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CHANGES OF WILLOW BIOMASS QUALITY AS A RENEWABLE ENERGY FEEDSTOCK HARVESTED WITH BIOBALER

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Abstract

Willow biomass can be collected in the form of entire or chipped shoots. The method depends on the harvest cycle of the plants, availability of necessary machines and the expected use of harvested raw material. Methods of harvesting influence on biomass quality during its acquisition and further in the storage period. Therefore, the aim of the research was to characterize the harvest of willow plantation with the use of a biobaler WB 55 and to assess the quality of the obtained biomass during the 9-month period of its storage. Willow was harvested with biobaler WB 55 in January 2010 on a commercial plantation. The 3.5 ha plantation was situated in the north-east of Poland, in the village of Dorotowo (53°42′9.88″ N 20°25′11.02″ E). An analysis of the biomass quality in terms of its thermophysical and chemical properties was carried out at the laboratory of the Department of Plant Breeding and Seed Production of the UWM in Olsztyn. Willow harvesting with a unit consisting of a 129 kW tractor and biobaler WB 55 was conducted efficiently. The average harvesting efficiency was about 18 bales per hour of the unit operation (8.75 Mg h^{-1} FM). The fresh matter density in the bales averaged 358.10 kg m^{-3} FM, whereas in dry matter it was 166.16 kg m^{-3} DM. With extended duration of storage, the quality of willow biomass as an energy raw material improved. The biomass in the bales steadily lost its moisture, from 53.06% in January to 17.48% in September. On the other hand, the lower heating value increased during that same period from 7.75 MJ kg^{-1} to 15.65 MJ kg^{-1}. It has been found based on the observations made during the study period that the advantages of a biobaler WB 55 are the easy and efficient harvesting of plants on a plantation and bales can be used for energy production as needed.

Keywords: renewable energy, willow, biobaler, chemical composition, thermophysical features, lower heating value.

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INTRODUCTION

The method of soil preparation for willow cultivation and the agricultural procedures applied during its vegetation are largely based on traditional agricultural techniques. However, harvesting requires individual solutions due to the relatively high and variable resistance which occurs in the process of cutting shoots. Initially, technologies of wood harvesting employed techniques used in agriculture or in forestry (SPINELLI et al. 2009, SPINELLI et al. 2012). Over time, components or entire machines have been modified and, currently, specialist machines are available with modern solutions applied in the work and drive systems. Various cutting mechanisms are applied in machines for willow harvesting, such as circular saws, chain saws, knife discs, flail knives (SEIXAS et al. 2006, SAVOIE et al. 2010).

Willow biomass can be collected in the form of entire or chipped shoots. The method depends on the harvest cycle of the plants, availability of necessary machines and the expected use of harvested raw material. A one-stage plant harvest in the form of chips may be conducted with the use of a forage harvester (designed for harvesting single or twin rows) cooperating with tractors, or with the Claas Jaguar, Krone, New Holland and other harvesters with modified headers (SEIXAS et al. 2006, SPINELLI et al. 2009). With these machines, stems are cut, chipped and loaded onto biomass transport trailers (same as maize harvest). One-stage harvesting is the most common system in Europe. Harvesting with combine harvesters specially adapted to willow harvesting is quick and convenient, but they are not commonly used in Poland. The machines are expensive and their use is economically reasonable only on large plantations (SPINELLI et al. 2009). Plantations of energy willow in Poland are relatively small and sometimes they are at a considerable distance from each other. Therefore, the cost of using specialist machines is frequently too high for the plantation owner. Incidentally, willow shoots collected in winter have an average humidity of about 50%. The biomass should be used for energy production as soon as possible.

