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Investigations about the impact of the sowing time and rate of the biomass yield and quality of industrial hemp

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Abstract. The aim of this study was to find the optimum sowing rate of industrial hemp (*Cannabis sativa* L.) and to clarify the impact of the sowing rate on the production of biofuel from hemp biomass in Latvia. Field trials were carried out at the Research and Study Farm 'Pēterlauki' of the Latvia University of Agriculture in 2012–2014. The industrial hemp (*Cannabis sativa* L.) 'Futura 75' was sown in a Luvic Endogleyic Stagnosol soil: pHKCl 6.7; P – 52 mg kg^{-1}; K – 128 mg kg^{-1}; the organic matter content – 21–25 g kg^{-1}. Hemp was sown in 10 m^2 plots, triplicate, on May 8 and 17. The total sowing rate was 20 (100), 30 (150), 40 (200), 50 (250), 60 (300), 70 (350), 80 (400), 90 (450), and 100 (500) kg ha^{-1} (germinating seeds per 1 m^2). The plots were fertilised as follows: N – 120 kg ha^{-1}; P_2O_5 – 80 kg ha^{-1}; and K_2O – 112 kg ha^{-1}. Hemp was harvested when the first matured seeds appeared. The biometrical indices (height and stem diameter), harvesting time, the amount of fresh and dry biomass, and the fibre content were evaluated. Depending on the sowing rate, the yield of dry matter was on average 9.2–12.1 t ha^{-1} when hemp was sown at the beginning of May, and 7.9–10.0 t ha^{-1} when hemp was sown in the middle of May.

Key words: industrial hemp, sowing time and rate, yield, quality.

INTRODUCTION

Hemp is considered to be one of the most promising renewable biomass sources to replace the non-renewable natural resources for the manufacturing of a wide range of industrial products in the world and also in Latvia (Adamovics et al., 2012; Ivanovs et al., 2015; Lekavicius et al., 2015).

The efficiency of industrial hemp (*Cannabis sativa* L.) from seed requires the establishment of an ideal sowing rate, which determines the final plant sowing density. Under-sowing may result in undesirable product qualities and poor yield (Ranalli, 1999) in addition to increased competition by weeds (Mosjidis & Wehtje, 2011), harvesting difficulty associated with thicker stems (Bocsa & Karus, 1998), and particularly reduced radiation use efficiencies (Bullard et al., 2009). Excessive planting densities in hemp crops result in increased self-thinning and a slowing down of crop growth rate in the later stages of development (Van der Werf et al., 1999). The appropriate density of planting varies with the variety, season, soil type, and range of other agronomic practices adopted for the crop. Hence, sowing density for any variety should be optimised for the particular location of interest. Industrial hemp is also sown at different densities depending on the purpose of the crop: whether it is for fibre or for grain. The recommended seed rate for the latter (i. e., seed crop) is often around 30 kg ha^{-1} or 100–150 plants m^{-2} (Bocsa & Karus, 1998). Low sowing density for a seed crop allows for greater branching, shorter plant height, and heavy individual plant weight compared to fibre crops sown at higher density. The latter suppresses branching and induces taller and lighter individual plants.

Harvesting of hemp crops for fibre at maturity is much easier when plants are upright and have few branches, and the quality of fibre is better in unbranched plants. Planting density for fibre hemp is roughly twice that of seed hemp. Early researches (Bocsa & Karus, 1998) suggest that no more than 80 kg seed ha^{-1} be sown for fibre hemp as little differences in the final yields were observed from 60 to 100 kg ha^{-1} (300–500 plants m^{-2}). These rates are considered, however, excessive for non-textile fibre hemp that is produced for the volume of fibre rather than for the quality. Sowing rates for non-textile fibre may be adequate at 30 kg ha^{-1} (Burczyk et al., 2009). High sowing rates generally produce shorter and thinner stemmed plants (Amaducci et al., 2008) with a higher proportion of fibre in the stem material, which is desirable for fibre hemp (Van der Werfet et al., 1999).

