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HEMP BIOMASS AND BIODISEL

Muhammad Arshad Ullah[1] and Ali Hassan[2]
[1]Pakistan Agricultural Research Council, Islamabad, Pakistan
[2]PMAS- University of Arid Agriculture, Rawalpindi, Pakistan

ABSTRACT: *Hemp (Cannabis sativa L.) is grown for various purposes of using the fibre, cha and seeds. It is one of the oldest non-food crops in the world. In Europe, hemp, together with flax, were the most important fibre plants from the 16th to 18th centuries. Later, hemp cultivation diminished but, recently, in many countries, such as Germany, France, the Netherlands, Great Britain, Spain and Italy, interest in this plant is growing, particularly in properties other than fibre. Hemp has been rediscovered as an interesting industrial plant with great uses that can be grown under a wide range of agro-ecological conditions, and is more efficient compared to many other plants. It is important that hemp biomass is also processed into a number of hemp-derived products, including oil, essential oils or CBD (cannabidiol) substances, building material and biofuel, thereby producing many components that have been of great interest to people lately. Properties of this plant have made it an excellent raw material for the development of multi-output systems through gradual distribution of biomass into several useful components. In terms of growing hemp, due to the abundant vegetative part of the plants, large biomass increases (up to 50 cm/month) show great opportunities to use solar energy and* CO_2 *during photosynthesis (up to 2.5 Mgha*$^{-1}$*), which strengthens its position in the group of energy plants contributing to renewable energy sources. In terms of its energy use, it is important that the green crop yield from hemp is, on average,14.5 tha*$^{-1}$ *(calculated on the dry matter), of which 70–75% are hemp shives (by-products of hemp processing), which are usually left in the field, constituting organic fertilizer. It is possible to obtain approximately 10.5 tha*$^{-1}$ *of raw material, which can be potentially used for energy purposes. At the same time, hemp biomass shows a significant variation in fuel properties (calorific value, heat of combustion, ash content, ash softening temperature) depending on the season in which the harvest takes place. Research conducted by).Hemp has high dry matter content and good energy concentration per hectare. Moreover, hemp has a good ratio of energy efficiency to input and is, therefore, an above-average energy crop. With respect to other energy crops, the advantages also occur outside the energy balance, e.g., they relate to the low level of required pesticides and good competition in relation to weeds. Biodiesel has many environmentally beneficial properties. It is one of the largest sources of energy reserves in the world as it approximately supplies 14% of world's energy consumption. Many initiatives are being given for promoting the biofuels. Among the biofuels, biodiesel gets more momentum as it has properties similar to the properties of diesel fuel. Biodiesels are biodegradable, renewable and more environment friendly than petroleum based fuels. One promising source for biodiesel production is the fiber crop Cannabis sativa. It is an annual herb and its cultivation has a low cost and a low environmental impact. Cannabis sativa plant grown in temperate zones as an annual cultivation from seed and can reach a height of up to 5 meters (16 feet). Seeds have high oil content, ranging from 26% to 42%. In addition, cannabis sativa has advantage as a fuel source. It has a high biomass content which can be fermented to create low carbon fuels, such as bioethanol or biobutanol.*

KEYWORDS: hemp, biomass, biodisel

INTRODUCTION

Energy crops have been repeatedly reported to have high potential to increase the share of renewable energy (Bo¨rjesson, 2007; EEA, 2007; Fischer *et al*., 2010; Hoogwijk *et al*., 2005). As the land available for food, feed and energy production is limited, high land use efficiency, i.e. indicated by high energy yields per hectare, is of critical importance (FAO, 2008). At present, it is often only the grains or seeds from conventional food crops that are used for energy production, e.g. ethanol from wheat grains or biodiesel from rape seed (Ruane *et al*., 2010). Crops in which the whole-plant biomass can be used for energy production can potentially result in higher land use efficiency (Ruane *et al*., 2010). However, few such so-called dedicated energy crops (e.g. maize in Germany) are currently grown in large-scale cultivation in Europe (Ericsson and Nilsson, 2006). Even fewer of those are annual crops that could be fitted into a crop rotation with food and feed crops, which is an important aspect of sustainability in bioenergy production (Amon *et al*., 2007).

Industrial hemp (*Cannabis sativa* L.) can potentially fulfill these requirements. Besides high land use efficiency, other factors such as low requirement for pesticides, good weed suppression and improvement of soil health justify the use of hemp as an energy crop (Bernesson, 2006; Bocsa and Karus, 2011) Also, farmers' preferences for annual or perennial crops have to be taken into account when comparing hemp biomass production to that of perennial energy crops, such as willow.

