produkce je ovlivněna především výší výnosu biomasy (navýšení výnosu o 1 tunu zvýšilo rentabilitu průměrně o 4.4 procentní body) a konkurenční prodejní cenou dřevěných briket. Z ekonomického hlediska se konopí neprokázalo jako vhodné pro produkci briket při současných podmínkách v České republice.

Klíčová slova: konopí, ekonomická analýza, konopné brikety, pevná biopaliva, výrobní náklady

Contents

List of Figures

List of Tables

List of Contractions

B	Bialobrzeskie
BY	Biomass yield
CO	Carbon oxide
CO_2	Carbon dioxide
CSO	Czech Statistical Office
DM	Dry matter
ERO	Energy Regulatory Office
EU	European Union
F	Ferimon
FADN	Farm Accountancy Data Network
FC	Fixed costs
GCV	Gross calorific value
GHGs	Greenhouse gases
MC	Moisture content
MIT	Ministry of Industry and Trade
MOA	Ministry of Agriculture
MOI	Ministry of the Interior
NPV	Net Present Value
OLS	Ordinary leased square
RES	Renewable energy sources
RR	Rate of return
SAPS	Single Area Payment Scheme
TC	Total costs
THC	Tetrahydrocannabinol
TR	Total revenue
ÚZEI	Ústav zemědělské ekonomiky a informací (Institute of agricultural economics and informations)
ÚZPI	Ústav zemědělských a potravinářských informací (Institute of agricultural and food information)
VAT	Value Added Tax

VC	Variable costs
VÚRV	Výzkumný ústav rostlinné výroby (Research institute of crop production)
VÚZT	Výzkumný ústav zemědělské techniky (Research institute of agricultural engineering)

1 Introduction

Energy is one of the most important commodities in today's world to ensure socio economic development of the country. Due to permanently decreasing reserves of conventional fossil fuels and their high environmental risks, countries have been looking for alternative sources of energy (Rehman et al., 2013). High potential lies in herbaceous biomass which has been on rise in recent years. To determine crops which are be the most suitable for energy production, its energy characteristics, ecological impact and production economy must be investigated thoroughly.

Based on results of long term research and practical experience in the Czech Republic and foreign countries, industrial hemp (*Cannabis sativa* L.) has appeared to be promising energy crop in conditions of Central and Northern Europe (Honzík et al, 2012). Industrial hemp has been suggested by various researchers for production of biodiesel (Rehman et al., 2013), bioethanol (Tutt, 2009), biogas (Prade, 2011) and also briquettes (Mankowski and Kolodzej, 2013) for household heating. Uniqueness of hemp consists in its ability to yield about 10 - 15 $t \cdot ha^{-1}$ in 100 – 120 days which is more than other energy crops (Široká, 2009). Hemp has proved positive energy balance (Prade, 2011) and combustion properties which are comparable to woody materials (Mankowski and Kolodzej, 2013). Furthermore, it showed to be suitable for crop rotation due to its phytoremediation characteristics. Since various energy crops with very similar or even better characteristics exist, production costs may play significant role in decision of producer which crop to cultivate. Until now many publications regarding hemp cultivation for various purposes have been published, however, any of them included detailed manual for evaluation of economy of hemp briquettes production. Thus the main purpose of this Thesis was to introduce methodology for economic assessment of cultivation and processing industrial hemp into briquettes. It is intended for farmers, producers of solid biofuels and other persons interested in cultivation and utilization of agricultural biomass as a renewable source of energy.

This Thesis is comprised of literature review and practical part. The first part of the study summarizes basic information about industrial hemp including its botanical description, legislation, possibilities of use, process of cultivation and manufacturing of hemp biomass into briquettes and published studies evaluating economic costs of hemp cultivation. In addition to that, brief pattern for calculation of costs and revenues in crop production is outlined too. Practical part presents detailed methodology for economic analysis of hemp briquettes production. Furthermore, total costs, revenue and profit from production are determined in conditions of the Czech Republic comparing two varieties of hemp plant (Bialobrzeskie and Ferimon) harvested in autumn and spring season.

2 Literature review

2.1 Renewable energies

Conventionally used fossil fuels are in serious threat of depletion as the world's population is still growing and the demand for energies is continuously increasing. It is expected that demand for energy will double within next 10 years. Moreover, the concern about environmental pollution has become very actual as burning of fossil fuels is tightly associated with emissions of greenhouse gases (GHGs) such as CO_2 and contributes to global warming and climate change. Renewable energy sources (RES) possess various advantages over traditional fuels such as sustainability of production, reduction of GHGs emissions (through mitigation of CO_2 emissions), an independence from volatile global market, etc. The Directive 2009/28/EC defined renewable energy as: "*energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases"*.

2.1.1 Use of renewable energy sources in the Czech Republic

The use of RES has been continuously developing in the Czech Republic due to the obligations given by the European Union (EU) Directives concerning the use of renewable energies (2001/77/EC and 2009/28/EC), by Kyoto Protocol and Doha Amendment to the Kyoto Protocol and others. The Directive 2009/28/EC has set a 20% target for the overall share of energy from RES and a 10% target for energy from renewable sources in transport for the EU as a whole by 2020. In accordance with the Directive 2009/28/EC, the Czech Republic committed to fulfil the indicative target of a 13% share of energy from RES in gross final energy consumption by 2020. It includes a mandatory target of 10% share of energy from RES in all kinds of transport in gross final energy consumption (MIT, 2010). Furthermore, the Czech Republic was committed by Kyoto Protocol (11 December 1997 in Kyoto, Japan, entered into force on 16 February 2005) to reduce its GHG emissions by 8% in 2012 in comparison with year 1990. In Doha Amendment to the Kyoto Protocol (8 December 2012 in Doha, Qatar) the Czech Republic is required to reduce them by 20% in 2020 below the base year (United Nations, 2007 and 2012).

The Ministry of Industry and Trade (MIT) publishes annually statistical report about renewable energy resources in the Czech Republic. The data used come from statistics and databases of MIT, Energy Regulatory Office (ERO), Czech Statistical Office (CSO), Czech Hydrometeorological Institute, State Environmental Fund and others.

2.1.2 Energy mix in the Czech Republic

The Czech Republic belongs to the EU countries with the lowest energy import dependencies – 27.7%. It is mainly because of its significant production of solid fossil fuels (coal) (Eurostat, 2011).

Electricity production in the Czech Republic is based on the use of coal. In 2011 it counted for almost 54% of the production (47.2% of brown coal, 6.6% of black coal). Nuclear power made another 33% of the electricity production. The share of RES on electricity production was 8.3%. Figure 1 below shows share of sources for electricity production. Presented data represented situation in 2011 since newer statistics were not available.

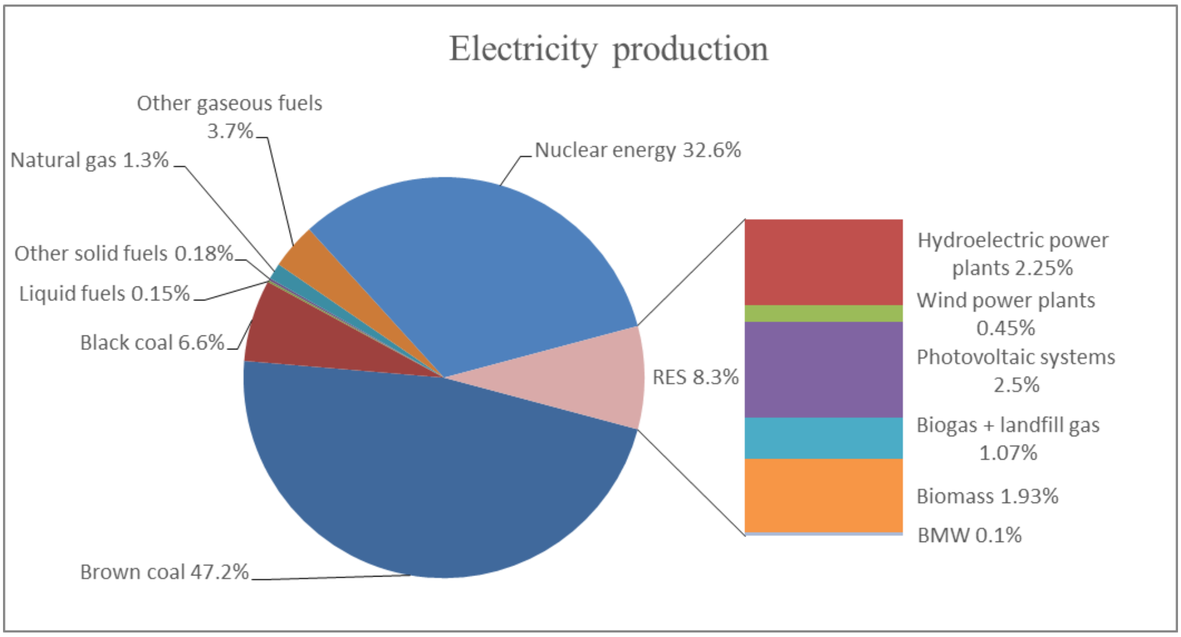

Figure 1. Electricity production in the Czech Republic in 2011 (Source: MIT, 2011)

According to ERO statistics gross domestic electricity consumption from RES in the Czech Republic has been steadily increasing in last years. It made up 11.43% of domestic gross consumption of electricity in 2012. In comparison with year 2004 the share in gross domestic consumption has increased by more than 7.5%. In 2010 the share counted for 8.3%, so the target of EU Directive 2001/77/EC has been reached (ERO, 2013).

2.1.3 Biomass

Since photovoltaic systems and hydroelectric power plants are of limited use in the Czech Republic, biomass has the greatest technically exploitable potential for both electricity and heat production from RES in Czech conditions. Furthermore demand for biomass utilization in transport as part of fuels and in industry as a renewable raw material has been raising in last years (MIT, 2009).

In general, biomass is all matter of organic origin. The Directive 2009/28/EC of European Commission defines biomass as: *"the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste".*

In accordance with Regulation No. 482/2005 Coll. of the Ministry of Agriculture (MOA) biomass is divided in a simplified way into 3 main groups with respect to types, utilization modes and parameters of biomass. Types of biomass, its source, conversion process for energy production and final products are listed in Table 1 below.

Table 1. Types of biomass, its source and conversion process for energy production

Biomass type	Source	Process	Product
Agricultural biomass	Energy crops, cereals, permanent grass growth, energy woody plants	Anaerobic digestion, fermentation, transesterification, combustion, gasification	Biogas, bioethanol, biodiesel, syngas
Forest biomass	Fire wood, sawdust, shavings, wood chips and cuttings and residues from wood - processing industry	Combustion, gasification	Syngas
Residual biomass	Residues from paper and cellulose, animal, industry, biodegradable waste	Anaerobic digestion, fermentation, combustion, gasification	Biogas, bioethanol, biodiesel, syngas

Source: MOA, 2009; Prade, 2011

Agricultural biomass possesses several advantages such as well – known and constant composition in comparison with residual biomass which may strongly vary in its composition as well as level of contamination. On the other side, costs of agricultural biomass are much higher (Prade, 2011).
Biomass may serve for various purposes such as production of solid fuels (chips, pellets, briquettes and logs), liquid fuels (methanol, ethanol, and diesel), gaseous fuels (synthesis gas, biogas, hydrogen) and heat (Sims et al., 2006).

Use of biofuels made out of biomass is quite traditional in the Czech Republic, particularly in heat production. Following types of biomass are used for electricity and heat production (MIT, 2011):

- Wood chips, sawdust, bark, wood waste
- Vegetal substances (non – agglomerated)
- Pellets and briquettes
- Cellulosic ethanol
- Liquid biofuels

Electricity production from biomass has experienced the sharp rise in the last decade. It has increased more than 3 times in comparison with 2004. The most used types of biomass for electricity production in 2011 were wood fuels (48.68%), cellulosic ethanol (31.24%) and pellets and briquettes (12.94%) (MIT, 2012).
In last decade household consumption of briquettes for heating has raised, however, most of them were made of wood. Production and consumption of vegetable briquettes is not significant in the Czech Republic. Herbaceous briquettes used to be made of sorrel or industrial hemp, nowadays they are rather manufactured from straws of cereals and oil crops. In larger scale vegetable briquettes have been offered in retail trade from 2009. Since that some producers have terminated the production because of the high cost of raw material and low interest of customers (MIT, 2013).

2.1.4 Energy crops

Energy crops are annual or perennial crops grown specifically for direct combustion or other energetic use (El Bassam, 2010). Energy crops can be divided by many criteria. The basic division is into herbaceous plants and woody plants. In conditions of the Czech Republic, following crops are suitable for cultivation (Petříková et al., 2006):

- Annual crops: Sweet sorghum (*Sorghum vulgare* Pers.), Hemp (*Cannabis Sativa*)
- Perennial crops: *Miscanthus × giganteus*, *Miscanthus sinensis*, Giant knot weed (*Reynoutria*), Giant reed (*Arundo Donax*), Safflower (*Carthamnus tinctorius*), Sorrel *(Rumex patientia L.and Rumex tianschanicus A. LOS)*, Amaranth *(Amaranthus)*
- Fast woody plants: Willow (*Salix*), Poplar (*Populus*).

According to Sladký et al. (2002) specific requirements on energy crops are high yield of biomass with possibility of harvesting with common agricultural or forestry machines, resistance to diseases (at least as cereals), richness in leaves to ensure high level of photosynthesis (for solid biofuels), low requirements on water use and fertilizers, perspective economic yields (55 $t{\cdot}ha^{-1}$ for C_4 plants, 33 $t{\cdot}ha^{-1}$ for C_3 plants), capability of genetic modifications to ensure requirements described above and elimination of unsuitable characteristics. Kludze et al. (2011) highlighted the characteristics such as high lignin and cellulose contents, positive environmental impact, ability to recycle and store nutrients, and low requirements for fertilizers and agrochemicals. Strašil and Šimon (2009) presented requirements such as fast growth, cultivation of above ground biomass (not crops with tubers) to ensure low harvesting costs and protect soil, low content of chemical elements (especially nitrogen), resistance to droughts among others. Slejška (2010) mentioned ability to adaptation in different climate conditions.

Due to the shortage of forest biomass and limited waste biomass, energy crops are likely to become more significant in energy production in the future (Rehman et al., 2013).

Energy production from energy crops brings many positives compared to traditional sources. First of all, energy is almost “carbon neutral”, meaning that CO_2 emitted during the biomass combustion is absorbed in the photosynthesis process and applied to plant growth in the vegetation process (Sims et al., 2006; Mankowski and Kolodziej, 2008).

Moreover, biomass contributes to the stability in electricity and heat production in rural areas and thus increases the independency on energy supplies. It supports development of rural areas as the main suppliers of energy from biomass and consequently contributes to increase of employment rate in these areas. Biomass biofuels may also decrease costs for heating in households. Stolarski et al. (2010) evaluated economic costs of heating a house in Poland with wood briquettes. Results were compared to other fuels such as oak pellets, willow chips, hard coal, natural gas and heating oil. Calculation excluded costs of depreciation, electric power and servicing of heating systems. The results indicated that costs of thermal energy production from biomass fuels were lower compared to fossil fuels; heat from sawdust briquettes was about 50% cheaper than heat from natural gas, 3.5 times cheaper than that from heating oil and 15 – 16% cheaper than using hard coal.
On the other hand biomass is utilisable mainly locally since the growing is effective only within 50 km from its location of use. Furthermore, first generation biofuels are made from food commodities such as corn, wheat, cereals, sugar cane and sugar beet and may come into contradiction with some food – safety regulations (Rehman et al., 2013). Thus, cultivation of non - food crops was recommended, since it does not threat food production but rather complement it. Various energy crops are annual plants and represent costs for cultivation on yearly basis (Prade, 2011; Finnan and Styles, 2013).

2.2 Industrial hemp

2.2.1 Botanical description

Hemp (*Cannabis*) is C_3 annual herbaceous plant (dioecious or monoecious) which is classified into the family of *Cannabaceae*. Three main types of *Cannabis* exist:

- *C. indica* possess high amount of psychoactive matter d-9-tetrahydrocannabinol (THC) and therefore cultivation of this variety is strictly prohibited in most countries of the world;
- *C. ruderalis* is a weedy variety possessing almost any significant intoxicating effect which grows freely on rubble site and rubbish dumps (Široká, 2009);
- *C. sativa* is commonly referred as industrial hemp (hereinafter hemp) which is primarily grown as an agricultural crop. It is cultivated for its fibre and seeds (Johnson, 2013). Types of *Cannabis* are shown on Figure 1 in Annex.

Cannabis sativa L. is divided into 4 groups based on its geographical location (see Table 2).

