INDUSTRIAL HEMP – A PROMISING SOURCE FOR BIOMASS PRODUCTION

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Abstract
The biometrical indices of eight hemp (*Cannabis sativa* L.) cultivars ('Beniko', 'Bialobrezskie', 'Epsilon 68', 'Fedora 17', 'Felina 32', 'Futura 75', 'Santhica 27' and 'USO 31') have been investigated at the Upytė Research Station of LRCAF in 2010-2011. The results of investigation show that this plant is a promising source of biomass, accounting for 38.7 t ha^{-1} of green biomass, and 13.1 t ha^{-1} of absolutely dry biomass. Results of investigation of biomass potential of 8 industrial hemp varieties are presented.
Key words: hemp, biomass production, biomass yield.

Introduction

Hemp has been cultivated over a period of many centuries in almost every European country. Many kinds of products could be produced from this useful plant: textiles for apparel and cottonized hemp, mats for thermal insulation in the construction industry, specialty pulp and paper for technical applications, press-moulded interior panels for the automotive industry, geotextiles for erosion control, needle-punched carpeting, hurds used as animal bedding, seed and oil for food sector, natural bodycare products, gamma linolenic acid in the cosmetics and pharmaceutical industries, natural THC-based therapeutic drugs, etc. (Bocsa et al., 1998).

Nowadays hemp has become very important as a crop for biomass production. Energy production in the form of solid fuel from the whole hemp stem is a relatively new use for the crop (Energy ..., 2009).

Hemp biomass could be used for energy purposes in different ways: by burning (co-fired with coal to reduce emissions and offset a fraction of coal use; burned to produce electricity; pelletized to heat structures; made or cut into logs for heating; gasification), as oils (vegetable, seed and plant oil used "as-is" in diesel engines; biodiesel – vegetable oil converted by chemical reaction; converted into high-quality non-toxic lubricants), by conversion of cellulose to alcohol (Castleman, 2006; Prade, 2011).

The aim of our research was the evaluation of the biomass potential of some industrial hemp varieties to be late on suggested to grow in Lithuania.

Materials and Methods

Research was carried out at the Lithuanian Research Centre for Agriculture and Forestry Upytė Experimental Station on a *Eutri-Endohypogleyic Cambisol*, *CMg-n-w-eu* (Buivydaitė et al., 2001) in 2010–2011. The content of available phosphorus in the soil plough layer was 137–245 mg kg^{-1}, content of available potassium – 129–152 mg kg^{-1} (determined in A-L extraction), pH_{KCl} level – 6.7-7.7 (potentiometrically), humus content – 1.89–2.33 % (by Hereus apparatus). In 2011 soil properties showed rather lower values.

In the field rotation, hemp followed winter wheat. Before sowing, 200 kg of complex fertilizers $N_7P_{19}K_{29}S_3$ and 200 kg of complex fertilizers $N_{16}P_{16}K_{16}$ were applied in 2010 and 300 kg+300 kg of the same fertilisers in 2011. Hemp was sown (seed rate 40-50 kg ha^{-1}) by sowing-machine SLN-1.6 at the beginning of May in the plots of 10 m^2, triplicate. Randomised plot design was used. Protective plots of the same size were sown on both sides of the trial.

All tested cultivars are monoecious (male and female flowers are present on the same plant). The cultivars 'Beniko' and 'Bialobrzeskie' are considered semi-early in Poland, the country of their origin. The cultivar 'Epsilon 68' is late-ripening in France, the cultivar 'Felina 32' (both are of French origin) – semi-late in France, the cultivar 'Futura 75' – late-maturing in France, and the cultivar USO 31 (of Ukrainian origin) is known as very early in France.

Hemp crop density was assessed after full crop emergence and at harvesting.

No pesticides (insecticides, herbicides, desiccants) were used.

Hemp was harvested by a trimmer (leaving the stubble of 5-8 cm) when the first matured seed appeared (it was on September 9th (for the cultivar USO 31) and 4th of October (for the rest part of cultivars) in 2010 and on the 13th of September (for the cultivar USO 31) and the 22-23rd of September (for the other cultivars tested) in 2011.

The yield of green and dry biomass (over-ground mass) was evaluated at hemp harvesting time. The main task of the research presented here was to evaluate biomass potential of different varieties, to discus some parameters influencing on biomass production.

For calculations and statistical evaluation, we used the statistical software developed at the Lithuanian Institute of Agriculture of the Lithuanian Research Centre for Agriculture and Forestry (Tarakanovas et al., 2003).