Hemp is an annual herbaceous crop historically grown predominantly for fibre production (Pahkala *et al*., 2008). Use of hemp biomass for energy purposes has been reported in many countries, e.g. in the USA (Castleman, 2006), Ireland (Rice, 2008), Spain (Casas and Rieradevall, 2005), Germany (Brodersen *et al*., 2002; Plo ¨chl *et al*., 2009) and Poland (Burczyk *et al*., 2008). In Sweden, hemp is already mainly grown for energy purposes (Sundberg and Westlin, 2005). In 2007, hemp was cultivated on approx. 800ha in Sweden (Rolandsson, 2008). Most of this biomass was processed into briquettes and sold locally as a solid fuel for private households.

Other energy applications such as biogas production by anaerobic digestion (AD) or ethanol production by fermentation from hemp are currently under investigation (Heiermann *et al*., 2009; Kreuger *et al*., 2010; Sipos *et al*., 2010). Utilization in combined heat and power (CHP) plants built for combustion of baled straw fuels has also been suggested (Sundberg and Westlin, 2005; Rolandsson, 2008 Heiermann *et al*., 2009; Kreuger *et al*., 2010; Sipos *et al*., 2010; Mattsson, 2006).

Growing hemp for energy purposes is relatively new and limited knowledge exists about the optimal harvesting dates and the potential biomass and energy yields for the above-mentioned applications. Hemp harvesting dates for biogas production appear to differ from those for briquette and pellet production (Bernesson, 2006; Rice, 2008). High biomass dry matter (DM) yield and high degradability are advantageous for methane energy yield and high moisture content (MC) is seen as no disadvantage (Kreuger *et al*., 2010). In contrast, a low MC is necessary for applications as a solid fuel in order to: (a) decrease losses due to microbial degradation during storage (MC<30%; (b) achieve sufficient cohesion of e.g. pellets after compression of biomass (10%<MC<20%; and (c) decrease energy losses in straw-fired boilers not equipped with flue gas condensation (MC<20% (Mattsson, 2006; van Loo and Koppejan, 2008).

The potential DM yield of industrial hemp has been reported in several studies investigating fibre production (Blouw and Sotana, 2007; Deleuran and Flengmark, 2005). However, the field trials in most investigations have been carried out in regions with a warmer climate or with shorter summer day length, or both, compared with the region investigated in this study. Late maturing varieties of hemp have been suggested to be able to produce high DM yields even in cold climate regions (Pasila, 2004), to which Scandinavia, Eastern Europe, Canada and the north-eastern quarter of the USA belong (Peel *et al*., 2007).

Nitrogen (N) fertilization has been found to have a positive effect on hemp biomass DM yields (Struik *et al*., 2000). However, the magnitude of the response is rather moderate and not consistent for all years and locations (Struik *et al*., 2000).

Hemp (*Cannabis sativa* L.) is grown for various purposes of using the fibre, cha and seeds. It is one of the oldest non-food crops in the world. In Europe, hemp, together with flax, were the most important fibre plants from the 16^{th} to 18^{th} centuries. Later, hemp cultivation diminished but, recently, in many countries, such as Germany, France, the Netherlands, Great Britain, Spain and Italy, interest in this plant is growing, particularly in properties other than fibre (Struik *et al*., 2000). Hemp has been rediscovered as an interesting industrial plant with great uses that can be grown under a wide range of agro-ecological conditions, and is more efficient compared to many other plants (Burczyk *et al*., 2008; 2016). Due to biological and agrotechnical features corresponding to economic, environmental and social criteria, this plant fits very well with the concept of sustainable development. It is important that hemp biomass is also processed into a number of hemp-derived products, including oil, essential oils or CBD (cannabidiol) substances, building material and biofuel, thereby producing many components that have been of great interest to people lately. Properties of this plant have made it an excellent raw material for the development of multi-output systems through gradual distribution of biomass into several useful components. This feature is ahead of many other industrial crops, from which only one type of raw material is usually extracted (Struik *et al*., 2000; Burczyk *et al*., 2016). Growing hemp is not difficult and requires little or often no biocides for cultivation because this plant effectively suppresses weeds and has limited requirements for the fertilizers used and crop rotation. The main problem may be establishing a crop because hemp is very sensitive to poor soil structure and water shortage or excess during the early stages of growth. There is also a high degree of heterogeneity in cultivation.

This is partly due to sexual dimorphism: differences in growth and development rates between male and female plants are large. Larger plants suppress smaller ones, thus, the variation between plants can become significant. Male plants tend to age earlier. In terms of growing hemp, due to the abundant vegetative part of the plants, large biomass increases (up to 50 cm/month) show great opportunities to use solar energy and CO_2 during photosynthesis (up to 2.5 $Mgha^{-1}$), which strengthens its position in the group of energy plants contributing to renewable energy sources. Particularly important is the pile root system of hemp, which can use nutrients and water found in deeper layers of soil, which creates good conditions for its production as well as obtaining high yields of organic matter. These features are important in connection with global warming and the lowering of the ground water level, especially in areas with small amounts of precipitation (<550 mm) (Burczyk *et al*., 2008;, Campiglia *et al*., 2017; *et al*., 2008;Doł ˙zy´nska *et al*., 2018; Saif *et al*., 2013).