Table 2. Division of *Cannabis sativa* L. based on geographical group

Geographical group	Vegetation period (days)	Stalks	Leaves	Seeds	Location	Yield
Northern *(borealis)*	60 - 80	up to 0.8 m, poor in branches	small, 3 - 5 leaflets	small	north of Russia, Finland	low in fibre and seeds
Russian (*medioru-thenica)*	90 - 120	up to 2 m, poor/rich in branches	medium size and wide, 3 - 9 leaflets	medium sized	Central and Eastern Europe	high in fibre, low in seeds
Southern (*australis*)	120 - 165	2 - 4 m, poor in branches	large, 9 - 13 leaflets	large, round shaped	warmer areas	medium in fibre, low in seeds
Hashish (*asiatica*)	130 - 150	1.1 - 1.15 m, rich in branches	very large and wide, 9 - 13 leaflets	small, oval shaped	India, Afghanistan, North Africa	low in fibre, medium in seeds

Source: Šnobl et al., 2004

Hemp roots grow 30 – 40 cm deep in soil, in very deep soils they might reach up to 2 m in depth. Hemp is characterized by long, thin flowers and palmate spiky leaves having 3 – 13 leaflets (Rehman et al, 2013). It grows from 2 – 6 meters in high yielding thin but very firm stalks. In the first growing phase the stalk is soft and fleshy, in later phase it becomes woody (Honzík et al., 2012). Hemp stalk consists of several layers (Hollebane, 1999):

1. Hollow core

2. Pith (thick woody tissue - hurds)

3. Cambium (growth area; produces hurds on inside and bast and bark on outside)

4. Parenchyma (short cells – chlorophyll + long cells – bast fibres)

5. Cortex (walled cells - chlorophyll)

6. Epidermis (protective layer of plant cells)

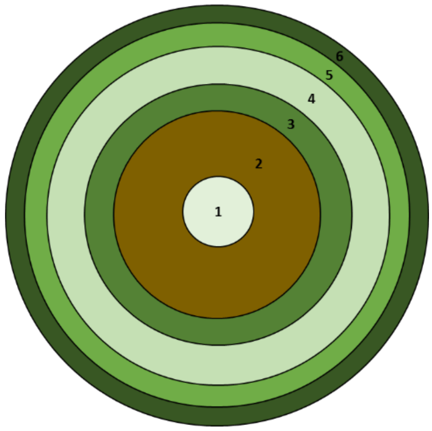

Figure 2. A cross section of hemp stalk (Source: Hollebane, 1999)

Hemp stem can be separated into two parts – bast fibre and hurds. Total fibre content varies about 25 – 35% of stalk depending on grown variety. The fibre contains high amount of cellulose (57 – 77%) and low lignin content (5 – 9%). On the contrary, hurds contain less cellulose (40 – 48%) and higher amount of lignin (21 – 24%) (Rehman et al., 2013). Based on Hollebane (1999) hemp fibre is divided into 3 groups:

- primary bast fibre (long and low in lignin),
- secondary bast fibre (medium sized and high in lignin) and
- libriform (short and high in lignin).

2.2.2 Use of hemp

Hemp is used in wide range of products. It is estimated that they are more than 25,000 products made out of hemp in global market (Johnson, 2013). Great advantage of hemp is its versatile use since whole plant can be processed without almost any waste (Široká, 2007).

Hemp seeds are mostly processed in food industry, cosmetic and pharmaceutical industry (Jankauskienė and Gruzdevienė, 2012). Hemp fibre is used for production of fabrics and textiles, construction and insulation materials, carpeting, yarns and spun fibres, paper, etc. According to study carried out by Benfratello et al. (2013) hemp showed to be suitable both for production of insulation panels (hemp fibres alone) and as a construction material (hemp basts and concrete mix) since it showed satisfactory insulation properties and mechanical resistance.

Long fibres are the most valuable part of the hemp plant, accounting for approximately one third of the total above – biomass (Prade, 2011). When processing, fibres are separated from the stalk through retting and scotching (Gandolfi et al., 2013). The rest of hemp plant consists of woody material - hurds that are considered as by – products. (Mankowski and Kolodziej, 2008). Currently they are mostly used as an animal bedding (around 95%), or they are added to lightweight concrete or used in garden mulch (Gandolfi et al., 2013). Hemp hurds are also marginally used for production of solid biofuels - briquettes and pellets (see Figure 2 in Annex) (Široká, 2009).

2.2.2.1 Hemp as a source of energy

Hemp biomass was used for energy production for hundreds of years, mostly for lightening from hemp seed oil. In recent years hemp has been also suggested as a potential source of bioenergy, such as biogas, bioethanol, biodiesel and as a solid biofuel (Mankowski and Kolodziej, 2008; Prade, 2011; Rehman et al., 2013) (see Table 3). Prade (2011) investigated hemp energy potential, both for biogas and solid biofuel production. He stated that its biomass energy yield per hectare was equal or even superior to that of most energy crops grown in northern European countries and thus it could compete with wood and willow for solid biofuel production and with maize and sugar beet for biogas production. Honzík et al. (2012) compared hemp methane yield with maize grown for biogas production and results revealed that maize surpassed hemp by almost 25%. Hemp was studied for potential use for production of biodiesel and it was found that oil content of hemp seeds was very similar to crops such as soybean, cottonseeds and olives grown in United States, China, Brazil and other countries (Rehman et al., 2013). Hemp could also take a leading role in bioethanol production due to its high cellulosic and relatively low lignin content (Barta, 2010; Tutt et al., 2011; Panoutsou, 2012). Bakken (2009) stated that from 1 tonne of hemp biomass was possible to obtain 250 litres of ethanol.

Table 3. Potential pathways of hemp use

Part of plant	Process	Product	Use
Whole plant	Anaerobic digestion	Biogas - digestate	Vehicle fuel, heat and/or power
Whole plant	Sacharification + fermentation	Bioethanol	Vehicle fuel, heat and/or power
Whole plant	Mechanical processing	Briquettes/pellets	Heat and/or power
Seeds	Processing	Oil	Food, cosmetics
	Transesterification	Biodiesel	Vehicle fuel, heat and/or power
Stems	Decortication	Fibres	Textiles, building materials, fibre boards
		Hurds	Animal bedding, lightweight composite, briquettes and pellets

Source: Prade, 2011

Furthermore, hemp can be used for production of solid biofuels. Hemp can be either burned directly in big boilers houses and heating plants or process into briquettes and pellets for household use. According to Olt and Laur (2009) compressed biomass possesses following advantages over the unprocessed biomass: material is cheaper to transport and store due to high bulk density and low moisture; material is preserved for a long time because dry fuel does not decompose biologically due to absence of fungus and microorganisms; equable moisture and size of briquettes allow to regulate the burning regime more precisely and thus ensure higher efficiency.

Several researchers studied suitability of hemp as a solid biofuels. Table 4 below presents combustion characteristics of hemp compared to other materials used for briquette production. From results it is evident that hemp possesses the lowest gross calorific value (GCV) from selected crops and also high ash content in DM. On the other side moisture of hemp briquettes was significantly low, comparable only to sunflower. Content of sulphur and chlorine was similar to other materials (Olt and Laur, 2009; Alaru et al., 2011). Havrland et al. (2013) also found that hemp GCV and maximum energy yield were the worst from energy crops selected as a suitable for Czech Republic (miscanthus, giant knotweed, giant reed and sweet sorghum). On the contrary Mankowski and Kolodziej (2008) stated that GCV of hemp was approximately 18 $MJ \cdot kg^{-1}$ which is comparable to the wood briquettes with GCV around 17 MJ·kg^{-1}. In their experiment hemp hurds were mixed with raw vegetable materials in order to improve its heat of combustion without an increase of gas emissions. As the most suitable crop to be added showed to be rape meal which increased GCV to 19.6 MJ·kg^{-1} and furthermore, decreased emissions of CO and CO_2. Quality of hemp briquettes depends on lignin content since it affects the briquettes compactness and durability. Alaru et al. (2011) ascertained that dioecious hemp showed to contain more lignin than monoecious hemp and thus was more suitable for briquetting.

Table 4. Different materials combustion parameters

Material	Moisture (%)	Ash (% in DM)	GCV (MJ·kg^{-1} in DM)	GCV (MJ·kg^{-1}, actual)	Sulphur (% in DM)	Chlorine (% in DM)
Hemp (dioecious)	6.5	5.8	16.67	15.35	0.05	0.36
Hemp (monoecious)	6.8	6.85	16.66	15.35	0.05	0.29
Meadow and rye straw	15.4	3.7	19.36	14.48	0.12	0.33
Rape and rye straw	13.5	4.6	18.7	14.66	0.14	0.42
Rye straw	11.4	3.6	19.04	15.37	0.08	0.29
Sunflower	6.05	9	17.22	15.85	0.05	0.04
Wheat straw	11.4	4.7	19.1	15.43	0.12	0.36

Source: Olt and Laur, 2009; Alaru et al., 2011

2.2.3 Hemp around the world

Hemp had been originally cultivated in countries of Central and Southern Asia like China, Iran, Pakistan, India and Russia for more than 5,000 years. Hemp was grown in some European countries until the second half of 20th century (Rehman et al, 2013). However, in 1961 hemp cultivation was prohibited worldwide by the United Nations because of the presence of phyto – chemical drug component THC. In 1990s the interest in natural fibres increased and hemp has become again legal in EU and Canada. Cultivation of industrial hemp was first approved for fibre production during 1990s and later for energy production in 2003. In some countries such as the United States or Norway, the prohibition still remains. Since 2007, EU has permitted to cultivate some varieties of hemp with maximum THC content 0.2%. Nowadays, 54 varieties of industrial hemp are allowed to cultivate by European Commission. Permitted varieties can be cultivated under the license (Prade, 2011). In present the most significant cultivator of hemp for fibre production is China. In Canada hemp is mainly grown for seeds used for food and cosmetic purposes.

Before the collapse of Soviet Union, cultivated areas with hemp plant in Eastern Europe amounted to 100,000 ha. Romania, Hungary, Bulgaria, Poland and the Czech Republic were of special importance in hemp cultivation (Karus, 2005). Only a small share has been left nowadays. According to reports, the EU made 29% of world hemp production in 2010 representing approximately 15,000 ha of cultivated land (Finnan and Styles, 2013). European countries mainly cultivate hemp for industrial purposes such as fibre and biofuel production or production of building materials. Prade (2011) mentioned that in Sweden hemp is mainly grown for briquettes and pellets production and sold on local market for domestic heating. The biggest European producer is France which accounts for 78% of hemp production in EU. Among other important cultivators belong Germany, Great Britain, Spain, Ireland, Finland, Poland and Latvia (MOA, 2010; Prade, 2011; Rehman et al., 2013).

2.2.4 Hemp in the Czech Republic

In the Czech Republic hemp is mostly cultivated for its fibre and seeds. Table 5 below shows cultivated area of hemp in 2004 – 2012. The highest growth of cultivated areas took place in years 2006 - 2007. Due to the economic crisis the price of stem felt down which resulted in sharp decrease of cultivated areas by 55% in 2008 and 80% in 2009 compared to 2006. Cultivation for energy purposes has been rather marginal until now. Cultivated area of land for energy reached its maximum in 2004, in following years decreased by almost 50%. Since 2008 there have not been any data available about hemp cultivation for production of bioenergy (MOA, 2010; MOA, 2013).

Table 5. Cultivated area of hemp in Czech Republic, 2004 – 2012

	Unit	2004	2005	2006	2007	2008	2009	2010	2011	2012
Total cultivated area	ha	307	156	1,155	1,538	518	228	130	267	279
Cultivated area for energy	ha	40	21		24					

Source: MOA, 2010; MOA, 2013

In the Czech Republic hemp cultivation is limited by Act No. 167/1998 "About narcotic substances", which regulates the cultivation of poppy and hemp. § 24a of the Act prohibits varieties of hemp (*Cannabis*) that can contain more than 0.3% of THC substances. § 29 sets the obligation to cultivator to report the cultivation of cannabis over an area of 100 m^2 to the customs office according to the place of cultivation. Producer must announce area of cultivated land, including grown variety and exact position of fields. In the harvesting period information about yield of stem and seeds must be provided (MOA, 2010).

The most cultivated hemp variety in the Czech Republic is Bialobrzeskie. Other varieties suitable for our climatic conditions are Ferimon and USO – 31 (Honzík et al., 2012). Table 6 below shows average stem yield (both retted and unretted), seeds yield and fibre content in stem.

Table 6. Yields of stem, seeds and fibre of hemp varieties

	Unit	Bialobrzeskie	Ferimon	USO - 31
Unretted stem	t/ha	9.29	7.49	8.08
Retted stem	t/ha	7.66	5.86	6.5
Seeds	t/ha	0.92	1.23	1.34
Fibre	t/ha	2.46	1.62	1.94
Fibre content	%	31.5	27.4	29.2

Source: Honzík et al., 2012

Hemp is mostly grown for combined production so farmers receive revenue both from stem and seeds. Price of stem seems quite stable over the years counting on average for 3,500 $CZK \cdot ha^{-1}$. Price of seeds has been steadily increasing over last years. In 2010 price of seeds accounted for 20 – 25 CZK·kg^{-1} and nowadays varies between 25 – 40 CZK·kg^{-1} depending on quality of seeds (Říha, 2010, 2014). The biggest obstacle of hemp cultivation in conditions of the Czech Republic is caused by lack of processing technologies. Yet in last decade several processing factories operated in the Czech Republic: Lenka Kacov with capacity of 19,000 t of hemp stem, Benedikt - Hevr with capacity of 3,852 t, factory in Hodonin in South Moravia and Bukovice in region Teplicko with expected capacity 3,000 t per year (Široká, 2007; MOA, 2010). Due to the economic crisis farmers left hemp cultivation which subsequently caused shortage of material in processing factories and they were closed. Since farmers cannot manufacture their production in local conditions, they mostly sell it abroad. According to European Industrial Hemp Association (2011) several processing factories operate in Europe, the nearest are situated in Germany (Badische) and Netherland (HempFlax, Hennepverwer). Due to high transportation costs economy of production is influenced considerably. Furthermore, producers are limited by capacity of processing factories which in most cases have contract with local suppliers (Kotyza, 2012).

Since processing technologies are of limited availability for Czech producers, one option could be getting own processing factory. It can be bought from abroad, however, the initial costs are high and require long term commitment for hemp production to become profitable. Based on Říha (2012) large capacity processing line costs approximately 120 million CZK. It could be also made by farmer himself. This is the case of farmer Václav Lapka from Rakovnik who has built his own processing line from old machinery for flax processing. He stated that there was still space for improvement since the line was labour demanding and processing capacity is quite low (1t of stem per day). Lapka makes use of whole plant; he sells both seeds and long fibres and from residual hurds presses briquettes for own consumption and neighbourhood sales. Nowadays, he is the only hemp briquettes producer in the Czech Republic. Other option might be processing of whole plant (including long fibres and leaves) into briquettes or pellets. This option will be discussed in detail in following chapter.

2.2.5 Production of hemp briquettes

2.2.5.1 Hemp cultivation

Hemp is high yielding crop which does not need any special condition to grow, therefore by some experts it is considered to be ideal source of biomass. Široká (2009) stated that in vegetative period of 100 – 120 days on 1 ha grows at least 2.5 times more of hemp woody biomass than on the same area of forest which grows for decades. Hemp does not require almost any herbicides, pesticides or fungicides and it is drought and micro bacterial resistant. In addition, inputs of fertilizers are relatively low in comparison with other crops (Rehman et al., 2013). Honzík et al. (2012) pointed out that hemp could be grown on lands which are not suitable for cultivation of other crops (e.g. sloping land or lands threatened by erosion, contaminated soil, etc.) so the need for use of arable land is reduced. Furthermore, due to its deep rooting system it can serve as a break crop from cereals and other food crops as it maintains soil fertility and can improve yields of subsequent crops (Finnan and Styles, 2013). Hemp does not require any special previous crop; recommended crops are cereals, root crops and clover crops, legume plants and alfalfa (Prade, 2011).

For successful hemp cultivation following requirements have to be met. It is desirable to have well – prepared seedbed with no perennial weeds or debris (Slejška, 2010). In autumn soil is prepared by ploughing 25 – 30 cm in depth. Based on Weger et al. (2012) it is recommended to apply 60 to 100 $kg{\cdot}ha^{-1}$ of nitrogen (N) and complete with 30 - 60 $kg{\cdot}ha^{-1}$ of potassium (K). If hemp is cultivated for seed production, it is advisable to add phosphorus (P) in amount of 30 - 60 $kg{\cdot}ha^{-1}$. In autumn it is also possible to fertilize with 30 – 40 $t{\cdot}ha^{-1}$ of manure or compost (AGC, 2011). Hemp is sown in rows to a depth of 3 – 4 cm by drilling with a drill grain. The distance of rows depends on its post harvesting use. For seed production wide rows of 50 – 70 cm are recommended since hemp plants have enough space to branch and to yield higher amount of seeds (Šnobl, 2004). Hemp grown for fibre production is sown into narrow rows of 12 – 15 cm and of 20 – 25 cm when grown for biomass (Široká, 2007). Seed rate is also vary by focus of production: for fibre production the high density of seed (80 – 120 $kg{\cdot}ha^{-1}$) is required and for seeds production lower plant density (15 – 30 $kg{\cdot}ha^{-1}$) is recommended. When hemp is grown for energy purposes seeding rate should range between 40 – 60 kg·ha^{-1} (Šnobl, 2004). Sowing is done during period of April and May; however it can be also sown later depending on cultivation area and weather conditions (Weger et al., 2012). After sowing the soil has to be rolled by light rollers. With average temperatures 8 - 10° C hemp germinates after 8 – 12 days after sowing. Spacing takes place 4 – 6 weeks after sowing (AgroConsult – AGC, 2011). Vegetative period lasts 100 – 120 days with biomass yield of 10 – 15 t·ha^{-1} (Široká, 2009).