Meteorological conditions (Table 1) during the experimental years were diverse, but both growing

Table 1

Meteorological conditions during hemp growing season

Month	Ten-day period	Mean air temperature ºC			Rainfall mm		
		2010	2011	Long-term average	2010	2011	Long-term average
May	I	12.6	11.2	11.0	25.0	1.0	16.0
	II	15.6	12.6	12.6	18.0	18.7	16.0
	III	15.1	14.9	13.5	20.5	7.0	18.0
	Average	**14.4**	**12.9**	**12.4**	**63.5**	**26.7**	**50.0**
June	I	18.4	16.5	14.4	11.0	11.0	22.0
	II	15.9	18.7	15.3	49.5	15.0	23.0
	III	**17.8**	**19.6**	16.2	21.0	13.5	24.0
	Average	17.4	18.3	**15.3**	**81.5**	**39.5**	**69.0**
July	I	21.3	22.6	17.2	28.0	37.0	25.0
	II	24.5	22.6	18.0	17.0	28.0	25.0
	III	**23.9**	**21.4**	18.0	72.0	69.5	26.0
	Average	23.2	22.2	**17.7**	**117.0**	**134.5**	**76.0**
August	I	23.9	16.7	17.2	11.0	29.5	28.0
	II	23.3	18.2	16.1	30.5	36.5	29.0
	III	15.4	17.0	15.0	34.5	29.0	28.0
	Average	**20.9**	**17.3**	**16.1**	**76.0**	**95.0**	**85.0**
September	I	12.5	14.1	–	8.0	21.0	–
	II	11.3	12.6	–	20.0	28.0	–
	III	14.7	13.6	–	27.0	1.0	–
	Average	**12.8**	**13.4**	–	**55.0**	**50.0**	–

Source: Upytė Experimental Station, 2010, 2011.

seasons were abundant in rainfall which differed only at hemp growing stages.

In 2010, the period for hemp seed emergence was favourable, but later on a lack of precipitation occurred (1st ten-day period of June). Then conditions for hemp growing and developing were favourable (2nd and 3rd ten-day periods of June). The weather in July was warm, and the rainfall was sufficient for hemp growing. The weather in August was warm and rainy (except the 1st ten-day period), September was cooler and dryer.

In 2011, the period for hemp seed emergence was again favourable. Later on the weather was warm, but the lack of precipitation appeared in June. Warm weather and especially abundant precipitation in July and August delayed and prolonged the hemp flowering period, delayed the seed ripening period. In September, it was still warm and rainy.

Thermal and irrigation conditions during the growing season could be described by one of the most informative agrometeorological indicators – G. Selianinov's hydrothermal coefficient (1) (Bukantis, 1998):

$$HTK = \frac{\Sigma p}{0.1\Sigma t} \quad (1)$$

where:

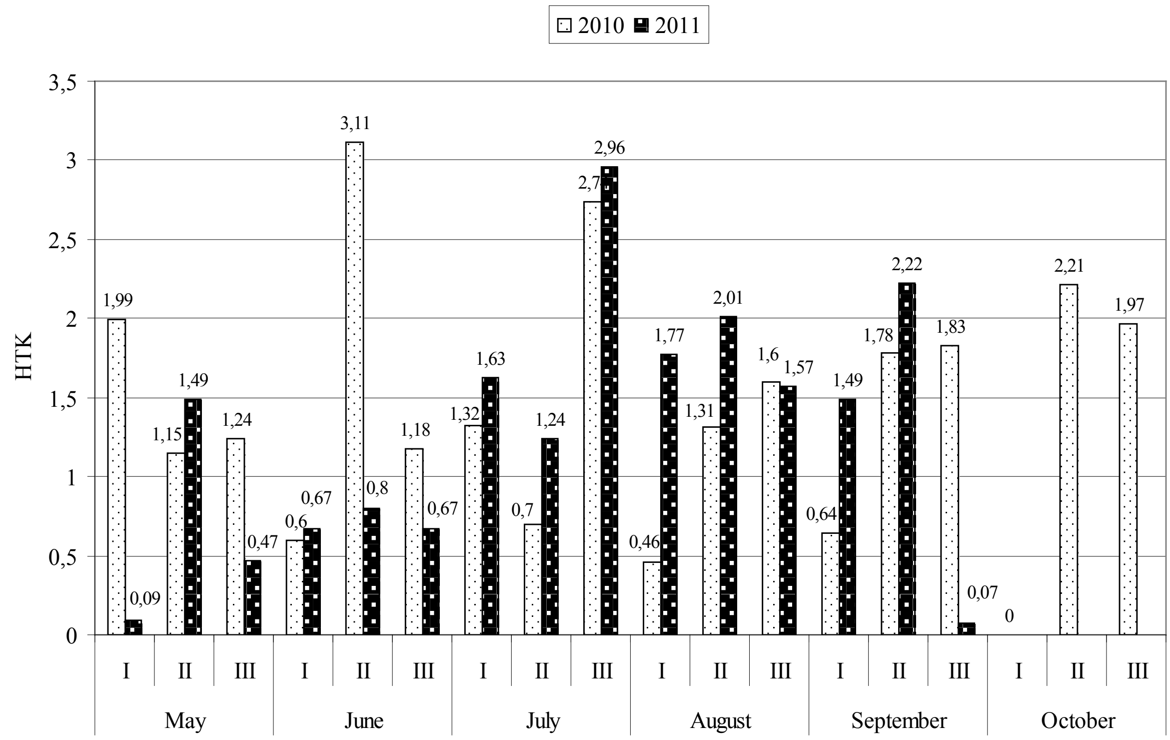
Σp – total precipitation (mm) sum during the given period, the temperature of which is above 10 ˚C;