Two-stage harvesting is another method of willow biomass acquisition. A certain part of the biomass, however, must be stored as a reserve. It is necessary in the case of the lack of harvesting possibility, which may be the result of unfavourable weather conditions (abundant snowfall) or the season of the year (the stems harvest is conducted from the first decade of November until the end of March). Therefore, a two-stage harvest would be a good solution in specific circumstances. It is possible to collect entire willow stems with specially-designed machines, either self-propelled or operated together with tractors. Potentially, willow plants can also be pressed into bales, similar to those of straw. In Canada, Poland and other countries a biobaler machine working in cooperation with a tractor is used (SAVOIE et al. 2009). It cuts and bales several-year-old willow stems simultaneously. Apart from biobaler, the following machines are used for two-stage harvesting: Bundler, Empire 2000, Frobbesta and Rodster (SEIXAS et al. 2006).

Harvested willow, after natural drying, can be ground down by a chipper equipped with an engine or driven by the receipt shaft of an agricultural power tractor. The chipping process may be carried out successively, as needed. Entire stems collected from a plantation can be stored in natural conditions, on an open, hardened stockpile in piles up to autumn. During this period their moisture content will decrease (GIGLER et al. 2000, FITZPATRICK et al. 2013). The two-stage method of harvest and preparation of willow biomass enables its regular delivery to a customer because it can be used when it is most needed.

Biobaler WB 55 was designed in Canada, and it is intended for harvest of biomass of agricultural and forest origin, in difficult conditions, on different types of land. According to Anderson Group (biobaler producer) willow harvesting with a biobaler combines its cutting, compacting and baling during a single production cycle by a single machine. The biobaler cuts down, pre-comminutes and presses plants and trees with the diameter of up to 100 mm and cuts up plants with the height of up to about 7 m. Most machines for willow harvesting are fitted out with a cutting system, with circular saws, whereas the biobaler WB 55 is the only willow harvesting machine on the market with a mulcher head. However, as an option, the machine can be fitted out with circular saws (SAVOIE et al. 2010). The mulcher head of the biobaler WB 55 is designed to collect the material and transfer the biomass to the main feeder. There are 50 teeth spirally arranged on the head, which cut up, lift and move the material over the rotor. Bales are of the same size as the pressing chamber and they weigh about 0.5-0.6 Mg; their density is about 0.370 Mg m^{-3} (SAVOIE et al. 2009).

Therefore, the aim of the research was to characterize the harvest of willow plantation with the use of a biobaler WB 55 and to assess the quality of the obtained biomass during its storage.

MATERIALS AND METHODS

Harvest of willow biomass

Willow was harvested with biobaler WB 55 in January 2010 on a commercial plantation. The 3.5 ha plantation was situated in the north-east of Poland, in the village of Dorotowo (53°42′9.88″ N 20°25′11.02″ E). *Salix viminalis* plants were cultivated on poor sandy soil of the lowest quality class, on which rye is typically cultivated. The rows were spaced every 0.9 m and plants within a row - every 0.25 m. The willow plantation was run extensively and no fertiliser or pesticides was applied. Three-year-old plants were harvested by means of a set consisting of a biobaler WB 55 and a Case IH MX170 tractor. After the harvest, 15 bales were weighed to determine their average mass. The bales were left in the field until the end of May and they were subsequently transported to the farmstead and piled up.

Evaluation of the biomass quality

On the day of willow harvest, an examination was started to determine the biomass quality and its changes during the storage period. Measurements and analyses were performed in the third decade of each month, beginning with January 2010 and ending in September of the same year. The temperature inside the bales was measured and biomass samples were taken for laboratory analyses. An analysis of the biomass quality in terms of its thermophysical and chemical properties was carried out at the laboratory of the Department of Plant Breeding and Seed Production of the UWM in Olsztyn. Each analysis was carried out in triplicate.

First, moisture content in *Salix* spp. biomass was determined by drying and weighing. To this end, the biomass was dried at a temperature of 105±2°C until a constant mass was achieved. It was subsequently ground on an analytic grinder IKA KMF 10 basic, with a 0.25 mm sieve mesh. The prepared and dried samples were used for determination of the higher heating value with an IKA C 2000 calorimeter, by the dynamic method. Subsequently, the lower heating value was determined. Fixed carbon and volatile matter, as well as ash content were determined with an ELTRA TGA Thermostep thermogravimetric analyser. Carbon, hydrogen and sulphur content was determined in a CHS 500 ELTEA analyser. Nitrogen content was determined by the Kjeldahl method with a K-435 mineraliser and a B-324 BUCHI distiller, and chlorine content was determined with the use of an Eschka mixture.