2.2.5.2 Hemp harvesting

Type of hemp harvesting process depends on purpose of cultivation (production of fibre, seeds or combined use). Majority of studies regarding hemp mowing concludes that is suitable to shorten stems (which come up to 3.5 m) to 60 cm long pieces. Besides of preventing entangling into pressing chamber, it decreases drying time, facilitate spacing, moulding and further processing. In conditions of the Czech Republic the most used is traditional cutter bar mower. In the Czech Republic hemp is commonly harvested in late September or early October. The cut material is left on field for some days in order to decrease its moisture content (MC) which is about 55 – 74% after harvest. It is recommended to turn and loosen mown hemp stem at least once to support drying process. When hemp gets dry enough it is put into swaths to be prepared for moulding (Honzík, 2007). For bale fixing string or net is used depending on type of moulding machine. Široká (2007) conducted the experiment testing various balers and stated that the most suitable was the baler with fixed chamber producing round bales; other machines making angular bales were totally unfit. In case of unfavourable weather conditions hemp has to be stored in warehouses to dry out naturally (Prade, 2011). MC can be decreased also in drying machines; however, this method may result costly for the producer due to high acquisition costs of dryer and high energy consumption. In the spring harvest (March – April) hemp biomass MC is 15 – 20% so it is dried enough to be further processed directly.

Recommended harvesting time of hemp biomass varies based on its post harvesting use. Hemp seeds have to be harvested in autumn. Stalks for fibre production are usually mowed in autumn as well, however, it can be left on the field till the March (Široká, 2007). When hemp is cultivated for energy purposes, spring harvest is suggested for its use as solid biofuels (Prade, 2012) and autumn harvesting is preferred for biogas production (Rehman et al, 2013).

2.2.5.3 Processing of hemp into briquettes

Hemp briquettes are made by compressing of biomass. Based on Plíštil (2004), following requirements on briquetting material must be fulfil: purity of biomass (no dirt), maximum fraction of 20 mm and MC below 20%. Hemp briquettes are produced in shape of cylinder, prism or hexahedron with diameter from 40 to 100 mm and length of 300 mm (MIT, 2013). They are manufactured in special briquetting presses with no chemical additives (Stupavský and Holý, 2010). The most common presses are piston presses and screw presses. Piston presses can be either mechanical or hydraulic with the piston as a main working body. Infinitely long briquettes in cylindrical shape are produced which are then cut by saw – cut at press output. Output efficiency is 0.05 – 0.5 $t \cdot h^{-1}$ for hydraulic piston presses and about 1 $t \cdot h^{-1}$ for mechanical piston presses. The main working body of screw presses (extruders) has a shape of a screw which rotates in conical chamber. Briquettes produced in screw presses are usually of rectangular or hexagonal shape (Andert et al., 2006). Although the density of briquettes produced by piston presses is lower in comparison with extruders, they are more economic efficient with lower specific energy consumption. According to research of Muntean at al. (2012) the piston presses with performance from 50 up to 400 $kg \cdot h^{-1}$ has specific energy consumption 1.15 – 1.85 times lower (70 – 108 $kWh \cdot t^{-1}$) than screw presses (132 – 180 $kWh \cdot t^{-1}$). Also the life period is significantly higher than that of extruders (2,000 hours and 50 hours) (Andert et al., 2006). Based on Olt and Laur (2009) following processes are involved in the briquetting:

1. pressure is applied to the briquetting material;
2. temperature goes up because of the friction between the particles of briquetting materials and the friction between the press and the briquetting material;
3. as a result of the high temperature and pressure during the process, the wooden plants cellular structure breaks;

4. because of the heat the lignin contained in the material softens and glues the particles of the material together.

In EU countries producers of briquettes must fulfil various requirements regarding physical and chemical properties of briquettes. In the Czech Republic quality of solid biofuels is ensured by following standards (Technical norms ČSN, 2010 – 2011):

- ČSN EN 14588: Solid biofuels – Terminology, definitions and descriptions (in effect 1. 7. 2011)
- ČSN EN 14961-1: Solid biofuels - Fuel specifications and classes - Part 1: General requirements (in effect 1. 7. 2010)
- ČSN EN 15234 -1: Solid biofuels – Fuel quality assurance – Part 1: General requirements (in effect 1. 10. 2011)
- ČSN EN 14775: Solid biofuels – Determination of ash content (in effect 2010).

Based on Ruman and Klvanová (2008), briquettes produced from 1 ha of hemp may satisfy demand for heat production in family house for one heating season in the Czech Republic. Hemp briquettes can be burned in any kind of boilers, in fireplaces, tiled stoves or boilers for central heating (Hutla, 2010). Residual ash produced during combustion can be used as a fertilizer as it contains many minerals (phosphorus, potassium, calcium, magnesium etc.) and important trace elements. (Stupavský and Holý, 2010).

2.2.6 Economy of hemp production

For the economy of hemp briquettes production following factors are of crucial importance: biomass yield (BY), cultivation costs, costs for processing into solid biofuels, available grants and subsidies (Kára et al., 2005) and selling price of final product (Havlíčková et al., 2007).

Many researchers agreed that costs of any agricultural production are affected by amount of BY. Generally higher yield makes the production more profitable. Hemp BY varies depending on climate conditions, weather conditions (precipitation and temperature), soil quality, variety of hemp, sawing date, sowing rate, time of harvesting, amount of fertilizers, harvesting date etc. (Heneman and Červinka, 2007; Prade, 2011; Havrland et al, 2013; Kolaříková et al., 2013).

Although hemp can be grown in diverse environmental conditions from northern to southern Europe (Panputsou, 2012), weather conditions have a strong effect on plant's morphological characteristics such as plant density and stem length and diameter (Rehman et al, 2013). Hemp is suitable for cultivation in the temperate zone, with average annual temperature 8 – 10° C. Based on research of Cosentino et al. (2013) the optimal temperatures varied around 24° C, however, temperatures above 27° C negatively affected BY for studied varieties in Italy. Hemp can be grown also at lower yields on poorer soils in colder areas up to altitudes of 450 m. In first phase of growth hemp requires enough irrigation, in later phases is able to resist droughts (Weger et al., 2012). Sladký (2004) recommended the sum of precipitation to be at least 500 mm for growing season.

Quality of soil influences the ability of hemp to yield high amount of biomass. The best soils for hemp cultivation are medium – heavy soils, especially silty loam, clay loam, and silty clays (Prade, 2011). The soil should be deep enough and well supplied with nutrients, primarily N and K. According to statistics soils with very low content of P and K make 25% and 12% in the Czech Republic, respectively (AGC, 2011). Hemp does not grow in acidic soil; if maximum pH of soil exceeds 5, it is recommended to apply limestone. Hemp can be also grown on fertilized marshlands, ploughed up meadows or dried ponds. (Weger et al., 2012).

BY is influenced by sowing date. Based on Rice (2008) hemp yield decreased with later sowing date (see Table 7). This was confirmed by Slejška (2010) and Weber et al. (2012) who recommend earlier date of sowing to ensure higher yields.

Table 7. Comparison of hemp yield according to sowing date, cultivated variety Fedora 19

Sowing date	Unit	End of March	Mid April	Beg. of May	Mid May
Yields	t/ha	13.9	11.1	9.4	7.5

Source: Rice, 2008

BY might be also influenced by amount of applied fertilizers. Slejška (2010) stated that BY increased with higher amount of fertilizers. On the other side, Prade (2011) found that hemp showed no significant increase in yield due to N fertilization. Finnan and Burke (2013) reported that hemp yield was steady when fertilizing rate was 90 kg·ha^{-1} with no response in increased yield after 150 kg·ha^{-1}. Honzík et al. (2012) proved that 60 kg·ha^{-1} of N increased BY by 15% and 120 kg·ha^{-1} by 25.3% in comparison with scenario where no fertilizers were applied (see Table 8). Based on research of Finnan and Burke (2013), no relationship was found between BY and K fertilization rate.

Table 8. Comparison of hemp yield according to amount of fertilizers and station in 2001 - 2004, cultivated variety Bialobrzeskie

Location	Unit	0 kg of N	60 kg of N	120 kg of N
Lukavec	t/ha	5.26	7.75	7.95
Ruzyně	t/ha	9.94	10.15	11.43
Average	t/ha	7.93	9.12	9.94

Source: Honzík et al., 2012

BY varies considerably based on harvesting season. Yields are generally higher in autumn harvest period because during the winter hemp plants losse leaves (Rice, 2008). Majority of authors concluded that spring harvest was preferable for energy purposes because MC was lower and thus was more suitable for direct combustion (Weger et al., 2012). Prade (2011) mentioned that hemp biomass MC decreased from circa 80% in July to around 30% in March and April. Honzík et al. (2012) demonstrated that beside of lower MC spring harvests brought advantages such as low content of nutrients which was favourable for later combustion and emission production (see Table 9). This was confirmed by Prade (2012) who stated that chemical properties such as alkali, chlorine and ash content and ash melting temperature were improved when harvested in spring.

Table 9. Content of chemical components in dry matter (%)

	N	P	K	Ca	Mg
Autumn harvest (%)	0.66	0.06	0.58	0.85	0.09
Spring harvest (%)	0.41	0.05	0.3	0.68	0.06

Source: Honzík et al., 2012

Total costs of production depend on actual prices of inputs (diesel, labour, fertilizers, etc.) To be economically viable a plant must have low cultivation and harvest costs and thus be cost competitive with other energy crops. Several studies have been conducted regarding this issue until now. Jevič et al. (2008) calculated production costs of several energy crops in the Czech Republic and the study denoted that the highest production cost per tonne required miscanthus due to high material costs which accounted for 75% of total costs. Miscanthus was followed by sorghum and hemp, respectively but surpassed by sorrel, knotweed, reed and triticale. Panoutsou (2012) evaluated economic potential of various crop across EU countries. Results showed that apart from marigold, hemp (Poland - PL, Netherlands) belonged to the most expensive crops from selected plants together with kenaf (Ireland – I, Greece – GR), flax (PL) and maize (GR) with cultivation cost around 1,500 €, followed by rapeseed (France, Denmark), sunflower, potatoe (GR, DE) and shorghum (I, GR) with costs around 1,000 €. Kovářová et al. (2006) evaluated production costs of hemp, miscanthus, reed canarygrass and triticale among others and concluded that hemp had the highest production costs per tonne from studied energy crops, followed by miscanthus, reed canarygrass and triticale. Irish researchers Finnan and Styles (2013) have conducted study with objective to compare economic costs of hemp grown for bioenergy with two perennial crops, miscanthus and short rotation coppice willow by applying Net Present Value (NPV) economic assessment. Results showed that hemp had higher annual cost compared to perennial crops because of annual soil preparation, costs of purchased seeds and higher amount of fertilizers. However, in some cases hemp became more profitable than perennial crops. Profit from hemp exceeded the most significantly profit of perennial crops when organic fertilizers were used with no grant available, irrespective of discount rate or biomass price on the market. Mužík and Abraham (2013) focused on economy of briquettes production comparing economic demand of hemp, sorrel, miscanthus, reed canarygrass and triticale in the Czech Republic.

According to results the best crop for briquettes production in terms of economic costs showed to be reed canarygrass and sorrel, meanwhile the highest production costs were those of miscanthus and hemp, respectively. Based on Honzík et al. (2012) production costs of biogas made out of hemp biomass was about 8% more expensive than that of maize.

Even though available data revealed that hemp required generally higher production costs and could not economically compete with perennial crops, hemp in comparison with perennial crops ensured immediate return of investments in planning year, meanwhile perennial crops required high initial investment, commitment of land for at least 20 years and relatively long time before the production becomes profitable (Finnan and Styles, 2013).

2.2.7 Grants and subsidies

Nowadays, following national or EU grants are available for farmers dedicated to crop production in the Czech Republic:

- National grants,
- Direct payments (SAPS) – unified payment for area, paid for 1 ha of land,
- National supplementary grant (TOP – UP) - paid for 1 ha of land,
- Other subsidies – e.g. FLA is compensation subsidy for crop production in less favourable areas which is provided only for grass cultivation on meadows, grazing land and other grass fields.

Hemp producers may ask for both SAPS and TOP - UP subsidies. Based on data of MOA amount of financial support available for farmers varied over time. SAPS was continually increasing on annual average by 12% in years 2005 – 2013. On the other hand, complementary payment TOP UP showed drop by almost 80% in comparison with 2005. Since 2005 hemp cultivation was supported by program I.U – Support of energy crop cultivation but in 2008 it discontinued. Development of subsidies for hemp cultivation is shown in Table 10 below.

Table 10. Development of subsidies for hemp cultivators in the Czech Republic (2005 – 2013)

	Unit	2005	2006	2007	2008	2009	2010	2011	2012	2013
SAPS	CZK/ha	2,111	2,518	2,792	3,073	3,710	4,060	4,687	5,387	6,069
TOP - UP	CZK/ha	2,315	2,240	1,755	1,341	1,184	514		491	
I.U	CZK/ha	2,000	2,000	3,000						

Source: MOA, 2010; MOA, 2014

To receive financial support, producer has to fulfil following requirements: cultivated land must be kept in Evidence of agricultural land (LPIS) based on the Act No. 252/1997 Sb. about agriculture. Farmer must give evidence of certified seeds and provide with written declaration in which promise to announce beginning of hemp flowering (THC is mostly concentrated in flowers). The application must be submitted before 15th May of respective year (MOA, 2010).

2.3 Economic analysis of crop production

The economic analysis of agricultural crops traces all costs of production, harvesting, storage and transportation of plants. All necessary operations (including soil preparation, seeding, fertilization, harvesting and other operations) are broken down into single activities and each of them is analysed in terms of material need, duration and costs. The economic analysis is essential tool for the correct valuation of production processes of agricultural products as it measures all important costs elements. It indicates possible improvements or costs saving opportunities. Moreover, estimation of costs of crop production can be helpful for future decision making and price setting (Soldatos et al., 2009).

2.3.1 Total costs in crop production

2.3.1.1 Classification of costs

Costs are one of the most important characteristics of management of every company. Costs are usually sorted by type (primary and secondary costs), by purpose (direct and indirect costs) or by dependence of costs on changes in production volume (fixed and variable costs), etc. (Poláčková et al., 2010).

2.3.1.2 Calculation of costs

Costs in crop production are most commonly divided to variable and fixed costs. Variable costs comprise of costs of material inputs, mechanized work (amount of labour and fuels) and other direct costs. Fixed costs include land rent and buildings rent (alternatively government land taxes from own land), depreciation of machines and buildings, loan repayments and factory and administrative overheads (Kára et al., 2005; Poláčková et al., 2010).

Material inputs costs consist of a sum of costs of seeds, fertilizers (organic and industrial), pesticides and other direct material (string for bale compressing, bags and wrappers used for expedition, etc.). Mechanized work includes costs of human labour and fuels used within the production. Labour costs cover wages for hired workers including costs for social and health insurance. According to Soldatos et al. (2009) labour costs depend particularly on cultivation characteristics of crop production (e.g. perennial crop do not require such an effort as annual crops, since most of the tasks are not done on annual basis) and type of labour need (rates of skilled labour are much higher than unskilled labour rates). Other directs costs include costs of rented buildings, machinery or services, property insurance (individual insurance for each crops, insurance of buildings), property tax, repair and maintenance of machinery, facilities and buildings, etc.

Land is the crucial factor of crop production. The cost of rented land usually represents the most expensive item. In some cases, costs of land exceed 30% of the total costs. Costs of land may vary depending on various factors such as availability, the type of land (fertile, semi – fertile, meadow, mountainous, irrigated or non – irrigated), etc. (Soldatos et al., 2009).