Σt – total sum of active temperatures (˚C) of the same period.

If HTK>1.6 – the irrigation is excessive, HTK=1...1.5 – optimal irrigation, HTK=0.9...0.8 – weak drought, HTK=07...0.6 – moderate drought, HTK=05...0.4 – strong drought, HTK<0.4 – very strong drought.

According to the data presented in Figure 1, we can see that in 2010 it was enough wet for hemp seed germination (May month). In the first ten-day period it was drought, but on the 2nd ten-day period the irrigation was excessive, then it was close to the normal for 2 (2nd and 3rd) ten-day periods. The abundant precipitation in July 3rd ten-day period and in September (2nd, 3rd ten-day periods) allowed hemp plants to thrive, but led to a long vegetation period, a long flowering period, late seed ripening. Hemp was harvested only in October.

In 2011 the hydrothermal coefficient was favourable for seed germination. Later on (in June) it was moderate drought in the field, but the rest part of



Source: Upytė Experimental Station, 2010, 2011.

Figure 1. **Hydrothermal coefficient during the hemp vegetation period**

hemp vegetation period had a plenty of precipitation. The irrigation was excessive in July 1st ten-day period, July 2nd, August 1st, 2nd, September 2nd ten-day period. Of course, abundance of precipitation prolonged the hemp flowering, vegetation period.

Results and Discussion

In 2010, the established crop density was between 150–431 plants m^{-2}, while in 2011 it was between 153–199 plants m^{-2} (Table 2). In 2010, the cultivar 'Bialobrzeskie' showed bad results of seed germination determined in the laboratory before sowing, so the seed rate was calculated rather higher than that for other cultivars. But in the field, the cultivar 'Bialobrzeskie' emerged perfectly and showed very high crop density – 431 plants m^{-2} after full emergence and 323 plants m^{-2} at harvesting while the lowest crop density was found in the plots of cultivars 'USO 31' (150 plants m^{-2} after full emergence and 115 plants m^{-2} at harvesting), 'Futura 75' (171 and 131, respectively), 'Beniko' (172 and 139, respectively) (the differences were significant). In 2011 the lowest crop density after full emergence was recorded for the plots of cultivars 'Beniko' (153 plants m^{-2}) and the highest – in the plots of 'Futura 75' (199 plants m^{-2}). At hemp harvesting time, the lowest crop density was found in the plots of 'Epsilon 68' (111 plants m^{-2}) and the highest – in the plots of 'USO 31' (146 plants m^{-2}), but the differences were not significant. We guess that crop density at the beginning of the growing season was different between cultivars because of the difference in 1000 seed weight.

On average, crop density after full emergence was close to 173 and 224 (in 2011 and in 2010) plants m^{-2} and at harvesting time it was close to 134 and 184 plants m^{-2} (in 2011 and in 2010), i.e., crop density decreased during the crop vegetation period. „Self-shading" or "self-thinning" in hemp crop, or in other words – reduction of crop density, was mentioned by a parade of authors (Amaducci et al., 2002, Jankauskienė et al., 2010, Mediavilla et al., 1998, Struik et al., 2000, van der Werf et al., 1995 a and b), etc.