Statistical analysis

The statistical hypothesis assumed that the quality of biomass harvested by a biobaler in the form of bales should improve in terms of its thermophysical and chemical properties during the period of storage. Variation analysis (Anova) of a completely random model was applied in three replications ($n = 27$) at $p < 0.05$. Arithmetic means and standard deviation were calculated for the examined features: moisture, ash content, fixed carbon, volatile matter, higher heating value, lower heating value, and C, H, S and N content. Homogenous groups were determined with the use of the SNK (Student Newman-Keuls) multiple test combining means of similar values at the significance level of $\alpha = 0.05$. All statistical analyses were carried out with a Statistica 9.0 PL software package (StatSoft Inc.).

RESULTS

The average harvesting efficiency in the experiment carried out with a biobaler WB 55 and a Case IH MX170 tractor (Figure 1) amounted to about 18 bales per hour of work.

Fig. 1. A set for willow harvesting, consisting of Biobaler WB 55 and a Case IH MX170 tractor

Since the average bale weight was 486±19.91 kg, the weight of fresh *Salix* biomass, harvested during an hour, is about 8.75 Mg. The yield of fresh biomass on an extensively run three-year plantation was only 39.4 Mg ha^{-1}. Considering the biomass moisture content at the moment of harvesting, the dry matter yield was equal to 6.09 Mg ha^{-1} year^{-1}. On the other hand, the energy value of the biomass obtained was 305.23 GJ ha^{-1} (101.74 GJ·ha^{-1} year^{-1}). The willow bales were 1.2 m x 1.2 m in size and they were stable and transportable for a year. Fresh matter density (FM) in bales was, in average, 358.10 kg m^{-3} FM, whereas that of dry matter was equal to 166.16 kg m^{-3} DM.

After the willows had been cut, willow rootstocks damaged by the mulching head of biobaler WB 55 were found (Figure 2). However, over 96% of the plants were found to have resumed vegetation.

Fig. 2. The willow plantation after the harvest, the 3rd decade of April

Figure 3 shows the average temperature of the willow bales and the air temperature between January and September. The temperature of the bales increased between January and July and the most rapid increase took place between June and July. Subsequently, the temperature decreased in August and September to reach the values close to those measured in June and May. The temperature pattern of the bales followed that of the air temperature. In general, the bales' temperature was slightly lower than that of the air. Only in May and June was their temperature higher than that of the air. The temperatures in September differed more than in other months.

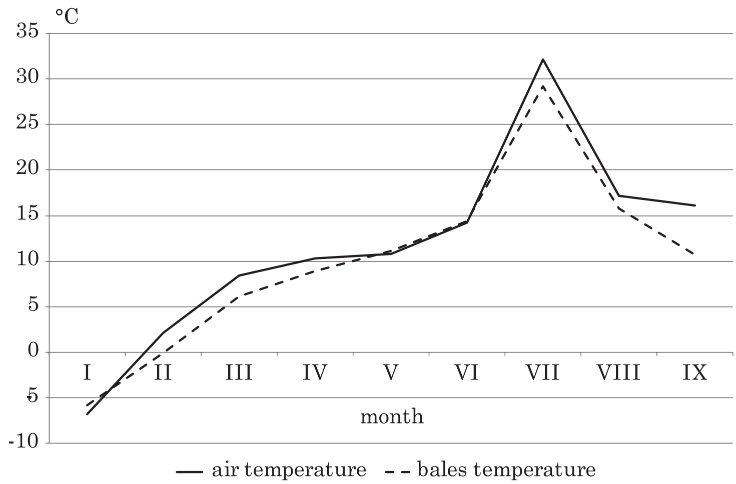

Fig. 3. The average temperature of stored willow bales and the air temperature during the study period