Depreciation of assets represents the loss of the value during a period (usually year) due to breakage, wear and tear, technological devaluation, etc. Generally, it can be defined as a difference between the value of the asset at the beginning and at the end of the period. To express the depreciation of assets objectively, it is necessary to divide them into single and multi – purpose machinery and buildings. Single – purpose machinery and buildings are tied to corresponding output (e.g. potato planting machine, a potato lifter, a harvesting machine for sugar cane, flax and hemp, storage for potatoes, drying room for hop, greenhouses, etc.) Depreciation of multi – purpose machinery and building comprises of assets which are used for cultivation of more crops (machinery for tillage, machines for fertilizing and spraying, harvesting machines, irrigation devices, etc.) In this case depreciation is included in overhead costs since it is not possible to assign it to particular section of crop production. Costs for depreciation depends primarily on time period which they are used for. In long – term production (more than 6 years) machines are amortized and are not included into costs. On the other side, more frequent and costly reparations are needed. In first 6 years of its life, determinative factor of costs is their annual use. The lowest costs are reached when machines are used in their full capacity.

Factory overheads covers all primary and secondary costs associated with the management and operations in crop production. Administrative overheads include all primary and secondary costs of whole company (Poláčková et al., 2010).

A production may be advantageous when income from production covers variable costs and at least some part of fixed costs. Fixed costs are not directly related to the amount of production, as they must be paid whether or not anything is produced. It is effective to increase the production volume up to maximum, since it decreases fixed costs per production unit (Soldatos et al., 2009; Poláčková et al., 2010).

2.3.2 Total revenue in crop production

Total revenue is sum of revenue from the main product(s) and alternatively revenue from subsidiary product(s) (e.g. revenue from sales of hemp stem and hemp seeds). It may include grants and subsidies (Poláčková et al., 2010).

3 Aims of the Thesis

3.1 Main Aim

- to develop methodology for economic evaluation of hemp grown for energy purposes (production of briquettes)

3.2 Specific Aims

- to determine economic potential of hemp briquettes production in the Czech Republic
- to calculate production costs, revenues and profitability of hemp briquettes comparing two varieties of *Cannabis sativa* L. (Bialobrzeskie, Ferimon) harvested in two seasons (autumn, spring)

4 Material and Methods

4.1 Material

The hemp plant (*Cannabis sativa* L.) of two varieties – polish variety Bialobrzeskie (B) and french variety Ferimon (F) was cultivated on experimental field in 2012 – 2013. The field was located in Suchdol in Prague (50°7’52.372"N, 14°22’11.299"E) with altitude of 285 m over the sea. The plot size was 98 m^2. Row spacing was 12.5 cm, sowing rate 60 $kg \cdot ha^{-1}$ and sowing depth 3 cm. Any pesticides or fertilizers were applied during the cultivation. Hemp was harvested in two periods (October and March) in order to compare biomass yield. Cultivation season for autumn harvest lasted 149 days (14th May to 10th October). The sum of precipitations accounted for 255 mm and the sum of temperatures 2,604.4° C. Cultivation season for spring harvest took 296 days (14th May to 6th March) with precipitations of 464.8 mm and temperatures 3,040.3° C.

4.2 Technological process of hemp briquette production

Economic analysis was calculated for large – scale utilization, therefore technological process of hemp cultivation was adopted from Research Institute of Agricultural Engineering (hereinafter VÚZT). Process included all necessary operations, including fertilizing, tillage, hauling, soil preparation, sowing, mowing, compressing and transport and field treatment after harvest. Furthermore, repeatability of operations per cultivation season was provided as well. For hemp processing into solid biofuel briquetting line was designed. It comprised of separator RSM Turbo 180 of power 8.25 kW suitable for round bales up to 1.8 m of diameter and shredder STM 201HL of power 22 kW. Depending on the material and size of fractions the output of shredder ranges between 500 – 2,000 $kg \cdot h^{-1}$. Based on consultation with an expert from Himel company, output of 1,000 $kg \cdot h^{-1}$ using screen of 12 mm was considered (Himel, 2014). For pressing of the material briquetting device BrikStar 400 of power 32 kW was used (see Figure 5 in Annex). The output of the press is 380 - 420 $kg \cdot h^{-1}$ so the average (400 $kg \cdot h^{-1}$) was assumed in this analysis. The material suitable for briquetting must be of maximum fraction 15 mm with moisture 8 – 15%. Produced briquettes are of cylindrical shape with length 50 – 70 mm and diameter 55 mm (Briklis, 2014). Dry BY was recounted for MC 12% which was optimal for processing into solid biofuel. Loses during the separating and crushing were considered as 10%.

4.3 Economic inputs

Amount of material was determined based on research of VÚZT which recommended 60 kg of seeds per hectare for high biomass yield. For hemp grown for energy purposes it was considered 80 kg of pure nutrient of nitrogen, 45 kg of potassium salt and 30 kg of phosphorus which was equal to 0.3 t of ammonium nitrate, 0.075 t of potassium salt and 0.17 t of superphosphate. Also 4.5 t of farmyard manure and 0.2 t of limestone were considered. Hemp is well – known for its ability to supress weed and to resist droughts, thus no pesticides were taken into account. Hemp biomass was compressed into bales of 250 kg. For 1 bale 0.1 kg of string for fixing was considered. Briquettes were packed into 15 kg polyethylene (PE) bags. Amount of string and PE bags was determined according to Norms for agricultural production elaborated by Institute of agricultural and food information (ÚZPI, 2008). Prices of seeds in 2013 were taken from company Agritec Sumperk which is one of the few sellers of certified seeds in the Czech Republic. Prices of fertilizers were adopted from Statistical Report on Agriculture in 2013 published by CSO. Prices of string and PE bags were assumed based on actual market prices.

Amount of labour and fuels was determined as a sum of labour requirements for component technological operations including hemp cultivation, harvesting and processing into briquettes. Work requirements and fuel consumption were taken from ÚZPI (2008) based on average conditions of production. Market prices of fuels and average salary in agriculture were adopted from CSO in 2013. Average gross wage in agriculture accounted for 19,666 CZK per month of full time job. Average price per litre of diesel for final customer was 36.11 $CZK \cdot l^{-1}$. In compliance with regulation of MOA 40% refund from consumer tax on diesel for farmers was in force for year 2013. Average water consumption and its costs were taken from statistics of agricultural enterprises in 2012 (Farm Accountancy Data Network - FADN, 2013). Property insurance included natural disaster cover which was assumed to be 3% of total gross revenue (AGC, 2011).

To estimate depreciation of machines it was assumed that producer cultivated multiple crops not only hemp, thus machines were used in their full capacity. Machinery was bought in less than four years. Indicative prices of machines and recommended annual use were taken from ÚZPI (2008). From two level prices lower one (for domestic machinery) was chosen. Purchasing prices of press and separator with crusher were discussed with experts from selling companies as well as its recommended annual use. It was supposed that producer cultivated hemp on rented land. Price was taken from database of MOA and represented average price for land in the Czech Republic in 2012. Costs for maintenance and reparation of machines and building as well as taxes and fees were assumed based on statistic of FADN (2013). Producer owned all machines and performed all operations by himself, thus rent of machinery or services was not included. Overhead costs such as loan, leasing, etc. were not taken into consideration.

4.4 Total costs of briquettes production

Total costs (TC) of hemp briquettes production were calculated as a sum of fixed (FC) and variable costs (VC) (see formula 1). VC included costs of seeds (C_s), fertilizers (C_{fe}), string (C_s), PE bags (C_{bg}) human labour (C_l), diesel (C_d), electricity (C_e), water consumption (C_w) and property insurance (C_i). FC comprised of depreciation (D) of machines, land rent (L), reparation of machines and buildings (R) and taxes and fees (T). Prices excluded value added tax (VAT - 21%) and were valid for year 2013. Exchange rate of euro (25.97 CZK) was taken from Czech National Bank and represented average exchange rate in 2013.

$$TC = VC + FC \text{ [CZK·ha}^{-1}\text{]} \qquad (1)$$

$$TC = (C_s + C_{fe} + C_s + C_{bg} + C_l + C_d + C_e + C_w + C_i) + (D + L + R + T) \text{ [CZK·ha}^{-1}\text{]}$$

Since cost of labour per hour paid by employer and price of diesel for farmers in actual conditions were not found in available sources, they were adjusted by following calculations (see formulas 2 and 3). Price of labour per hour was determined from average month salary, increased by social insurance (25%) and health insurance (9%) divided by amount of working hours per month (160 hours). Price per litre of diesel was calculated from average price of fuel in 2013 decreased for refund of consumption tax (40% from 10.90 CZK).

$$P_l = \frac{S * I}{\mathrm{d}} \text{ [CZK·h}^{-1}\text{]} \quad (2)$$

Where: S – month salary (CZK)

I – insurance rate (34%)

d – working hours/month

$$P_d = p_d - (r * T_c) \text{ [CZK·ha}^{-1}\text{]} \quad (3)$$

Where: p_d – selling price of diesel (CZK·l^{-1})

r – refund (40%)

T_c - consumption tax

Table 11. Prices of inputs (CZK·unit^{-1})

Item	Unit	Price per unit (CZK)	Source
Seeds			
Bialobrzeskie	kg	110	Agritec (2013)
Ferimon	kg	155	
Fertilizers			
Limestone (50% CaO)	t	757	Czech Statistical Office (2013)
Superphosphate (18% P_2O_2)	t	9,473	
Potassium salt (60% K_2O)	t	10,360	
Ammonium Nitrate (27.5% N)	t	6,604	
Farmyard manure	t	230	
Fuel			
Diesel	l	24.6	Own calculations (2013)
Electricity	kWh	2.62	Czech Statistical Office (2013)
Human labour	h	165	Own calculations (2013)
Land	ha	1,430	Ministry of Agriculture (2012)
Other material			
String	kg	60	Average market prices (2013)
PE bags	bag	1.5	

Amount of string and PE bags was calculated based on formulas 4 and 5:

$$Q_s = \frac{BY}{wt_b} * q_s \text{ [kg·ha}^{-1}\text{]} \quad (4)$$

Where: BY – biomass yield with MC 12% ($t \cdot ha^{-1}$)

wt_b – weight of bale (t)

q_s – quantity of string for bale (kg)

$$Q_{bg} = \frac{\mathrm{BYc}}{wt_{bg}} \text{ [PE bags·ha}^{-1}\text{]} \quad (5)$$

Where: BY_c –biomass yield with MC 12% including 10% loses during crushing ($t \cdot ha^{-1}$)

wt_{bg} – weight of PE bag with briquettes (t)

Amount of electricity was calculated as electric input power of briquetting line multiplied by number of hours used for processing of 1t of material and amount of hemp biomass produced from 1ha of land (see formula 6).

$$Q_e = q_e * h * BY \text{ [kWh·ha}^{-1}\text{]} \quad (6)$$

Where: q_e – input power ($kW \cdot h^{-1}$)

h – working hours ($h \cdot t^{-1}$)

BY – biomass yield with MC 12% ($t \cdot ha^{-1}$)

C_s – C_e were determined by multiplication of quantity of spent material and human labour (kg, ton, kg, PE bags, hour, l, kW) and price per single unit (CZK) (see formula 7). Prices of inputs are summarized in Table 11.

$$C_x = Q_x * P_x \text{ [CZK·ha}^{-1}\text{]} \quad (7)$$

Where: Q_x – quantity of spent material or labour (kg, ton, hour, l, kW)

P_x – price per unit ($CZK \cdot unit^{-1}$)

Depreciation of machinery was calculated as a purchase price of machine divided by depreciation period of particular machine (6 years for agricultural machinery, 4 years for machines for chemical protection and fertilizing, 4 years for briquetting line) and by recommended annual use and multiplied by hours used for production process (see formula 8).

$$D = \frac{p_m}{(\mathrm{n} * \mathrm{R})} * h \text{ [CZK·ha}^{-1}\text{]} \tag{8}$$

Where: P_m – purchase price of machine (CZK)

n – depreciation period (years)

R – recommended annual use (years)

h – hours of use ($h \cdot ha^{-1}$)

4.5 Total revenue from briquettes production

Total revenue (TR) was determined by the quantity of hemp briquettes produced from 1 ha of land ($t \cdot ha^{-1}$) multiplied by respective price per ton of hemp briquettes ($CZK \cdot t^{-1}$) and decreased by VAT valid for 2013 - 21% (see formula 9). Since the absence of herbaceous briquettes on the Czech market, the price of hemp briquettes was considered the same as that for woody briquettes in 2012 (MIT, 2013).

$$TR = Q_b * P_b * VAT \text{ [CZK·ha}^{-1}\text{]} \tag{9}$$

Where: Q_b – quantity of briquettes ($t \cdot ha^{-1}$)

P_b – price per unit ($CZK \cdot t^{-1}$)

VAT – value added tax (21%)

4.6 Profit from briquettes production

Profit from production was calculated as total revenue minus total costs (see formula 10).

$$Pr = (\mathrm{TR} - \mathrm{TC})\ [\mathrm{CZK \cdot ha^{-1}}] \qquad (10)$$

Where: TC – total costs ($CZK \cdot ha^{-1}$)

TR – total revenue ($CZK \cdot ha^{-1}$)

4.7 Grants and Subsidies

Subsidies SAPS (Single area payment scheme) and TOP - UP were considered in the calculation. Others were not taking into account since they were not stable and change over time. In 2013 SAPS accounted for 6,069 $CZK \cdot ha^{-1}$. The most updated data stated complementary payment TOP - UP to be 491 $CZK \cdot ha^{-1}$ in 2012.

4.8 Rate of return

Rate of return (RR) was calculated both with and without grants and subsidies in order to evaluate the influence of subsidies on the competiveness of hemp briquettes with other solid fuels. RR was determined as a profit (increased by grants and subsidies) divided by TC and multiplied by 100 to obtain percentage result (see formulas 11 and 12).

$$RR = \frac{\mathrm{Pr}}{\mathrm{TC}} * 100\ [\%] \qquad (11)$$

Where: Pr – profit ($CZK \cdot ha^{-1}$)

TC – total costs ($CZK \cdot ha^{-1}$)

$$RR = \frac{(\mathrm{Pr+S})}{\mathrm{TC}} * 100 \text{ [\%]} \quad (12)$$

Where: Pr – profit ($CZK \cdot ha^{-1}$)

S - grants and subsidies ($CZK \cdot ha^{-1}$)

TC –total costs ($CZK \cdot ha^{-1}$)

4.9 Dependence between hemp yield and profitability

Dependence of profitability on amount of BY was tested by econometric techniques in spreadsheet application Excel 2013 using linear regression. Ordinary leased square (OLS) method was applied to data set containing 151 observations of different yields ranging between 5 – 20 $t \cdot ha^{-1}$ and corresponding profitability (%).

In present regression analysis the dependent variable (y) was profitability of hemp briquettes production and independent variable (x) was hemp BY obtained from 1 ha. The relationship between variables *y* and *x* was described using the equation of the line of best fit (see formula 13):

$$y = a + bx \quad (13)$$

where *a* is a constant which was calculated using following formula (see formula 14):

$$a = \bar{y} - b\bar{x} \quad (14)$$

and *b* is a slope coefficient (also known as the regression coefficient). Formula for *b* was as follow (see formula 15):

$$b = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sum(x_i - \bar{x})^2} \quad (15)$$

Coefficient *b* can be interpreted as: For each unit change in *x*, the average change in the mean of *y* is *b*.

To assess the statistical significance of regression coefficient, t- test was used (see formula 16)

$$t_{score} = \frac{b - b_0}{SE_b} \sim T_{n-2} \tag{16}$$

b_0 was set to 0 as the null hypothesis was that *b* was equal 0, SE_b was standard error of *b*. T_{n-2} was student t - distribution with $_{n-2}$ degrees of freedom.

R – square gave the percentage of the deviance in the response variable that could be accounted for by adding the explanatory variable into the model (Moutinho, 2011).

5 Results

5.1 Hemp yield

5.1.1 Autumn harvest

In autumn harvest 22.1 t·ha^{-1} of B was harvested with MC 56.8%. When decreasing MC to 12% biomass yield accounted for 10.91 t·ha^{-1}. Variety F yielded 25.6 t·ha^{-1} of green biomass with MC 59.8% which produced 12.16 t·ha^{-1} of material prepared for further processing (see Table 12).

Table 12. Biomass yield and moisture content in autumn harvest

Autumn harvest,2012				
Bialobrezskie	MC (%)	56.8	12	0
	Yield (t/ha)	22.1	10.91	9.6
Ferimon	MC (%)	59.8	12	0
	Yield (t/ha)	25.6	12.16	10.7

5.1.2 Spring harvest

When harvested in spring, yield was significantly lower due to loses of leaves – 8.36 t·ha^{-1} of B and 9.79 t·ha^{-1} of F which accounts for loses about one quarter of yield for both varieties. On the other hand MC was low enough to use it without almost any other additional drying (14.1 and 16.2%, respectively) (see Table 13).