In our trials, the reduction of hemp crop density was on average 40 plants m^{-2} in both years. Significantly higher reduction was recorded in 2010 for the cultivar 'Bialobrzeskie' (109 plants m^{-2}) and for the cultivar 'Futura 75' (61 plants m^{-2}) in 2011. We tried to express the reduction in percents also, hoping to find some relationship between crop density and reduction value. Some authors report that self-thinning showed negligible plant loss at low density (30-90 plants m^{-2}), while at high density (180 and 270 plants m^{-2}) 50 % and 60 % of the initial stand was lost (Amaducci et al., 2002). In our trials, the reduction of crop density was between 8.8-24.6 % in 2010 and between 13.6-33.7 % in 2011. The average data show that in our trials the percentage reduction of crop density was different in both years and was higher at lower crop density. Nevertheless, in several cases, the percentage reduction of crop density was highest at the highest crop density (as for cultivar 'Bialobrzeskie' in 2010).

We found some correlation between crop density after full emergence and reduction, expressed

Table 2.

Hemp crop density after full emergence, at harvesting, and reduction

Cultivar	Crop density after full emergence, plants m^{-2}	Crop density at harvesting, plants m^{-2}	Reduction,	
			plants m^{-2}	%
2010				
‘Beniko’	172*	139*	33	18.9
‘Bialobrzeskie’	431*	323*	109*	24.6
‘Epsilon 68’	209	179	29	14.5
‘Fedora 17’	207	174	33	16.2
‘Felina 32’	214	195	19	8.8
‘Futura 75’	171*	131*	39	22.7
‘Santhica 27’	241	215*	26	10.8
‘USO 31’	150*	115*	35	22.0
Average	224.2	183.9	40.3	17.34
LSD_{05}	35.11	27.52	29.07	10.58
2011				
‘Beniko’	153	133	20.7	13.6
‘Bialobrzeskie’	183	131	51.3	27.5
‘Epsilon 68’	169	111	58.0	33.7*
‘Fedora 17’	175	135	39.3	22.5
‘Felina 32’	163	135	28.0	17.0
‘Futura 75’	199	138	61.3*	30.3
‘Santhica 27’	169	141	27.3	16.5
‘USO 31’	194	146	48.0	24.6
Average	173.1	133.8	39.3	22.1
LSD_{05}	30.99	26.16	19.54	8.87

Source: Upytė Experimental Station, 2010, 2011.
* significant differences at 95 % probability level.

in plants m^{-2}. In 2010 it could be described by equation 2, determination coefficient 0.57, and in 2011 – by equation 3, determination coefficient 0.46:

$$y = -24.14 + 0.2875x \quad (2)$$
$$y = -46.80 + 0.5144x \quad (3)$$

where:

y – reduction of crop density, plants m^{-2};

x – crop density after full emergence, plants m^{-2};

Nevertheless, the 8.8-33.7 % of fully emerged plants died, but the rest of the survived plants produced sufficiently high biomass yield.

In 2010, hemp produced high amount (on average 32.3 t ha^{-1}) of green over-ground mass (stalks, leaves and panicles) (Table 3). Only plants of ‘Futura 75’ produced significantly higher amount of green mass (38.7 t ha^{-1}) than the other cultivars tested. The biomass of cultivar ‘Fedora 17’ was significantly lower (only 26.7 t ha^{-1}). In 2011, the green biomass yield was a little bit lower (on average 29.4 t ha^{-1}) than that in 2010 (on average 32.3 t ha^{-1}). The highest amount of green biomass was produced again by plants of cultivar ‘Futura 75’ (33.2 t ha^{-1}), but the differences between the cultivars were not significant. The lowest productivity of the tested cultivars was given again by ‘Fedora 17’ (23.2 t ha^{-1}).

The yield of absolutely dry hemp biomass was calculated according to the data of hemp green biomass and its moisture content at harvesting. The moisture content of green biomass was higher in 2010 (on average 67.4 %), while in 2011 it was 60.8 %. The significantly lowest moisture content in 2010 was found in the plants of ‘Santhica 27’ (64.6%). In 2010, the differences in moisture content between cultivars were not significant.

In 2010, plants of the tested hemp cultivars produced on average 10.5 t ha^{-1} of dry over-ground biomass, and 11.5 t ha^{-1} in 2011. In some our trials earlier, the average dry mass yield of 14.6 t ha^{-1} for the cultivar ‘Beniko’ was recorded (Jankauskiene et al., 2009). The average dry mass yield 19.8 t ha^{-1} was recorded

Table 3.