In terms of its energy use, it is important that the green crop yield from hemp is, on average, 14.5 tha^{-1} (Schluttenhofer andYuan, 2017) (calculated on the dry matter), of which 70–75% are hemp shives (by-products of hemp processing), which are usually left in the field, constituting organic fertilizer. It is possible to obtain approximately 10.5 tha^{-1} of raw material, which can be potentially used for energy purposes. At the same time, hemp biomass shows a significant variation in fuel properties (calorific value, heat of combustion, ash content, ash softening temperature) depending on the season in which the harvest takes place. Research conducted by (Prade *et al.,* 20111;2012) shows a qualitative advantage of hemp harvested in spring and winter over that harvested in autumn, e.g., the heat of combustion of hemp biomass collected in August–December was, on average, 18.4 $MJkg^{-1}$, versus that collected in January–April of 19.1 $MJkg^{-1}$,while research by Kołodziej et al. (2012); indicate that the heat of combustion of these plants is greater than the heat of Jerusalem artichoke (Helianthus tuberosus) (16.5 $MJkg^{-1}$) and only slightly smaller than the heat of burning Miscanthus, ca. 19.8 $MJkg^{-1}$).

Features of the raw materials of plant origin have a decisive influence on the process of their pressure agglomeration and on the quality of the obtained product (Doł ˙zy´nska *et al*., 2018; Hejft, 2012). There are three main activities necessary to produce molded solid fuel: drying, comminution and molding. Each of them, due to the mechanical properties of the fibre, requires an individual approach, however, due to the energy consumption of these processes, it would be expedient to use hemp biomass in the form of bales and cubes for energy purposes (Czekała *et al*.,2015; Niedziółka *et al*.,2015). Broader possibilities of using hemp biomass are given by its thermochemical transformation in biogas and ethanol production where both wet and ensiled biomass can be used (Idler *et al.*, 2011). However, these processes, according to Kreuger (2012), are economically dependent on the market prices of the raw material and require the cheapest raw materials for profitability. At the same time, the use of silage hemp for this production is very uncertain, because the ensilage process is not yet very popular in the Lublin region. In Lublin region however biomass is available on the market as a residue from hemp seed production. As indicated by Ivanova et al. (2018), grinding the hemp to a particle diameter of 8 mm requires an energy consumption of 117 $kWht^{-1}$, which is about50% smaller than the briquetting capacity for fruit biomass at 25 kg h^{-1}. However, compaction itself requires an energy demand of about 110 $kWht^{-1}$, which is almost 40% more energy-intensive than for fruit wood. At the same time, problems related to cutting the hemp biomass are the subject of research on reducing its energy consumption and optimizing the efficiency of this process (Kakitis *et al*., 2016; Kronbergs *et al*., 2011).

In the absence of high-pressure aggregation, the energy density of the plant material is low. Increasing this parameter is obtained by using plant biomass compacted to form cylindrical bales or cubes. However, the use of such biofuels is possible in boilers that are used in a specific group of installations and loading and achieved capacities often limit the possibility of using such devices. Thus, these forms of biofuels, intended for heating single-family buildings, are very popular in Poland (Heykiri-Acma, 2003; Mc Kendry, 2002; Kjallstr and Olsson, 2004). This analysis also serves as a measure of economic sustainability, as well as environmental impact LCA (life cycle assessment) and the possibility of reducing the CO_2 emission (greenhouse gases). Therefore, when assessing the energy use of hemp, energy balance and energy efficiency are important, which are key to clarifying the following doubts: indicating how much energy the crop produces pernit of energy input; and the energy balance can reveal existing reserves and optimization of energy expenditure in the production process.

However, studies from the literature show that hemp has high dry matter content and good energy concentration per hectare. Moreover, hemp has a good ratio of energy efficiency to input and is, therefore, an above-average energy crop. With respect to other energy crops, the advantages also occur outside the energy balance, e.g., they relate to the low level of required pesticides and good competition in relation to weeds (Kolarikova *et al*., 2013). There is little information in the available literature on the study of hemp briquette burning in low-power heating devices that would allow a more complete assessment of their suitability for energy use. It is important that the combustion of biomass fuels may favour the formation of increased loads of pollutants, both dust and gas, introduced into the environment, which was also observed when burning the hemp biomass pellets (Doł ˙zy´nska *et al*., 2018).