Table 13. Biomass yield and moisture content in spring harvest

Spring harvest, 2013				
Bialobrezskie	MC (%)	14.1	12	0
	Yield (t/ha)	8.36	8.16	7.18
Ferimon	MC (%)	16.2	12	0
	Yield (t/ha)	9.79	9.32	8.2

5.2 Total costs of briquettes production

5.2.1 Total costs for autumn harvest

Production of briquettes in autumn harvest cost 39,426 CZK·ha^{-1} for B and 44,120 CZK·ha^{-1} for F. Other direct costs took the highest share of TC for both scenarios including costs of fuels (21%, 20.2%), reparation of machines and buildings (7%, 6.2%), insurance against natural disasters (3.5% for both varieties), land rent (3.6%, 3.2%) and water (0.3% for both varieties), for B and F, respectively. Costs of material inputs (seeds, fertilizers and other material) accounted for 35% of TC. Figure 3 shows the proportional division of costs.

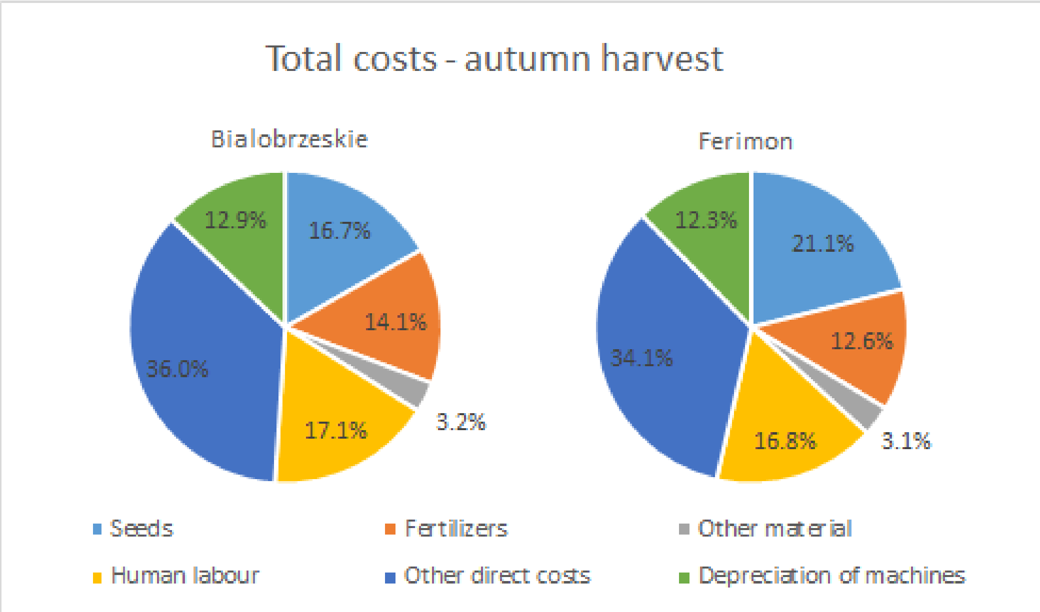

Figure 3. Total production costs of hemp briquettes in autumn harvest

5.2.2 Total costs for spring harvest

TC for spring harvest were 34,566 CZK·ha^{-1} and 39,116 CZK·ha^{-1} for grown varieties B and F which lowered the sum by 12.3% and 11.3%, respectively in comparison with autumn harvest. Division of costs was very similar as in autumn harvest (see Figure 4).

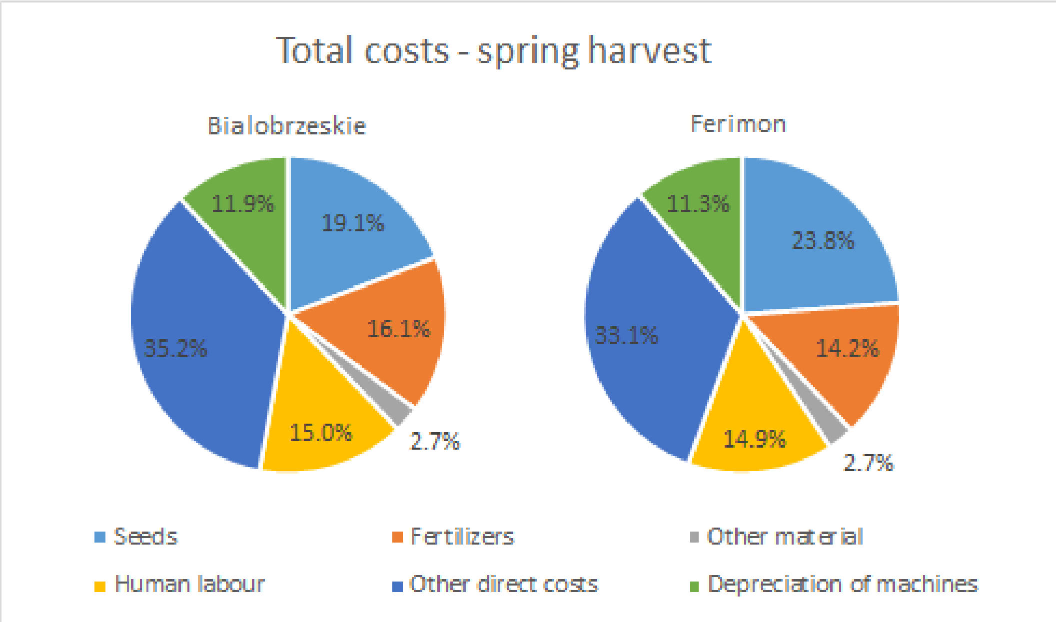

Figure 4. Total production costs of hemp briquettes in spring harvest

Higher costs of briquettes production from both varieties B and F in autumn harvest were caused by larger BY and thus higher labour demand, electricity consumption, etc. Although TC per hectare were higher in autumn in comparison with spring, when recalculated per tonne, they were 14.7% and 13.6% lower, respectively (see Figure 5).

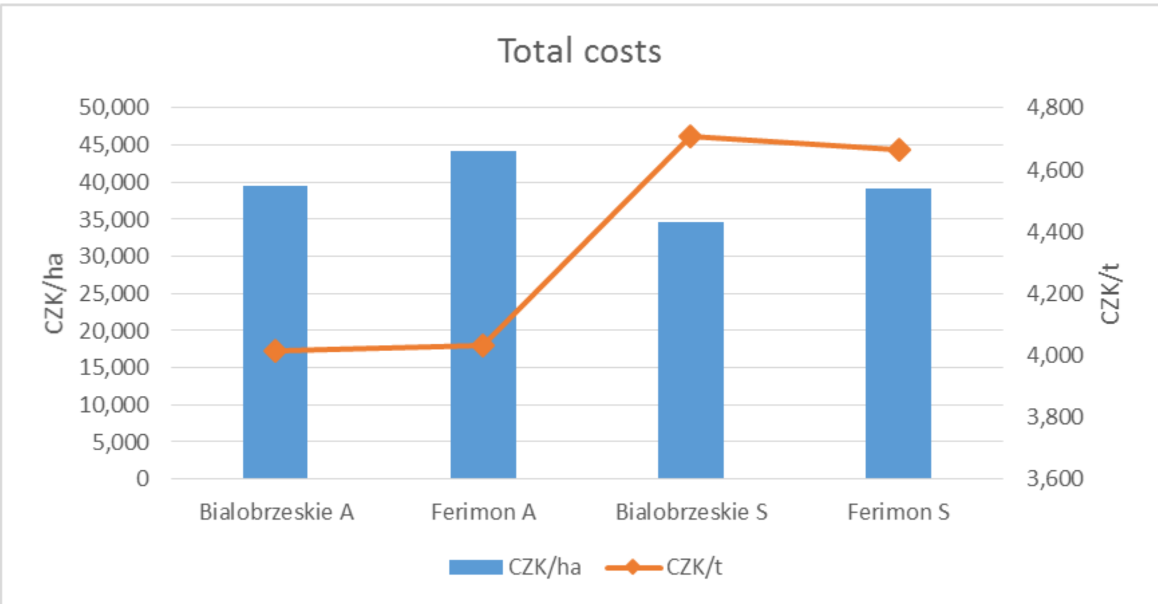

Figure 5. Total costs of briquettes production (comparison) (A – autumn harvest, S – spring harvest)

5.3 Variable costs

Tables 14 and 15 below show in full detail costs of variable inputs (seeds, fertilizers, other material, diesel, electricity and labour) listed by necessary operations needed for hemp briquettes production in both harvesting periods.

Table 14. Costs of inputs in autumn harvest

Autumn harvest	Seeds CZK/ha	Fertilizers CZK/ha	Other material CZK/ha	Fuel CZK/ha	Labour CZK/ha	Costs per operation CZK/ha
Liming		151		13	12	176
Manure spreading		1,035		89	37	1,161
Fertilization (0.17t P_2O_5, 0.08t K_2O)		2,387		59	59	2,506
Deep tillage				652	137	789
Hauling				160	36	196
Fertilization (0.3 t NH_4NO_3)		1,981		49	48	2,078
Seedbed preparation				202	48	250
Sowing						
Bialobrezskie	6,600			103	48	6,751
Ferimon	9,300			103	48	9,451
Hemp mowing				209	117	326
Tedding				162	66	228
Swathing				98	33	131
Baling						
Bialobrezskie			262	106	92	460
Ferimon			292	106	92	490
Transport				148	99	247
Stubble tillage				197	51	248
Total cultivation costs						
Bialobrezskie	6,600	5,555	262	2,246	1,024	15,687
Ferimon	9,300	5,555	292	2,246	1,024	18,417
Separating and crushing						
Bialobrezskie				865	1,800	2,665
Ferimon				964	2,006	2,970
Briquetting						

Bialobrezskie			982	5,145	4,050	10,177
Ferimon			1,094	5,735	4,514	11,343
Total briquetting costs						
Bialobrezskie			982	6,010	5,850	12,842
Ferimon			1,094	6,698	6,521	14,314
Total input costs						
Bialobrezskie	**6,600**	**5,555**	**1,244**	**8,256**	**6,874**	**28,529**
Ferimon	**9,300**	**5,555**	**1,386**	**8,945**	**7,545**	**32,731**

Table 15. Costs of inputs in spring harvest

Spring harvest	Seeds CZK/ha	Fertilizers CZK/ha	Other material CZK/ha	Fuel CZK/ha	Labour CZK/ha	Costs per operation CZK/ha
Liming		151		13	12	176
Manure spreading		1,035		89	37	1,161
Fertilization (0.17 t P_2O_5, 0.08 t K_2O)		2,387		59	59	2,506
Deep tillage				652	137	789
Hauling				160	36	196
Fertilization (0.3 t NH_4NO_3)		1,981		49	48	2,078
Seedbed preparation				202	48	250
Sowing						
Bialobrezskie	6,600			103	48	6,751
Ferimon	9,300			103	48	9,451
Hemp mowing				209	117	326
Swathing				98	33	131
Baling						
Bialobrezskie			196	106	92	394
Ferimon			224	106	92	422
Transport				148	99	148
Stubble tillage				197	51	248
Total cultivation costs						
Bialobrezskie	6,600	5,555		2,084	818	15,057
Ferimon	9,300	5,555		2,084	818	15,057
Separating and crushing						

Bialobrezskie				647	1,346	1,993
Ferimon				739	1,538	2,276
Briquetting						
Bialobrezskie			734	3,848	3,029	7,612
Ferimon			839	4,395	3,460	8,694
Total briquetting costs						
Bialobrezskie			734	4,495	4,376	9,605
Ferimon			839	5,134	4,998	10,971
Total input costs						
Bialobrezskie	**6,600**	**5,555**	**930**	**6,579**	**5,194**	**24,858**
Ferimon	**9,300**	**5,555**	**1,062**	**7,218**	**5,816**	**28,951**

The highest input costs were found for variety F harvested in autumn and the lowest for B in spring. The difference was caused by variations in BY which subsequently increased processing costs of hemp biomass into solid biofuel. Costs of individual inputs are further analysed below.

5.3.1 Material inputs

Material inputs included seeds, fertilizers and other direct material. Seeds represented the most expensive item for variety F harvested in spring; their share made 30% from VC. Costs of seeds differed among varieties accounting for 30% higher costs for F. Costs of fertilizers were the same for all scenarios since no difference in amount of fertilizers was considered. The highest share of fertilizers costs took ammonium nitrate (1,981 CZK·ha^{-1}), followed by superphosphate (1,610 CZK·ha^{-1}), farmyard manure (1,035 CZK·ha^{-1}), potassium salt (777 CZK·ha^{-1}) and limestone (151 CZK·ha^{-1}) (see Figure 6). Other material comprised of string for hemp bales and PE bags for packaging of briquettes. In hemp production 3.3 – 4.9 kg of string and 490 – 730 bags were used depending on BY. It made approximately 4% of VC in all scenarios.

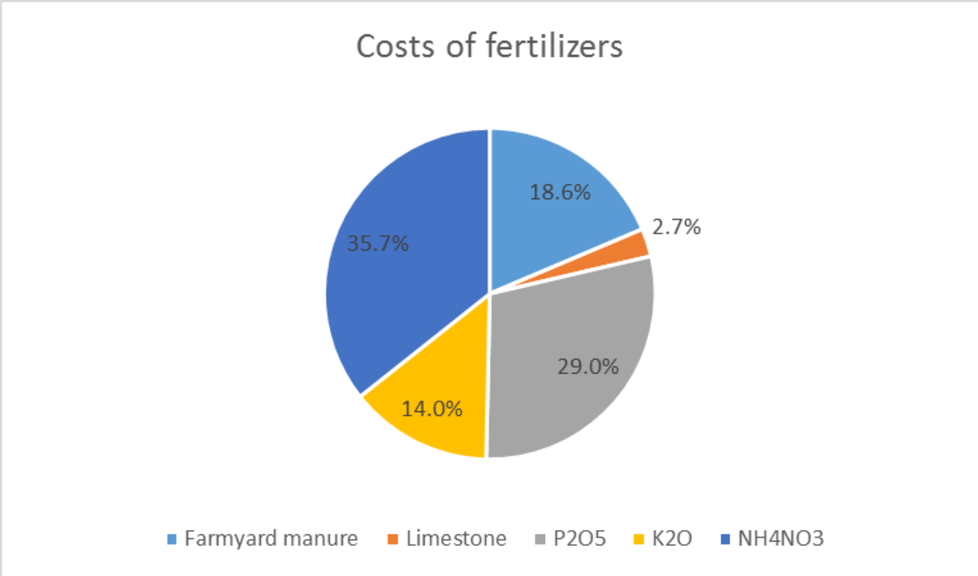

Figure 6. Costs of fertilizers used for hemp cultivation

5.3.2 Fuels

Costs of fuels were the most expensive item for B in both harvesting seasons and F in autumn representing more than 25% of VC. Table 16 below shows consumption of fuels according to operation in production process. Diesel was consumed in cultivation and harvesting operations and electricity was used for powering crushing and pressing machinery.

Table 16. Fuel consumption and fuels costs

		Autumn harvest		Spring harvest	
	Unit	Bialobrezskie	Ferimon	Bialobrezskie	Ferimon
Cultivation and harvest	l	91.31	91.31	84.71	84.71
Crushing and briquetting	kW	2,293.8	2,556.6	1,715.6	1,959.5
Total costs	CZK/ha	8,256	8,945	6,579	7,218

It is evident from results that costs for fuel change with harvesting period. Difference in diesel consumption was caused by extra operation (tedding) in autumn harvest. Costs for further processing increased with higher BY. Proportional share of both fuels in production process is presented in Figure 7. Costs of electricity were proportionally higher in all scenarios.

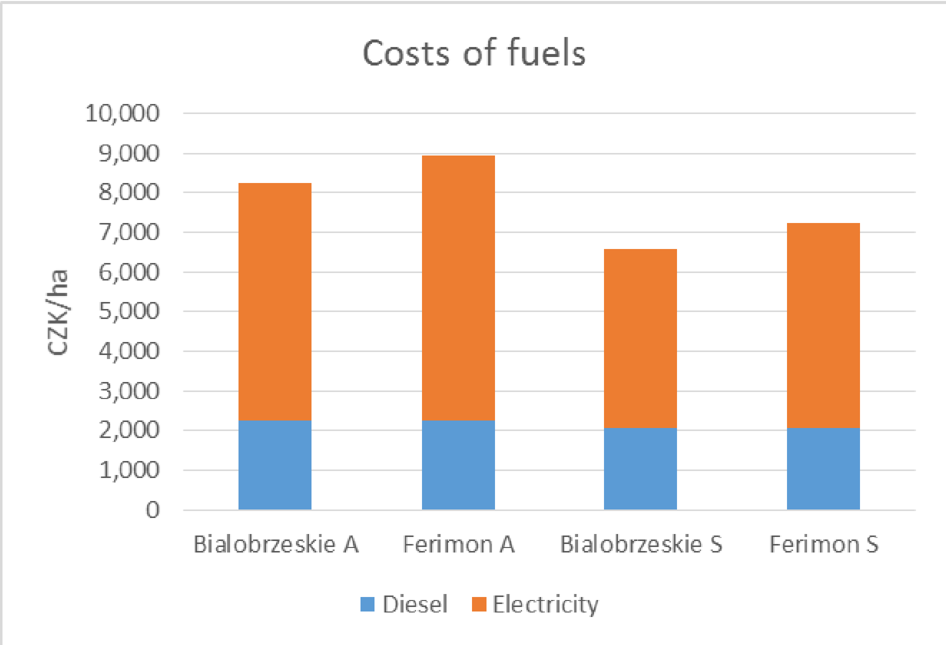

Figure 7. Costs of fuels in production process (A – autumn harvest, S – spring harvest)

According to results the most costly operation in terms of diesel consumption was deep tillage (652 CZK·ha^{-1}), followed by hemp mowing (209 CZK·ha^{-1}) and soil preparation (202 CZK·ha^{-1}) (see Tables 14 and 15).