Changes in moisture content and lower heating value of baled willow biomass are shown in Figure 4. Significantly, the highest moisture content was determined in January 53.60%. The value of this attribute decreased significantly until June (13.69%). The differences in moisture content in the samples between May and July were not statistically significant. Moisture content was found to increase significantly in August and September as compared to the previous months. This was caused by many factors, one of them being abundant rainfall before and during the period of biomass sample taking. Consequently, the lowest significant lower heating value of willow biomass was determined in January (7.75 MJ kg^{-1}). The value of the attribute increased significantly between January and June, when its highest values were found (16.47 MJ kg^{-1}). The value stabilised between May and July and the differences were not statistically significant. On the other hand, it decreased significantly as compared to the period between April and July and again increased in September.

The average higher heating value of willow biomass, as converted to dry matter, was equal to 19.48 MJ kg^{-1} (Table 1). The higher heating value was

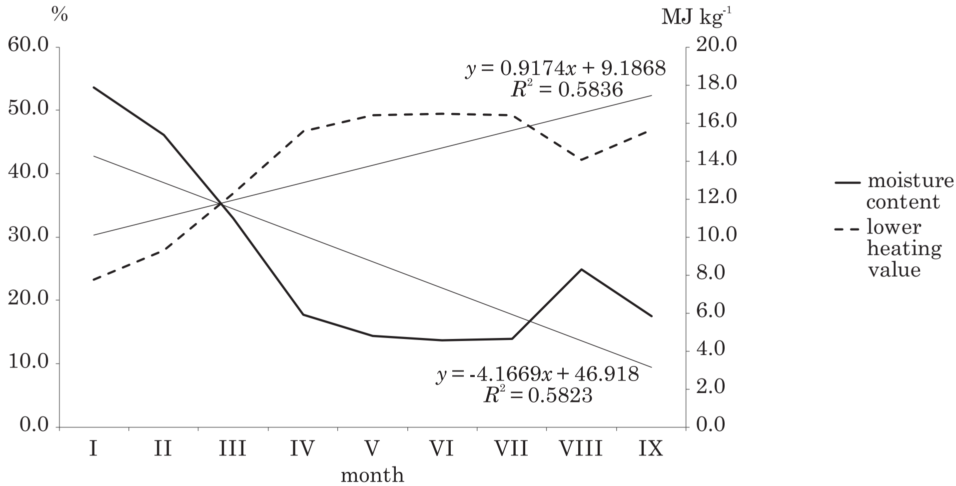

Fig. 4. The relationship between the moisture content and the lower heating value of willow bales in successive months of storage

Table 1

Thermo-physical characteristics of willow biomass during consecutive months of storage

Month	Higher heating value (MJ kg^{-1} DM)	Ash content (g kg^{-1} DM)	Fixed carbon (g kg^{-1} DM)	Volatile matter (g kg^{-1} DM)
I	19.44±0.02^b	10.70±0.34^e	183.62±0.35^c	787.05±0.82^a
II	19.36±0.05^c	16.39±0.24^a	195.88±0.27^a	770.89±0.53^c
III	19.54±0.01^a	14.51±0.15^c	198.70±1.34^a	769.36±1.68^d
IV	19.45±0.01^b	13.41±0.19^d	188.40±0.96^b	780.80±1.18^b
V	19.59±0.06^a	15.43±0.10^b	194.81±1.23^a	773.12±1.41^c
VI	19.47±0.01^b	14.10±0.21^c	189.42±2.77^b	779.64±2.67^b
VII	19.47±0.01^b	14.73±0.35^c	188.65±1.45^b	780.09±1.91^b
VIII	19.56±0.01^a	14.52±0.01^c	184.43±0.00^c	782.96±0.00^b
IX	19.48±0.03^b	15.73±0.04^b	190.20±1.16^b	779.39±1.21^b
Mean	19.48±0.07	14.39±1.59	190.46±5.02	778.14±5.73

± standard deviation; $^{a, b, c}$… homogenous groups

positively correlated with carbon content (Table 2). The dry matter of the willow biomass contained 190.46 g kg^{-1} DM of fixed carbon (Table 1). The volatile matter content in the dry matter of the samples under analyses was the highest in January and amounted to 787.05 g kg^{-1} DM and it was the lowest in March. Ash content in dry matter of willow biomass was low and it amounted to 14.39 g kg^{-1} DM. The ash content was significantly the lowest in January.