Biodiesel is a renewable energy alternative to fossil fuels that is composed of a group of long chain fatty acids called mono-alkyl esters. It is a highly efficient diesel replacement that is produced by a process called transesterification, a chemical reaction between vegetable or animal fat and alcohol in the presence of a catalyst to produce biodiesel (Mannan *et al*., 2006). Unlike diesel produced from petroleum, it contains very low level of sulfur, which produces sulfur oxide (SOx) emissions when burned, a major precursor to acid rain (He *et al*., 2009). Additionally, biodiesel requires no modifications to the diesel engine. Currently, biodiesel is produced commercially mainly from soybean oil in the United States, Palm Oil is Southeast and East Asia and rapeseed oil in Europe(Rosillo-Calle *et al*., 2009).

Statistics on Hemp biodiesel yield are scarce since the production of hemp biodiesel fuel remains an untapped territory. However, biodiesel yield can be estimated using a number of mathematical formulas taking into account hemp seed yield and oil content of the seed, biodiesel conversion rate, etc. The hemp seed yield of the most productive variety of hempseed can exceed 2000 Kg/Ha under good growing conditions (FINOLA, 2014) (Callaway, 2010). Hemp seeds contain an oil content of roughly 30-35% of the seed weight (FINOLA 2014) (Leizer *et al*., 2000). For the sake of this report, it is assumed that the average yield of hemp seed is 2000 Kg/Ha. Another important factor in calculating the hemp biodiesel yield is the biodiesel conversion rate, which is the rate of biodiesel output to hemp oil input in the process of transesterification. The conversion of Cannabis Sativa L. seed oil into biodiesel has a high rate of conversion that is greater than 99.5% with a total product yield of over 97%. This means that the product loss due to saponification is very low (Li *et al*., 2010).

Biodiesel is produced commercially from a variety of crops, mainly from soybean oil in the United States; Palm Oil is Southeast and East Asia and rapeseed oil in Europe (Rosillo-Calle *et al*., 2009).

Biodiesel can be blended with petroleum diesel at different percentages. The "B" factor is universally used to designate the percentage of biodiesel in the mix (National Biodiesel Board 2015). The most common of these blends are B100, B20, B5 and B2 which contain 20%, 5% and 2% respectively. Fuels are blended for various reasons such as environmental compliance. For example, the Brazilian government has made it mandatory for vehicles to run on blended fuels since 1976 (Biofuels UK, 2015). B20 biodiesel blend is one of the most common blended fuels. It is popular because it represents a good balance of improved performance, lower emissions, materials compatibility, cost and its ability to act as a solvent. Additionally, biodiesel blends of 20% or lower do not require any modification to the diesel engine (NREL, 2015). Biodiesel can also be used without blending (B100), however, certain modifications to the engine are required to avoid maintenance and performance issues (NREL, 2015). B100 (Pure Biodiesel) contains 8% less energy content than its petroleum counterpart. Hemp performs well in biodiesel blends. In one comparative study, it is found that hemp B20 blend provides better thermal efficiency, lower specific fuel consumption, reduced CO and CO_2 emissions in comparison to pure diesel and Jatropha B20blends. However, the hemp blend has a higher NOx emission in the study (Gill *et al*., 2011).

Effectively, hemp could provide the means to by which we are not introducing additional carbon into the environment. Therefore, offering another alternative fuel source to offset our reliance on fossil fuels (Thompson, 2013). The carbon dioxide emissions released to the atmosphere when burning biodiesel is reabsorbed through photosynthesis. The short life cycle of hemp allows for crop rotation such as winter cereals which is beneficial to the soil and the yield of both types of crops (Thompson, 2013).

Today, 86% of the world energy consumption and almost 100% of the energy needed in the transportation sector is met by fossil fuels. The limited availability of resources of fossil fuels and increased demand in various fields such as power generation, transport, and agriculture triggered the research in finding out alternate sources to replace or reduce the dependency of fossil fuels. Among the alternate fuels alcohols and biodiesel from various vegetable oils are the major resources (Rakopoulos *et al*., 2008).

Biodiesel has many environmentally beneficial properties. It is one of the largest sources of energy reserves in the world as it approximately supplies 14% of world's energy consumption (Capunitan and Capareda, 2012). Many initiatives are being given for promoting the biofuels. Among the biofuels, biodiesel gets more momentum as it has properties similar to the properties of diesel fuel (Biradar *et al*., 2014). Biodiesels are biodegradable, renewable and more environment friendly than petroleum based fuels (Ashok *et al*., 2016). One promising source for biodiesel production is the fiber crop Cannabis sativa. It is an annual herb and its cultivation has a low cost and a low environmental impact. Cannabis sativa plant grown in temperate zones as an annual cultivation from seed and can reach a height of up to 5 meters (16 feet). Seeds have high oil content, ranging from 26% to 42% (Schumann *et al*., 2004). In addition, cannabis sativa has advantage as a fuel source. It has a high biomass content which can be fermented to create low carbon fuels, such as bioethanol or biobutanol Moxley et al. (2008).

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