5.3.3 Human labour

Share of human labour in VC varied between 19 - 23% for F in spring and B in autumn, respectively. Labour cost varied significantly among scenarios. Total amount of working hours needed for briquettes production as well as its costs are shown in Table 17.

Table 17. Labour demand and labour costs

		Autumn harvest		Spring harvest	
	Unit	Bialobrezskie	Ferimon	Bialobrezskie	Ferimon
Cultivation and harvest	h	5.36	5.36	4.96	4.96
Crushing and briquetting	h	35.46	39.52	26.52	30.29
Total human labour	h	40.82	44.88	31.48	35.25
Total costs	CZK/ha	6,735	7,405	5,194	5,816

Labour demand for cultivation and harvesting was slightly lower in spring. It is due to low MC of harvested biomass so it was not necessary to carry out tedding in order to support natural drying process. Higher total labour demand in autumn resulted from higher yield which needed to be processed. Distribution of labour cost per technological operations was very similar in all scenarios. In descending order – briquetting (60%), separating and crushing (26.5%) and cultivation and harvesting (13.5%). The most labour demanding operation in cultivation process was deep tillage (137 CZK·ha^{-1}) followed by hemp mowing (117 CZK·ha^{-1}) and hemp compressing (92 CZK·ha^{-1}) (see Tables 14 and 15).

5.3.4 Other variable costs

Other variable costs comprised of costs of water and property insurance. Water consumption made proportionally smallest share of VC which represented approximately 0.5% in all scenarios.

Crop insurance against natural disasters accounted for 5% of VC in autumn and 4% of VC in spring harvest. Insurance was determined from gross production revenue production, thus it was higher in autumn when the production was higher.

5.4 Fixed costs

FC represented around quarter of TC in all scenarios. The highest share was made by depreciation of machines which accounted for 50% of FC. Depreciation varied between 4,116 CZK·ha^{-1} for B in spring and 5,429 CZK·ha^{-1} for F in autumn. The highest share of depreciation cost made briquetting press, since it is the most expensive machine and was used for about 60% of total production hours. Apart from depreciation FC covered also reparation of machines and buildings which contributed to FC by 30%, followed by land rent which took more than 15%. Taxes and fees made proportionally smallest share of FC accounting for less than 3%.

5.5 Total revenue from briquettes production

From 1 tonne of hemp briquettes gross revenue 4,701 CZK·t^{-1} was made. Net revenue from autumn yield was in average 24% higher than from spring yield. Within harvesting seasons, earning from briquettes production were similar, showing moderately better results for variety F in both seasons.

5.6 Profit from briquettes production

Since production costs of hemp briquettes were higher than revenues in all scenarios, none of them made any profit. Loses varied significantly between harvesting periods, being much higher in spring. Surprisingly, in both harvests F showed to be more lossmaking, even though its BY was higher and thus, higher profit was expected. When subsidies SAPS and TOP – UP were taken into account, economy of production slightly improved and moderate profit was gained in autumn harvest (see Table 18).

Table 18. Costs, revenues, subsidies and profit

		Autumn harvest		Spring harvest	
		Bialobrezskie	Ferimon	Bialobrezskie	Ferimon
Total costs	CZK/ha	39,426	44,120	34,566	39,116
Total revenue	CZK/ha	36,466	40,644	27,274	31,151
Subsidies	CZK/ha	6,560	6,560	6,560	6,560
Profit	CZK/ha	3,599	3,084	-732	-1,405

All scenarios showed negative profitability without any external financial support, even if included the profitability raised up to maximum 9% in the best case (B in autumn) (see Figure 8). Assumed briquettes price 4,701 CZK·t^{-1} (including VAT) was too low. The minimum selling price of briquettes to cover total production costs would have ranged between 5,151 CZK·t^{-1} to 6,070 CZK·t^{-1} depending on variety and harvesting period. To reach medium profitability of 30%, the selling price of hemp briquettes would have been 30% and 40% higher for autumn and spring production, respectively than considered price. If the selling price of hemp briquettes stayed the same as it was assumed, BY in DM had to increase by 1.6 – 4.1 t·ha^{-1} (11.2 – 12.3 t·ha^{-1}) for investigated scenarios to become profitable.

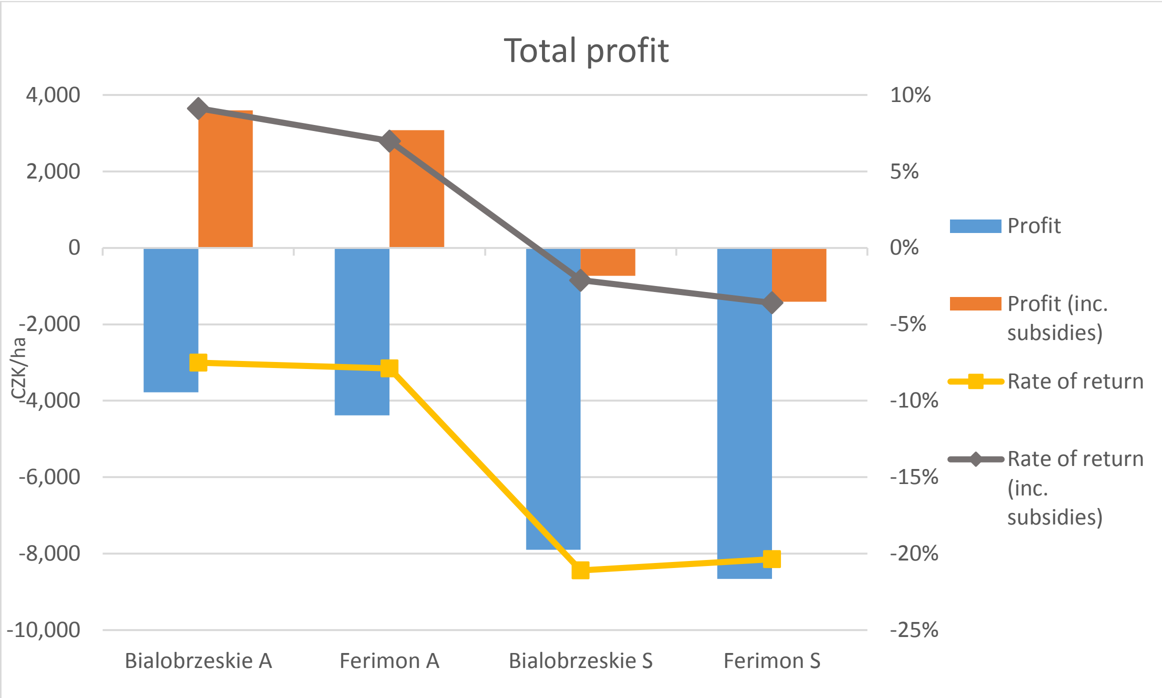

Figure 8. Profit and rate of return (including subsidies) from briquettes production (A – autumn harvest, S – spring harvest)

5.7 Dependence between hemp yield and profitability

From previous results it might be assumed that there was dependence between BY and profitability of hemp briquettes production. Results of OLS regression analysis for variety B harvested in autumn are shown in Table 19 below.

Table 19. Model OLS. Dependent variable: profitability B in autumn harvest

	Coefficient	Std. error	t-ratio	p-value
Constant	-0.586132	0.00730755	-80.21	1.79e-124 ***
Yield	0.0439778	0.000552004	79.67	4.77e-124 ***

Mean dependent variable	-0.036409	S.D. dependent variable	0.194577
Sum squared residual	0.130257	S.E. of regression	0.029567
R-squared	0.977063	Adjusted R-squared	0.97691
F (1, 149)	6347.194	P-value (F)	4.80E-124

Dependence between yield and profitability was:

$$Profitability = -0.586132 + 0.0439778 * BY$$

Coefficients were statistically significant on 0.05 level of significance. Model as a whole was also statistically significant according to F – test. R - square was 0.977 which means that BY explained 97.7% variance in profitability of hemp briquettes production.

When BY increased by 1 unit, the average increase in the mean of profitability was 0.0439778 units. If simplified this could be interpreted as that for each ton increase of BY, profitability of hemp briquettes production increased by 4.4 percentage point. In other scenarios results were similar and can be found in Annexes (see Tables 2 – 4).

6 Discussion

6.1 Hemp yield

According to Strašil and Šimon (2009) energy crop is considered economically viable reaching the BY of at least 15 $t{\cdot}ha^{-1}$. The experimental field in Suchdol yielded at least 3 $t{\cdot}ha^{-1}$ less in all scenarios, thus this condition was not met. However, yields in DM from all harvests were comparable to results of other researchers. Rice (2008) reported yield 11.7 $t{\cdot}ha^{-1}$ and Finnan and Burke (2013) 12.3 $t{\cdot}ha^{-1}$ for variety F. Hutla (2004) mentioned DM yield 10 $t{\cdot}ha^{-1}$ for autumn harvest of B. Strašil (2005) stated DM yield 10.25 $t{\cdot}ha^{-1}$ for autumn and 7.06 $t{\cdot}ha^{-1}$ for spring harvest. Heneman and Červinka (2007) presented slightly higher result of 12.05 $t{\cdot}ha^{-1}$. Yield from F in the present study was 30% higher than that of B in both harvesting seasons. This is in contradiction with Honzík et al. (2010) who ascertained average yield 9.29 $t{\cdot}ha^{-1}$ of B and 7.49 $t{\cdot}ha^{-1}$ for F. Biomass loses in spring harvest were in accordance with Kára et al. (2005) who stated that yield may vary by 31%. In experiment no fertilizers were used, so it is likely that applying fertilizers could improve BY and decrease TC per ton (Široká 2009; Rehman et al., 2013).

6.2 Total costs of briquettes production

From 1 ha of land 7 - 11 t of hemp briquettes was produced. Loses were considered 10%, however, in reality they might be higher due to unexpected loses on the field (pests) or during processing. TC of hemp briquettes in this study ranged from 4,015 – 4,707 $CZK{\cdot}t^{-1}$ (154.6 – 181.25 $€{\cdot}t^{-1}$) depending on variety and harvesting period. In comparison with production costs of briquettes made from other vegetable materials in Poland, costs in present study were quite high: willow (105.39 $€{\cdot}t^{-1}$), rape straw (96.04 $€{\cdot}t^{-1}$), pine sawdust (82.71 $€{\cdot}t^{-1}$) and mixture of straw and willow (83.45 $€{\cdot}t^{-1}$). However, that study assumed purchasing of raw material with material price varying from 30.71 $€{\cdot}t^{-1}$ for rape straws to 61.19 $€{\cdot}t^{-1}$ for willow which accounted for only 30 – 60% of cultivation and harvesting costs calculated in this Thesis (Stolarski et al. 2013). Since only outdated studies dealing in particular with hemp briquettes economy were found in scientific sources, cultivation and harvesting costs were compared with available data. Cultivation and harvest costs were in line with findings of Irish researchers Finnan and Styles (2013) who stated 98.1 $€{\cdot}t^{-1}$ (2,548

CZK·t^{-1}) when mineral fertilizers were applied. Panoutsou (2012) presented cultivation costs in Poland and Netherlands with estimated yield 10 and 7 t·ha^{-1} 163.19 €·t^{-1} (4,209 CZK·t^{-1}) and 186.14 €·t^{-1} (4,801 CZK·t^{-1}), respectively. Cultivation costs were generally lower in other studies conducted in the Czech Republic: 1,750 – 2,670 CZK·t^{-1} for yield 6 – 12 t·ha^{-1} (Říha, 2010); 2,523 CZK·t^{-1} for yield 10.2 t·ha^{-1} (Honzík et al. 2012); 2,523 CZK·t^{-1} with yield 8 t·ha^{-1} (Kotyza, 2012). TC in both periods were in line with Mužík and Abrham (2013) who presented costs 2,063 CZK·t^{-1} with 12 t·ha^{-1} of biomass. FC were higher than stated in other studies - 3,500 CZK·ha^{-1} (Jevič et al., 2008; Mužík and Abrham, 2013). Costs of briquetting accounted for 1,307 CZK·t^{-1} which was almost 40% lower than stated Alaru et al. (2013) (80.50 €·t^{-1} – 2,091 CZK·t^{-1}) for hemp BY below 7.6 t·ha^{-1} grown in Estonia.

6.3 Variable costs

6.3.1 Material inputs

Prices of material input depend on producer and size of packaging, so they may vary with regard to the production volume. Kotyza (2012) assumed yield 9 t·ha^{-1} with the same amount of fertilizers of same composition and presented following results: 2,700 CZK·ha^{-1} of ammonium nitrate which was about one third higher than costs in this paper; 1,150 CZK·ha^{-1} for superphosphate which was on the contrary almost 30% less. Honzík et al, 2012 ascertained that phosphorus improved quality of seed but does not affect stem, thus for energy purposes amount of this fertilizer could be decreased with subsequent decrease of TC.

6.3.2 Fuels

In production process 91.31 l·ha^{-1} in autumn and 84.71 l·ha^{-1} in spring of diesel was used for cultivation and harvesting. This result did not coincide neither with Mužík and Abrham (2008) who stated 71.6 l·ha^{-1} nor with Havlíčková et al. (2007) who presented 75 l·ha^{-1} and Jevič et al. (2008) 67.6 l·ha^{-1}. This could be explained by the fact that for calculated scenarios machines with higher power output were chosen. Based on analysis of data from ÚZPI, higher output generally means raised fuel consumption and higher costs for depreciation but lower labour costs and vice versa (ÚZPI, 2008).

6.3.3 Human labour

Calculated labour demand for hemp cultivation and harvesting was lower than stated Havlíčková et al. (2007) – 7 hours·ha^{-1} but higher than stated Jevič et al. (2008) – 4.5 hours·ha^{-1}. Experts from VÚZT assumed labour demand to be between 6 - 8 hours·ha^{-1}. Processing hemp into solid biofuel included separating, crushing and briquetting of material which made more than 85% of total labour costs. Kára et al. (2005) stated labour costs of briquetting 63 CZK·t^{-1} which was about 10 times less that calculated in this Thesis. It could be explained by the fact that 1 worker employed for operating the briquetting line was considered, meanwhile Kára et al. supposed only 0.25 of operating staff.

In this Thesis costs of labour were calculated from average salary of full time worker. If producer hired just seasonal labour force, his costs would be lower since he would not pay social and health insurance. Salary in agriculture may also differ depending on region of the Czech Republic.

6.3.4 Other variable costs

Water costs represented average water consumption of agricultural enterprises in the Czech Republic. Kára et al. (2005) ascertained that hemp requires 1.5 - 2 times more water than wheat or oat, thus amount of water might be in reality higher.

VC could be cut down by omitting crop insurance against natural disasters. It would decrease total costs by approximately 3.5% in autumn and 3% in spring, however, in such case producers face the risk that whole production might be lost due to unfavourable weather conditions.

6.4 Fixed costs

This study considered cultivation of hemp on rented land calculating with average rent for the Czech Republic. Prices of land vary according to its location ranging from 808 CZK·ha^{-1} for mountainous areas to 2,080 CZ·K·ha^{-1} for corn areas (MOA, 2012). If producer was owner of agricultural land, he would pay only land tax (0.75% from selling price of land) which would decrease land costs by approximately 60%. In this Thesis land rent accounted for slight share of TC (on average 4%). On the contrary, in the Netherlands costs of rented land were exceptionally high - 54% of TC (Panoutsou, 2012).

The difference in depreciation costs for harvesting periods was caused by higher hour use of machines due to higher yields in autumn. Depreciation costs in autumn harvest were higher than average costs of agricultural enterprises amounting to 4,247 CZK·ha^{-1} (FADN, 2013). Discrepancy resulted from the fact that calculation included depreciation costs of briquetting line which was the most expensive machine in the whole production process.