The sowing rate, depending on the intended use, may not change greatly among the varieties. In a study conducted in Wales by Bennett and other researchers (2006), five varieties were sown at 150 and 300 plants m^{-2}. The results indicated that although the final total fibre yield increased at a higher density, no inter-varietal interaction with sowing rate was observed. The proportion of fibre in the harvested straw increased slightly at a higher density despite the proportion of the long fibre remaining the same. Hemp fibre yields of around 2–3 t ha^{-1} and the final plant heights of 1.5–3.0 m are typical of economically viable hemp crops in Europe (Bocsa & Karus, 1998). Crop maturity with respect to harvest times is often not well defined in the literature and differs depending on the final crop use or the opinion of the researcher (Hall et al., 2013).

Harvest times for the current experiment were based on growth rates (harvest was conducted when plant heights ceased to increase), which may have affected the quality of the final best fibres.

The aim of this study was to find the optimum sowing rate of industrial hemp (*Cannabis sativa* L.) and to clarify the impact of the sowing rate on the production of biofuel of hemp biomass in Latvia.

MATERIALS AND METHODS

Field trials were carried out at the Research and Study farm ‘Pēterlauki’ (56°53' N, 23°71' E), supervised by the Latvia University of Agriculture, in 2012–2014. The industrial hemp (*Cannabis sativa* L.) ‘Futura 75’ was sown in a Luvic Endogleyic Stagnosol soil: pHKCl 6.7; P – 52 mg kg^{-1}; K – 128 mg kg^{-1}; the organic matter content – 21–25 g kg^{-1}. ‘Futura75’ is a French monoecious variety, medium height (2.5–3.0 m), late-maturing in Latvia (125–135 days), grown for fibre and pulp.

Hemp was sown in 10-m^2 plots, triplicate, on May 8 and 17, using a ‘Wintersteiger’ plot sowing machine. The total sowing rate was 20 (100), 30 (150), 40 (200), 50 (250), 60 (300), 70 (350), 80 (400), 90 (450), and 100 (500) kg ha^{-1} (germinating seeds per 1 m^2). The plots were fertilised as follows: N – 120 kg ha^{-1}; P_2O_5 – 80 kg ha^{-1}; K_2O – 112 kg ha^{-1}. Hemp was harvested using a small mower MF-70, when first matured seed appeared. In the field rotation, the industrial hemp followed the previous crop – spring barley.

The parameters of meteorological conditions (mean air temperature, °C, and rainfall, mm) were recorded by the weather station located on the trial field (Adamovics et al., 2016). In the years 2012–2014, the period for hemp seed emergence was favourable, but in 2013, there was a lack of precipitation (the 1st ten-day period of June). In 2016, drought and warm weather were recorded in June and July, while in 2014, this period was much more abundant in rainfall. The rainfall in June and July is important as it strongly influences the yield. The mean air temperature in August was very similar in all the research years, but the amount of rainfall differed markedly: in 2014, it was twice as high as the long-term average, and in 2013, it was approximately twice as low as the long-term average. In September and in the 1st ten-day period of October, the weather was quite dry (not favourable) in all the research years.

The quality of fuel is characterized by the following main characteristics: higher and lower calorific value, ash content, and ash melting point. The net calorific value of biomass fuel is significantly affected by fuel moisture content. The gross calorific value was measured according to the standard LVS EN 14918 using the oxygen bomb calorimeter. Ash content was determined according to the standard LVS EN 14775. Ash melting temperature determination should be carried out using a number of recommendations for the standards ASTM D1857, ISO540, and LVS EN 15370-1. Ash melting temperature was determined using the standard ash cone shape change by heating the ash with oxygen-enriched environment. The combustion characteristics of the samples were tested in the company ‘Virsma' Ltd in accordance with the above mentioned standards.

Ash melting temperature tested according to the standard was defined for four characteristic points of a sample cone: DT, ST, HT, and FT.

Ash melting temperature has four phases: DT – the initial point of deformation, when the sharp peak is rounding; ST – softening temperature, when the ash cone deforms to such extent that the height of the structure reduces to the size of its diameter; HT – the point of the formation of hemisphere, or the cone collapses and becomes dome-shaped; FT – flow temperature, when the liquid ash dissipates along the surface (Kakitis et al., 2009). The chemical composition of biomass was determined in the Agricultural Scientific Laboratory for Agronomic Analyses of LLU. The yield of absolutely dry hemp biomass was calculated according to the data of fresh biomass and its moisture content at harvesting in the study years. The DM yield data were statistically processed using the analysis of variance. Means were separated by the LSD and were declared different at the $P < 0.05$ level.