Green over-ground biomass yield, its moisture content, and dry biomass yield of hemp crop

Cultivar	Green biomass kg ha^{-1}	Moisture content in green biomass %	Absolutely dry mass kg ha^{-1}
2010			
‘Beniko’	31 538	69.1	9 732
‘Bialobrzeskie’	34 359	66.3	11 607
‘Epsilon 68’	35 897	68.6	11 277
‘Fedora 17’	26 667*	66.8	8 883
‘Felina 32’	28 718	66.8	9 565
‘Futura 75’	38 718*	69.4	11 838
‘Santhica 27’	28 974	64.6*	10 312
‘USO 31’	33 333	68.2	10 616
Average	32 275.6	67.45	10 478.7
LSD_{05}	5 606.53	2.804	2 225 62
2011			
‘Beniko’	33 067	60.4	13 124
‘Bialobrzeskie’	28 356	59.8	11 358
‘Epsilon 68’	28 533	62.2	10 626
‘Fedora 17’	23 156*	63.3	8 456*
‘Felina 32’	29 667	60.1	11 844
‘Futura 75’	33 244	63.1	12 288
‘Santhica 27’	29 289	59.3	11 937
‘USO 31’	25 644	62.3	9 676
Average	29 348 2	60.8	11 519.2
LSD_{05}	4 626.98	2.55	1 894.41

Source: Upytė Experimental Station, 2010-2011.
* significant differences at 95 % probability level.

in 2009 for the varieties ‘Beniko’, ‘Bialobrzeskie’, ‘Epsilon 68’, ‘Felina 32’ and ‘USO 31’ (Jankauskiene et al., 2010). In Denmark the total average dry matter yield of the cultivars ‘Fedora’, ‘Fedrina’, ‘Felina’ and ‘Futura’ was reported to be approximately 13 t ha^{-1} (Deleuran at al., 2006). Very high yields (up to 22.5 t dry matter ha^{-1}) were obtained in Italy when later cultivars were used (Struik et al., 2000).

In our resent trials, the best results of the absolutely dry mass yield were shown by the cultivars ‘Futura 75’ (11.8 t ha^{-1}), ‘Bialobrzeskie’ (11.6 t ha^{-1}) and ‘Epsilon 68’ (11.3 t ha^{-1}) in 2010. In 2011, the most productive were the cultivars ‘Beniko’ (13.1 t ha^{-1}) and ‘Futura 75’ (12.3 t ha^{-1}). The differences between the cultivars were insignificant, just in 2011 the cultivar ‘Fedora 17’ produced significantly lower dry mass yield (8.5 t ha^{-1}).

According to some authors (Werf et al, 2009 b), in hemp the relationship between yield and optimum plant density is approximated by the equation of its self-thinning line. In our investigation, we didn’t find any correlation between crop density (after full emergence or at harvesting) and the yield (of green or absolutely dry biomass) in 2010. But in 2011, some correlation between investigated parameters was found. Weak correlation was found between crop density after full emergence and green/dry biomass yield for cases of all varieties. Strong correlation (determination coefficient 0.99) was found for the variety ‘Bialobrzeskie’ between crop density at harvesting and green (4) and dry (5) biomass yield:

$$y = 60292.65 - 243.18x \tag{4}$$

where:

y – yield of green biomass, kg ha^{-1};

x – crop density at harvesting, plants m^{-2};

$$y = 22650.31422 - 85.98x \tag{5}$$

where:

y – yield of dry biomass, kg ha^{-1};

x – crop density at harvesting, plants m^{-2};

Similar correlations were found also for the varieties 'Fedora 17' and 'Felina 32'.

Conclusions

Nevertheless, the 8.8-33.7 % of fully emerged plants died, but the rest of the survived plants produced sufficiently high biomass yield. In 2010, hemp produced high amount (on average 32.3 t ha^{-1}) of green over-ground mass (stalks, leaves and panicles), and plants of 'Futura 75' produced significantly higher amount of green mass (38.7 t ha^{-1}) than the other cultivars tested. In 2011, the green biomass yield was a little bit lower (on average 29.4 t ha^{-1}) than that in 2010 (on average 32.3 t ha^{-1}). The highest amount of green biomass was produced again by plants of cultivar 'Futura 75' (33.2 t ha^{-1}), but the differences between the cultivars were not significant.

In 2010, plants of the tested hemp cultivars produced on average 10.5 t ha^{-1} of dry over-ground biomass, and 11.5 t ha^{-1} in 2011. The best results of the absolutely dry mass yield were shown by the cultivars 'Futura 75' (11.8 t ha^{-1}), 'Bialobrzeskie' (11.6 t ha^{-1}) and 'Epsilon 68' (11.3 t ha^{-1}) in 2010. In 2011, the most productive were the cultivars 'Beniko' (13.1 t ha^{-1}), 'Futura 75' (12.3 t ha^{-1}).

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