6.5 Technological process of briquettes production

Table 1 (in Annex) shows all technological operations used in hemp briquettes production with their repetitiveness, amount of fuels and labour spent and used machinery. Data for cultivation process were considered for average conditions and intensity of production (Kára et al., 2005) so it may fluctuate in different conditions. Most of operations repeated every year besides of liming and manure fertilizing which happen only once per 10 and 15 years respectively, so only their year's ratio was considered. The study assumed that producer carried out all operation by himself. Compared to Kotyza (2012) who calculated with rented services, costs of individual operation were significantly lower. The highest difference was found for hemp compressing which resulted almost 88% more expensive when rented (5,400 CZK·ha^{-1}) and deep tillage accounting for more than 30% of savings when performed by farmer himself. Total cultivation and harvesting costs were evidently lower than it would be in case of rented services. However, Kára et al. (2005) stated that hemp stems are very firm and make harvest technologically demanding. Hemp cannot be harvested with common machinery since long fibres may destroy machines (Honzík, 2007). Nowadays, machinery suitable for hemp harvesting is available in Western Europe, nonetheless, it would mean high initial investments of millions of CZK. Some authors recommended to use services of experienced farmers with adjusted agricultural machinery. Říha (2010) admitted that total costs might be higher in such case, however, it would prevent damages on own machinery.

For processing of material into solid biofuel briquetting lined was designed – separator and crusher Himel of power 30.25 kW, press BrikStar 400 and bagging equipment. Choice of machines was discussed with experts from selling companies. Even though, the most appropriate machines were selected, experts pointed out some problems with processing hemp biomass. Likewise in case of harvesting, long fibres tangle up onto components of separator and crusher which slow down the production since it is necessary to fix it manually.

6.6 Total revenue from briquettes production

From economic point of view autumn harvest was recommended because BY was significantly higher which subsequently increased revenue from 1 ha of cultivated land by 23 – 25%. However, majority of authors argued that spring harvest was preferable for energy purposes due to lower MC and improved chemical properties (Weger et al., 2012; Prade, 2012, Honzík et al., 2012). Thus, the optimal harvesting time must be found to ensure both high BY and suitable chemical features of hemp.

6.7 Profit from briquettes production

Study revealed that cultivation of hemp solely for briquettes production without any subsidies was not profitable for producers in current market conditions of the Czech Republic. Panoutsou (2012) made economic analysis of hemp cultivation for stalks in Poland and Netherlands and ascertained that in both countries the cultivation was not profitable without receiving any financial help (- 38% and - 46%, respectively). Široká (2009) stated that whole hemp plant (stalks, seeds) must be processed to be economically viable. This was confirmed in present study when production for seeds was considered too, counting with average seeds yield 0.92 $t \cdot ha^{-1}$ for B and 1.23 $t \cdot ha^{-1}$ for F (Honzík et al., 2012) and actual price 25 $CZK \cdot kg^{-1}$ (Říha, 2014). Profitability of combine production raised significantly, ranging from 16.5% for B harvested in spring to 33% for F in autumn, with only slightly increased TC (10% and 8%, respectively). Kotyza (2012) found cultivation of B variety for stem export (selling price 3,500 $CZK \cdot t^{-1}$) lossmaking even with subsidies and recommended combine production for both stem and seeds which improved profitability by more than 40%.

The selling price of solid biofuels depends on the briquette quality and on the supply and demand for the fuel (Stolarski et al., 2013) Consumption of herbaceous briquettes (including hemp briquettes) has been marginal in the Czech Republic until now. No official statistics were available, however, it was estimated that in 2012 the consumption did not exceed 1 – 2 thousand tonnes (MOA, 2013). On the market with solid fuels hemp briquettes are overcome by other products, especially brown coal and wood briquettes. Prices of these fuels are at such a low level that hemp could not compete with them. Results showed that if the price of hemp briquettes was the same as that of wood briquettes it did not even cover production costs and no profit was generated. Alaru et al. (2013) stated that hemp briquettes production in Estonia was unprofitable when above BY decreased below 7.6 $t{\cdot}ha^{-1}$ and its selling price copied the market price of wood briquettes (133 $€{\cdot}t^{-1}$). This was in contradiction with results of this study because except of B harvested in spring, all scenarios yielded more than 8 $t{\cdot}ha^{-1}$ and none of them was profitable without subsidies. Jevič et al. (2008) analysed production costs of hemp briquettes in the Czech Republic and although subsidies for farmer were considered, TC were slightly higher than selling price of brown coal. When subsidies were included profitability turned to positive values in autumn scenarios but still was much lower than that of other crops suitable for energy production: corn (87.8%), rapeseed (19.8%), wheat (68.9%) (MOA, 2013). Furthermore, amount of subsidies has fluctuated over time, thus production profit should not entirely rely on them.

Results indicated that for improving profitability of hemp briquettes production, either selling price of briquettes or BY had to raise. Since selling price could not be set higher due to competitive price of wood briquettes, the main focus has to be aimed at increasing hemp BY.

Economic analysis of hemp briquettes production in the Czech Republic was calculated for given conditions in this Thesis. However, presented methodology could serve as a model also for producers from foreign countries where similar cultivation processes are used (Central, Eastern and Northern Europe). Prices of inputs and selling price of final product as well as coefficients of technological operations must be adjusted to actual situation in particular country.

7 Conclusions and Recommendations

Based on analysis of results, following conclusions were formulated:

- Biomass harvested in autumn produced 9.6 $t \cdot ha^{-1}$ of variety B and 10.7 $t \cdot ha^{-1}$ of F resulting in TC 39,426 $CZK \cdot ha^{-1}$ (1,518 $€ \cdot ha^{-1}$) and 44,120 $CZK \cdot ha^{-1}$ (1,698.9 $€ \cdot ha^{-1}$), respectively. When harvested in spring, yield was 30% lower accounting for 7.18 $t \cdot ha^{-1}$ of B and 8.2 $t \cdot ha^{-1}$ of F with TC 34,566 $CZK \cdot ha^{-1}$ (1,334 $€ \cdot ha^{-1}$) and 39,116 $CZK \cdot ha^{-1}$ (1,506.2 $€ \cdot ha^{-1}$). Higher TC in autumn were caused by higher BY which subsequently required more human labour and fuel for processing and higher depreciation costs due to higher use rate of briquetting line.
- Although TC per hectare were higher in autumn harvest, when recalculated per tonne they were 15% lower for B and 14% lower for F than in spring (4,015 $CZK \cdot t^{-1}$, 4,031 $CZK \cdot t^{-1}$, respectively).
- Structure of costs was very similar in all scenarios. FC made approximately one quarter of TC. Material inputs accounted for almost 40% of TC in all scenarios. Fuels made approximately one fifth of total costs; 70% of costs were made by consumption of electricity. Labour costs represented on average 16% of TC. Share of depreciation costs was quite high; varying between 11 – 13%. Costs of water consumption and taxes and fees were insignificant representing less than 1%.
- Production of briquettes from whole hemp plant showed to be unprofitable without grants and subsidies with current market prices of competitive solid biofuels. Hemp economy slightly enhanced with subsidies in autumn scenarios, however the profitability remained still above average in comparison with other crops.
- From the economic point of view autumn harvest was recommended since BY and revenue from production were higher than in spring. Within the harvesting periods variety B was more profitable.
- Although hemp did not show to be economically viable solely for briquettes production, combine production for both stem and seeds could be suggested.
- Profitability could be improved either by raising the selling price of hemp briquettes (5,151 – 6,070 $CZK \cdot t^{-1}$) or by increasing BY (11.2 – 12.3 $t \cdot ha^{-1}$) compared to actual situation.

- Hemp outstanding features such as high biomass yield in relatively short time, good energy characteristics, low input requirements, versatile use, etc. should be taken into consideration. Furthermore, unlike perennial crops hemp does not require any long term commitment for its cultivation and ensures immediate return of investment.
- To conclude, utilization of whole hemp plant for briquettes production did not show to be economically feasible due to relatively high production costs and low prices of competitive wood briquettes. The future development depends mainly on final price of product and situation on the market with other solid biofuels.
- Since higher BY positively affected hemp production economy, further research regarding improvement of hemp yield would be suggested to decrease TC and enhance hemp competitiveness on the market with solid fuels.
- Based on available resources and own results hemp would be recommended rather as a break crop in fields planted with food crops than for targeted annual cultivation. Due to unfavourable situation on wholesale market with solid biofuels, hemp is not feasible as a main cash – crop for producer, but rather like complementary plant which brings additional income from sales and provides ecological biofuel for own heat consumption.

8 References

Abrham Z, Kovářová M, Mužík O, Richter J, Herout M, Scheufler V. 2009. Technology and economics of crops – Industrial Hemp. VÚZT. Available at http://svt.pi.gin.cz/cgi-bin/start99.cgi: Accessed 2013 – 12 – 15.

Alaru M, Kukk L, Olt J, Menind A, Lauk R, Vollmer E, Astover A. 2011. Lignin content and briquette quality of different fibre hemp plant types and energy sunflower. Field Crops research 124: 332 – 339.

Alaru M, Kukk L, Astover A, Lauk R, Shanskiy M, Loit E. 2013. An agro – economic analysis briquette production from fibre hemp and energy sunflower. Industrial Crops and Products 51: 186 – 193.

Andert D, Sladký V, Abrham Z. 2006. Energetické využití pevné biomasy (Energy utilization of solid biomass). Prague: VÚZT. 59p.

Bakken E.H. 2009. BioEthanol: Fuel of the future? Háskólinn á Akureyri: University of Akureyri. 111p.

Barta Z, Oliva J. M, Ballesteros I, Dienes D, Ballesteros M, Réczey K. 2010.Refining Hemp Hurds into Fermentable Sugars or Ethanol. Chemical & Biochemical Engineering Quarterly. Zagreb: Croatian Society of Chemical Engineers, vol. 24, no. 3, p331-339.

Benfratello S, Capitano C, Peri G, Rizzo G, Scaccianoce G, Sorrentino G. 2013. Thermal and structural properties of a hemp – lime biocomposite. Construction and building materials 48: 745 – 754.

Briklis, spol. s.r.o. 2014. Briquetting press BrikStar 400. Available at http://www.briklis.cz: Accessed 2014 – 2 – 5.

Cosentino S L, Riggi E, Testa G, Scordia D, Copani V. 2013. Evaluation of European developed fibre hemp genotypes (*Cannabis sativa* L.) in semi – arid Mediterranean environment. Industrial crops and products 50: 312 – 324.

Czech Statistical Office. 2013. Available at www.czso.cz: Accessed 2014 – 2 – 5.

ČSN EN 14588. 2011. Solid biofuels – Terminology, definitions and descriptions. Prague: Český normalizační institut. 68p.

ČSN EN 14961-1. 2010. Solid biofuels - Fuel specifications and classes - Part 1: General requirements. Prague: Český normalizační institut. 48p.

ČSN EN 15234 -1. 2011. Solid biofuels – Fuel quality assurance – Part 1: General requirements. Prague: Český normalizační institut. 72p.

ČSN EN 14775. 2010. Solid biofuels – Determination of ash content. Prague: Český normalizační institut. 10p.

El Bassam N. 2010. Handbook of Bioenergy Crops: A Complete Reference to Species, Development and Applications. London: Earthscan Ltd. 516p.

European Industrial Hemp Association. 2011. Hemp Fibres for Green Products – An assessment of life cycle studies on hemp fibre applications. Hürth: Nova - Institute GmbH - Michael Carus. 20p.

Energy Regulatory Office. 2012. Roční zpráva o provozu ES ČR 2011 (Yearly report on the Operation of the Czech Electricity Grid for 2011). Prague: Energy Regulatory Office. 31p.

European Union. 2001. Directive 2001/77/EC of the European Parliament of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market. Luxembourg: Official Journal of the European Communities vol. 44, p33 – 40.

European Union. 2009. Directive 2009/28/EC of the European Parliament of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Luxembourg: Official Journal of the European Union vol. 52. 140p.

European Union. 2011. Eurostat Statistics. Available at http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home: Accessed 2013 – 11 – 28.

Finnan J, Burke B. 2013. Potassium fertilization of hemp (*Cannabis sativa*). Industrial crops and products 41: 419 – 422.

Finnan J, Styles D. 2013. Hemp: A more sustainable annual energy crop for climate and energy policy. Energy Policy 58: 152 – 162.

Gandolfi S, Ottolina G, Riva S, Fantoni G P, Patel I. 2013. Complete Chemical Analysis of Carmagnola Hemp Hurds and Structural Features of Its Components. BioResources 8 (2): 2641 - 2656.

Havlíčková K., Weger J., Boháč J., Štěrba Z., Hutla P. – et al. 2008. Rostlinná biomasa jako zdroj energie (Herbaceous biomass as a source of energy). Prague: Výzkumný ústav Silva Taroucy pro krajinu a okrasné zahradnictví, Pelhřimov. 83p.

Havrland B, Ivanova T, Lapczynska – Kordon B, Kolaříková M. 2013. Comparative analysis of bio – raw materials and biofuels. 12th International Scientific Conference Engineering for rural development. Jelgava: Latvia University of Agriculture, p541 – 545.

Havrland B, Pobedinschi V, Vrancean V, Pecen J, Ivanova T, Muntean A, Kandakov A. 2011. Biomass processing to biofuel. Prague: Power Print Ltd. 86p.

Heneman P, Červinka J. 2007. Energy crops and bioenergetics in the Czech Republic. Agricultural engineering 51: 73 – 78.

Himel CZ s.r.o. 2014. Biomass shredder STM 201HL Available at http://himel.cz: Accessed 2014 – 2 – 5.

Hollebane J E. 1999. Industrial Hemp Factsheet. Kamloops: Ministry of Agriculture and Food. Available at http://www.agf.gov.bc.ca/speccrop/publications/documents/hempinfo.pdf: Accessed 2014 – 1 – 5.

Honzík R. 2007. Nové technologické postupy sklizně technického konopí (New technological processes of industrial hemp harvesting). Prague: VÚRV. 28p.

Honzík R, Bjelková M, Muňoz J, Váňa V. 2012. Pěstování konopí setého *Cannabis sativa* L. pro výrobu bioplynu (Cultivation of hemp (*Cannabis sativa* L.) for biogas production. Prague: VÚRV. 29p.

Hutla P. 2010. Tuhá paliva z místních zdrojů (Solid biofuels from local sources). Biom.cz. Available at http://biom.cz/cz-pelety-a-brikety/odborne-clanky/tuha-biopaliva-z-mistnich-zdroju: Accessed 2014 – 1 – 3.

Jankauskienė Z, Gruzdevienė E. 2012. Industrial Hemp – Promising source for biomass production. Renewable Energy and Energy Efficiency Conference Upyté, p13 – 18.

Jevič P, Hutla P, Šedivá Z. 2008. Udržitelná výroba a řízení jakosti tuhých paliv na bázi agrárních bioproduktů (Sustainable production and solid biofuels quality management on basis of agricultural bio-products). Prague: VÚZT. 132p.

Johnson R. 2010. Hemp as an Agricultural Commodity. CRS Report for Congress. Congressional Research Service. 25p.

Kára J., Strašil Z., Hutla P., Ušťák S. 2005. Energetické rostliny - technologie pro pěstování a využití (Energy crops – technology of cultivation and utilization). Prague: VÚZT. 81p.

Karus M. 2005. European Hemp Industry 2001 till 2004: Cultivation, raw material, products and trends. EIHA. Huerth: Nova – Institute. 4p.

Kavka M et al. 2008. Výběr z normativ pro zemědělskou výrobu ČR pro rok 2008/2009 (Norms for agricultural production 2008/2009). Prague: ÚZPI. 298p.

Kludze H, Deen B, Dutta A. 2011. Report on literature review of agronomic practices for energy crop production under Ontario conditions. Guelph: University of Guelph. 169p.

Kolaříková M, Havrland B, Ivanova T. 2013. Energy Balance of Hemp (*Cannabis sativa L.)* Grown for Energy Purposes. Agricultura Tropica et Subrtopica 46 (1): 10 – 15.

Kotyza P. 2012. Economics of Hemp production in the Czech Republic: Case study of Rakovnik region. Scientific conference Think Together 2012. Prague: Czech University of Life Sciences, p45 – 56.

Kovářová M, Abrham Z, Jevič P, Šedivá Z. 2006. Pěstování a využítí energetických a průmyslových plodin. Prague: VÚZT.

Lapka V. 2014. Personal interview with long term producer of industrial hemp in the Czech Republic. Chlum u Rakovníka. Visited: 2014 – 1 – 25.

Mankowskij J, Kolodziej J. 2008. Increasing Heat of Combustion of Briquettes Made of Hemp Shives. International Conference on Flax and Other Bast Plants. Poznan: Institute of Natural Fibres, p344 - 352.

Ministry of Agriculture of the Czech Republic. 2009. Biomass Action Plan of the Czech Republic for 2009 – 2011. Prague: Ministry of Agriculture. 19p.

Ministry of Agriculture of the Czech Republic. 2009. Situační a výhledová zpráva - Len a konopí (Report on flax and industrial hemp). Prague: Ministry of Agriculture. 47p.

Ministry of Agriculture of the Czech Republic. 2012. Situační a výhledová zpráva – Půda (Report on Land). Prague: Ministry of Agriculture. 101p.