RESULTS AND DISCUSSION

Field trials established that in Latvia’s agro-climatic conditions, the yield of hemp dry matter is dependent on hemp cultivation year, meteorological conditions, sowing times, and sowing rate. In the three-year study period independently of the sowing rate, the dry matter yield was on average 11.74 t ha^{-1} when hemp was sown at the beginning of May, and 10.75 t ha^{-1} when hemp was sown at the end of the second decade of May.

A 10-day delay of the sowing time decreased the hemp dry matter yield by approximately one ton per hectare (Table 1).

Table 1. The biomass yield of industrial hemp depending on different sowing times and rates, 2012–2014

Sowing rate (F_A)		Dry biomass, t ha^{-1}			
		Years (F_C)			
		2012	2013	2014	
Hemp was sown on May 8 (F_B)					
20	100	8.46	9.32	12.24	10.01
30	150	9.00	10.11	13.66	10.92
40	200	9.81	10.29	14.54	11.55
50	250	10.02	10.65	14.61	11.76
60	300	10.91	10.72	15.18	12.27
70	350	11.23	11.03	16.13	12.80
80	400	11.23	12.17	16.77	13.39
90	450	10.84	11.36	16.62	12.94
100	500	9.44	10.21	13.55	9.45
Average		10.10	10.65	14.81	11.86
Hemp was sown on May 17 (F_B)					
20	100	9.50	7.83	11.01	9.45
30	150	9.51	8.46	12.21	10.06
40	200	9.56	8.99	12.53	10.36
50	250	9.68	9.74	13.25	10.89
60	300	10.30	9.77	13.8	11.29
70	350	10.57	9.96	15.82	12.12
80	400	10.17	9.92	15.34	11.81
90	450	10.21	9.21	14.46	11.29
100	500	9.85	8.86	13.01	9.45
Average		9.93	9.19	13.49	10.87
LSD(F_A)$_{0.05}$ sowing rate			0.72		
LSD(F_B)$_{0.05}$ sowing time			0.42		
LSD(F_C)$_{0.05}$ year			1.53		
LSD(ABC)$_{0.05}$ trial			2.81		

The largest dry matter yield was obtained from the hemp 'Futura 75' when sowing it in an interval of 60–80 kg ha^{-1} or 300–400 germinating seeds per 1 m^2.

In the Directive 2009/28/EC set by the EU countries on the fuel quality parameters, the preferable ash content is set as 0.7–1.5% (Directive 2009/28/EC). In our research, the ash content in hemp differed widely and, on average, exceeded 1.5%, which is the permissible level for fuel.

The average ash content in hemp dry matter is 3.94% (Table 2), which is considerably higher than that of wood pellets and less than that of cereal straw (Kakitis et al., 2009).

An important parameter characterising the burning properties of biomass fuel is ash melting temperature. A low value of ash melting temperature leads to ash slag sintering and causes problems in boiler operation. Point DT characterizes the beginning of cone deformation, and it is the lowest temperature at which the ash melting starts. In all samples, the temperature at which deformation starts was found higher than 1,300 °C.

Ash flow point temperature for all samples exceeded 1,400 °C. The results are similar to wood ash melting point and significantly exceed the cereal straw ash melting temperature (Kakitis et al., 2009). Ash melting temperature is high enough to avoid ash melting and sintering inside the burners. A significant change in the ash melting temperature depending on the sowing norm was not detected.

Reduction of melting temperature is most commonly associated with potassium oxide content increase (Kalnačs et al., 2008). The researchers explain the differences even within the same species by the chemical composition of plants or individual elements, which under the influence of high temperature result in certain chemical reactions (Kaķītis et al., 2009).

The use of wood pellets ensures the use of automatic boilers. In order to ensure automaticity, ash melting temperature should be at least 1,100 °C. The most important phase is DT, as it is usually the shortest phase and more affected by different conditions: chemical composition, applied fertiliser, and the precipitation and air temperature during the period of vegetation (Poisa & Adamovics, 2012; Poisa et al., 2013). In comparison with coal, the ash melting temperature of which exceeds 1,000 °C (Kakitis et al., 2009) or 1,150–1,500 °C (Kronbergs, Šmits, 2009), biomass has a comparatively low ash melting temperature (usually between 750 and 1,000 °C), as it has a very different ash chemical and mineralogical composition (Kakitis et al., 2009).

The research on the relationship between the changes in hemp chemical composition and sowing rate failed in the three-year trials; therefore, the studies should be continued.

The average crude fiber content in hemp DM was 57.3%, lignin content – 9.29% (Table 2).

Table 2. Biomass yield quality of industrial hemp depending on different sowing rates, 2012–2014

Sowing rate of hemp		Content in DM				
kg ha^{-1}	germinating seeds per 1 m^2	Crudefiber, %	Lignin, %	Ash, %	C, %	S, ppm
20	100	56.70	9.14	3.68	42.47	287.23
30	150	58.20	8.08	4.15	43.34	305.12
40	200	56.64	8.99	4.27	42.01	311.12
50	250	58.85	10.11	3.96	44.32	387.74
60	300	60.63	9.55	4.16	41.69	457.50
70	350	56.58	9.57	4.20	43.57	487.58
80	400	55.57	9.94	4.03	43.27	547.47
90	450	57.25	9.12	3.37	41.15	589.65
100	500	55.28	9.14	3.68	42.47	415.15
Average		57.30	9.29	3.94	42.70	420.95

The lignin-containing products could be used to supplant fossil resources (Gosselink et al., 2004). At present, there is a lot of research regarding lignin as a by-product of wood-pulp processing. In Latvia, it is traditional to produce energy from wood products, and in the light of the steep price increase for fossil energy, it has become advantageous also to produce energy from the biomass of agricultural plants.

Lignin content is of great importance for energy crop plants, as chemical additives (glue, lacquer, etc.) are not allowed in granule production. Lignin holds the biomass granule together and does not allow it to disintegrate.

Our results demonstrated only a small difference in the carbon content of hemp depending on the sowing rate, and on average it made 42.70 (41.15–44.32)% in hemp stalk. Also, other studies have shown that carbon content differs within various genera of one family, within various sorts of one species, and even within parts of a single plant (Baxter & Koppejan, 2005; Kronbergs & Šmits, 2009). The content of sulphur in hemp was on average 420.95 (287–589) ppm, which increased with the increase in the sowing rate.

Calorific value is one of the most important indicators characterising the fuel quality. Gross calorific value is the energy contained in the mass unit of the dry matter of fuel. Standards for biofuel from grass (LVS EN ISO 17225 – 6:2014) indicate that the calorific value should comprise 16.3–19 MJ kg^{-1}.

The features of hemp stalks have a large resemblance to the characteristics of wood-pulp. There are cellulose and lignin both in hemp stalks and in wood-pulp. The calorific value of stalks is the same as that of wood-pulp; besides, in the burning process, less ashes are produced. By briquetting or making granules of hemp stalks, good solid fuel can be produced.

In the experiments, it was found that the gross calorific value at constant volume $Q_{gr\ ar}$ of the tested hemp varied from 16.02 to 17.15 MJ kg^{-1}. No significant impact of hemp sowing rates on the calorific values was detected.

In practice, the essential parameter is the total amount of energy that can be obtained from one ha of biomass fuels.

CONCLUSIONS

Hemp with its energy qualities – the high thermal capacity and relatively large dry matter yield – is a good source material for the production of energy, especially if it is utilised mixed with other energy source materials.

In order to obtain hemp biomass for energy production and shives, approximately 60–80 kg ha^{-1} of seed should be sowed. Such seed density produced higher raw fibre yields and qualities associated with the harvest of good-fibre hemp such as thin stalks than did lower planting densities.

The dry matter yield was on average 11.74 t ha^{-1} when hemp was sown at the beginning of May. A 10-day delay of the sowing time decreased the hemp dry matter yield by approximately one ton per hectare.

In all investigated hemp samples, ash melting temperature was higher than 1,300 °C, which indicates the potential of hemp for the production of qualitative solid biofuel.

The carbon content depending on the sowing rate differed only slightly and on average made 42.70%.

The gross calorific value at a constant volume of all tested hemp sowing rates varied from 16.02 to 17.15 MJ kg^{-1}. The average ash content in hemp dry matter was 3.94%, which is considerably higher than that of wood pellets but less than that of cereal straw.

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