Ministry of the Interior. Act No. 180/2005 Coll. Act of 31 March 2005 on the promotion of electricity production from renewable energy sources and amending certain acts (Act on Promotion of Use of Renewable Sources). Česká republika: Sbírka zákonů České republiky, 2005, částka 66. p3726 – 3732.

Ministry of Industry and Trade. 2008. Pelety a brikety z biomasy v roce 2007 (Pellets and briquettes from biomass in 2007). Prague. Ministry of Industry and Trade. 8p.

Ministry of Industry and Trade of the Czech Republic. 2009. Report on the Fulfilment of the Indicative Target for Electricity Production from Renewable Energy Sources for 2008. Prague: Ministry of Industry and Trade. 29p.

Ministry of Industry and Trade of the Czech Republic. 2010. National Renewable Energy Action Plan of the Czech Republic. Prague: Ministry of Industry and Trade. 109p.

Ministry of Industry and Trade. 2012. Obnovitelné zdroje energie v roce 2011 (Renewable energy sources in 2011). Prague. Ministry of Industry and Trade. 61p.

Ministry of Industry and Trade. 2012. Ceny pevných biopaliv pro domácnosti (Prices of solid biofuels for households). Prague. Ministry of Industry and Trade. 624.

Ministry of Industry and Trade. 2013. Pelety a brikety v roce 2012 (Pellets and briquettes in 2012). Prague. Ministry of Industry and Trade. 13p.

Moutinho L, Hutcheson G D. 2011. The SAGE Dictionary of Quantitative Management Research. London: Sage publications, p224 – 228.

Muntean A, Ivanova T, Havrland B, Pobedinsky V. 2012. Comparative analysis of methods for fuel biobriquettes production. 12th International Scientific Conference Engineering for rural development. Jelgava: Latvian University of Agriculture, p496 – 499.

Mužík O, Abrham Z. 2013. Ekonomická a energetická efektivnost výroby biopaliv (Economic and energetic effectiveness of biofuels production). Biom.cz. Available at http://biom.cz/cz/odborne-clanky/ekonomicka-a-energeticka-efektivnost-vyroby-biopaliv: Accessed 2013 – 1 – 12.

Olt J, Laur M. 2009. Briquetting different kinds of herbaceous biomaterial. 8th International Scientific Conference Engineering for rural development. Jelgava: Latvian University of Agriculture, p224 – 228.

Panoutsou C. 2012. Non - food Crops – to - Industry schemes in EU27: Costs and socio – economic impact. London: Center for environmental policy. 26p.

Petříková V. et al. 2006. Energetické plodiny. Prague: Profi Press, 127p.

Plíštil D. 2004. Využití technického konopí pro energetické účely (Utilization of industrial hemp for energy purposes). Biom.cz. Available at http://biom.cz/cz/odborne-clanky/vyuzititechnickeho- konopi-pro-energeticke-ucely: Accessed 2014 – 1 – 17.

Poláčková J et al. 2010. Metodika kalkulací nákladů a výnosů v zemědělství (Methodology for calculation of costs and revenues in crop production). Prague: Ústav zemědělské techniky a informací. 59p.

Prade T. 2011. Industrial Hemp (*Cannabis sativa L.*) - a High Yelding Energy Crop. [Doctoral Thesis]. Alnarp: Swedish University of Agricultural Sciences, Alnarp. 90p.

Prade T, Svensson S E. Andersson A, Mattsson J E. 2011. Biomass and energy yield of industrial hemp grown for biogas and solid fuel. Biomass and bioenergy 35 (7): 3040–3049.

Prade T., et.al. 2012. Effect of harvest date on combustion related fuel properties of industrial hemp (*Cannabis sativa* L.). Fuel 102: 592–604.

Rehman M S U, Rashid N, Saif A, Mahmood T, Han J I. 2012. Potential of bioenergy from industrial hemp (*Cannabis Sativa*): Pakistan perspective. Renewable and Sustainable Energy Reviews 18: 154 – 164.

Resch G, Panzer Ch, Busch S, Ragwitz M, Rosende D. 2010. Renewable Energy Industry Roadmap for Czech Republic. Vienna: Vienna University of Technology. 48p.

Rice B. 2008. Hemp as a feedstock for biomass-to-energy conversion. Journal of Industrial Hemp 13(2): 145-156.

Ruman M, Klvaňová L. 2008. Konopí - staronový přítel. Chráštice: Konopa o.s. 31p.

Říha V. 2010. Technické konopí a jeho využití v praxi (Industrial hemp and its utilization). AgroBASE, vol. 4. Olomouc: Agrární komora ČR, p 25 – 26.

Říha V. 2012. Václav Říha: Konopí je jedna z nejvděčnějších rostlin (Vaclav Riha: Hemp is one of the worthiest crops). E15.cz. Available at http://nazory.euro.e15.cz/rozhovory/vaclav-riha-konopi-je-jedna-z-nejvdecnejsich-rostlin-761180: Accessed on 2014 – 2 – 12.

Říha V. 2014. Interview with manager of Hemp Production s.r.o. Březnice.

Saeidy E E. 2006. Renewable Energy in Agriculture in Egypt: Technological Fundamentals of Briquetting Cotton Stalks as a Biofuel. [Doctoral Thesis]. Berlin: Humboldt-Universität zu Berlin. 106p.

Sims R E H, Hastings A, Schlamadinger B, Taylor G, Smith P. 2006. Energy crops: current status and future prospects. Global Change Biology 12: 2054–2076.

Sladký V, Dvořák J, Andert D. 2002. Obnovitelné zdroje energie – fytopaliva (Renewable energy sources – phytofuels). Prague: VÚZT. 64p.

Sladký V. 2004. Konopí, šance pro zemědělství a průmysl (Hemp, the chance for agriculture and industry). Prague: ÚZPI. 64p.

Slejška A. 2010. Matematické modely pro pěstování energetických a průmyslových plodin v devastovaných oblastech (Mathematical models for cultivation of energy crops in devastated areas). Biom.cz. Available at http://biom.cz/cz/odborne-clanky/matematicke-modely-pro-pestovanienergetickych-a-prumyslovych-plodin-v-devastovanych-oblastech: Accessed 2014 – 1 - 12.

Soldatos P, Lychnaras V, Asimakis D. 2009. F4 – Future Crops: Cost Breakdown of Conventional Crops in Europe. Athens: Agricultural university of Athens. 33p.

Stolarski M J, Krzyzaniak M, Graban L. 2010. Evaluation of energy – related and economic aspects of heating a family house with dendromass in the north – east of Poland. Energy and Buildings 43: 433 – 439.

Stolarski M J, Szczukowski S, Tworkowski J, Krzyzaniak M, Gulczynski, Mleczek M. 2013. Comparison of quality and production cost of briquettes made from agricultural and forest origin biomass. Renewable Energy 57: 20 – 26.

Strašil Z, Šimon J. 2009. Stav a možnosti využití rostlinné biomasy v energetice ČR (Actual and potential utilization of herbaceous biomass in energetics). Biom.cz. Available at http://biom.cz/cz/odborneclanky/stav-a-moznosti-vyuziti-rostlinne-biomasy-v-energetice-cr: Accessed 2014 – 1 – 12.

Stupavský V, Holý T. 2010. Brikety z biomasy – dřevěné, rostlinné, směsné brikety (Briquettes from biomass – woody, herbaceous, mixed briquettes). Biom.cz. Available at http://biom.cz/cz/odborne-clanky/brikety-z-biomasy-drevene-rostlinne-smesne-brikety: Accessed 2014 – 1 – 12.

Široká M. 2007. Konopí jako alternativa pro zemědělství I průmysl České republiky (Hemp as an alternative for agriculture and industry of the Czech Republic). Agro 3 – 5: 87 – 89, 85 – 88, 64 – 67.

Široká M. 2009. Konopí seté – energetická a průmyslová plodina třetího tisíciletí (Hemp – energy and industrial crop of third millennium). Biom.cz. Available at http://biom.cz/cz/odborne-clanky/konopi-sete-energiticka-a-prumyslova-plodina-tretiho-tisicileti: Accessed 2014 – 1 – 14.

Šnobl J et al. 2004. Rostlinná výroba IV. (Crop production IV.). Prague: Power Print. 119p.

Tutt M, Olt J. 2011. Suitability of various plant species for bioethanol production. Agronomy Research Biosystems Engineering Special issue 1: 261-267.

United Nations. 1998. Kyoto protocol to the United Nations Framework Convention on Climate Change. New York. 20p.

United Nations. 2012. Doha Amendment to the Kyoto Protocol to the United Nations Framework Convention on Climate Change. New York. 82p.

Ústav zemědělské ekonomiky a informací. 2013. Výběrové šetření hospodářských výsledků zemědělských podniků v síti FADN CZ za rok 2012. Prague: ÚZPI. 131p.

AgroConsult. 2011. Normativy pro zemědělskou a potravinářskou výrobu: Pěstební technologie – Konopí pro stonek (Norms for agricultural production: Cultivation technologies – Hemp for cultivation of stem). Available at http://www.agronormativy.cz/docs/6050039_rslt.html: Accessed 2014 – 1 – 25.

Weger J, Strašil Z, Honzík R, Bubeník J. 2012. Možnosti pěstování biomasy jako enrgetického zdroje v Ústeckém kraji (Possibility of biomass cultivation as a source of energy in Ustecky region). Průhonice: Výzkumný ústav Silva Taroucy pro krajinu a okrasné zahradnictví. 78p.

9 Annexes

List of annexes

Table 1. Technological process of briquettes production from hemp

Operation	Repetition	Fuel (l, kW)	Labour (h)	Machinery
Liming up to 2t/ha incl. transport	0.1x	5.1*0.1 0.51	0.7*0.1 0.07	Wheel tractors 4x4 100 - 119 kW, self – propelled fertilizers spreaders
Manure spreading 30t/ha incl. transport	0.15x	24*0.15 3.6	1.5*0.15 0.23	Wheel tractors 120 - 199 kW, muck spreaders
Fertilization with solid mineral fertilizers 0.25 t/ha incl. transport	1x	2.40	0.36	Wheel tractors 4x4 100 - 119 kW, self – propelled fertilizers spreaders
Deep tillage	1x	26.50	0.83	Wheel tractors 120 - 199 kW, 7 bottom reversible plough, grooved rollers up to 5m
Hauling	1x	6.50	0.22	Wheel tractors 4x4 80 - 99 kW, tooth harrow over 9m
Fertilization with solid mineral fertilizers 0.3t/ha incl. transport	1x	2.00	0.29	Wheel tractors 4x4 100 - 119 kW, self – propelled fertilizers spreaders
Seedbed preparation	1x	8.20	0.29	Wheel tractors above 200 kW, combinators with swath over 6m
Sowing	1x	4.20	0.29	Wheel tractors 4x4 80 - 99 kW, universal drill machine above 6 m
Hemp mowing	1x	8.50	0.71	Wheel tractors 4x4 70 - 79 kW, mowing machine
Tedding - A	2x	3.3*2 6.6	0.2*2 0.4	Wheel tractors 4x4 80 - 99 kW tossing machine
Swathing	1x	4.0	0.2	Wheel tractors 4x4 80 - 99 kW, line spacing machine
Baling	1x	4.3	0.56	Wheel tractors 4x4 80 - 99 kW, baler 1.6 m
Transport for yields above 10 t	1.2x	1.2*5 6.0	1.2*0.5 0.6	Wheel tractors 4x4 100 - 119 kW, tipping trailers 10 - 14 t
Stubble tillage	1x	8.00	0.31	Wheel tractors 120 - 199 kW, plate cultivator 6.3 m
Separating and crushing				
Bialobrzeskie - A	1x	330.0	10.91	
Ferimon - A	1x	367.8	12.16	Separator 8.5 kW, shredder 22 kW
Bialobrzeskie - S	1x	246.8	8.16	
Ferimon - S	1x	281.9	9.32	
Briquetting				
Bialobrzeskie - A	1x	1,963.8	24.55	
Ferimon - A	1x	2,188.8	27.36	Brikstar 400
Bialobrzeskie - S	1x	1,468.8	18.36	

Ferimon - S	1x	1,677.6	20.97

(A – autumn harvest, S – spring harvest)

Table 2. OLS model. Dependent variable: profitability F in autumn harvest

	Coefficient	Std. error	t-ratio	p-value
Constant	-0.635604	0.00673498	-94.37	8.53e-135 ***
Yield	0.0433128	0.000508753	85.14	3.00e-128 ***

Mean dependent variable	-0.094194	S.D. dependent variable	0.191361
Sum squared residual	0.110645	S.E. of regression	0.02725
R-squared	0.979857	Adjusted R-squared	0.979721
F (1, 149)	7247.994	P-value (F)	3.00E-128

Table 3. OLS model. Dependent variable: profitability B in spring harvest

	Coefficient	Std. error	t-ratio	p-value
Constant	-0.577765	0.00739829	-78.09	8.73e-123 ***
Yield	0.0440608	0.000558859	78.84	2.19e-123 ***

Mean dependent variable	-0.027005	S.D. dependent variable	0.194992
Sum squared residual	-0.027005	S.E. of regression	0.029934
R-squared	0.97659	Adjusted R-squared	0.976433
F (1, 149)	6215.858	P-value (F)	2.20E-123

Table 4. OLS model. Dependent variable: profitability F in spring harvest

	Coefficient	Std. error	t-ratio	p-value
Constant	-0.62872	0.00681841	-92.21	2.55e-133 ***
Yield	0.0434243	0.000515055	84.31	1.24e-127 ***

Mean dependent variable	-0.085916	S.D. dependent variable	0.191892
Sum squared residual	0.113403	S.E. of regression	0.027588
R-squared	0.979469	Adjusted R-squared	0.979331
F (1, 149)	7108.183	P-value (F)	1.20E-127

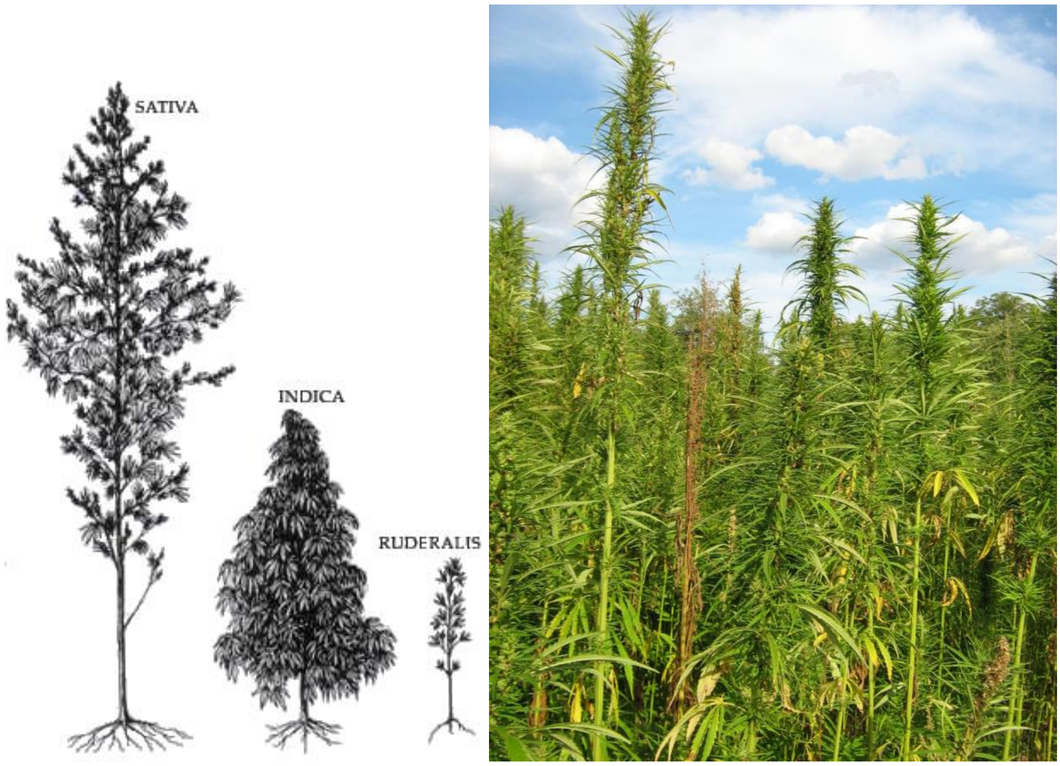

Figure 1. (from the left) Hemp plants according to type; hemp field of *Cannabis sativa* L (Source: Ruman and Klvaňová, 2008; Konopa, 2007)

Figure 2. Briquettes and pellets from industrial hemp (Source: Široká, 2009)

Figure 3. Hemp experimental field in Prague - Suchdol - sowing of hemp, 14.5.2012

Figure 4. Hemp experimental field in Prague - Suchdol - harvesting, 10.10.2012

Figure 5. (from the left) Biomass shredder STM 201HL, briquetting press BrikStar 400