Table 2

The simple correlation coefficients for the attributes under study

Item	C	H	S	N	Higher heating value	Moisture content	Lower heating value	Fixed carbon	Volatile matter	Ash
C	1.00	0.76*	-0.50*	-0.24	0.56*	-0.63*	0.63*	-0.39	0.32	0.25
H	0.76*	1.00	-0.32	0.12	0.28	-0.82*	0.82*	-0.04	0.01	0.50*
S	-0.50*	-0.32	1.00	0.56*	-0.11	0.48*	-0.48*	0.60*	-0.62*	0.21
N	-0.24	0.12	0.56*	1.00	-0.16	0.03	-0.03	0.74*	-0.79*	0.61*
Higher heating value	0.56*	0.28	-0.11	-0.16	1.00	-0.41	0.43	0.03	-0.05	0.06
Moisture content	-0.63*	-0.82*	0.48*	0.03	-0.41	1.00	-1.00*	-0.02	0.03	-0.39
Lower heating value	0.63*	0.82*	-0.48*	-0.03	0.43	-1.00*	1.00	0.03	-0.03	0.39
Fixed carbon	-0.39	-0.04	0.60*	0.74*	0.03	-0.02	0.03	1.00	-0.99*	0.61*
Volatile matter	0.32	0.01	-0.62*	-0.79*	-0.05	0.03	-0.03	-0.99*	1.00	-0.68*
Ash	0.25	0.50*	0.21	0.61*	0.06	-0.39	0.39	0.61*	-0.68*	1.00

* correlation coefficients significant at the level of ≤ 0.05

Carbon content in dry matter amounted to 496.49 g kg^{-1} DM (Table 3). The lowest carbon content in dry matter was found in February (487.90 g kg^{-1} DM) and the highest was in August (507.41 g kg^{-1} DM). The carbon content in biomass was significantly the lowest as compared to the period between April and September. The hydrogen content in dry matter of willow

Table 3

Elemental composition of willow biomass in consecutive months of the biomass storage

Month	C (g kg^{-1} DM)	H (g kg^{-1} DM)	S (g kg^{-1} DM)	N (g kg^{-1} DM)
I	489.29±0.28^{c}	51.64±0.32^{c}	0.20±0.02^{b}	3.45±0.18^{c}
II	487.90±0.52^{c}	53.02±0.27^{b}	0.26±0.02^{a}	4.64±0.09^{a}
III	493.12±1.38^{b}	53.79±0.00^{b}	0.26±0.01^{a}	4.51±0.10^{a}
IV	495.94±0.75^{b}	54.48±0.21^{a}	0.19±0.01^{b}	4.05±0.03^{b}
V	497.99±0.92^{b}	53.61±0.46^{b}	0.20±0.04^{b}	3,98±0.03^{b}
VI	496.29±6.09^{b}	54.71±0.55^{a}	0.19±0.01^{b}	3.94±0.03^{b}
VII	498.36±2.20^{b}	54.54±0.06^{a}	0.16±0.02^{b}	4.17±0.06^{b}
VIII	507.41±0.48^{a}	54.74±0.11^{a}	0.19±0.02^{b}	3.90±0.01^{b}
IX	502.12±0.12^{a}	55.32±0.18^{a}	0.17±0.02^{b}	3.82±0.06^{b}
Mean	496.49±6.12	53.98±1.10	0.20±0.04	4.05±0.35

± standard deviation; $^{a, b, c}$... homogenous groups

biomass amounted to 53.98 g kg^{-1} DM (Table 3). Significantly the lowest hydrogen content in dry matter was determined in January (51.64 g kg^{-1} DM) and the highest was in September (55.32 g kg^{-1} DM). This attribute was found to increase between January and April and it decreased in May. The value of this attribute was found to fluctuate slightly and insignificantly between June and September. A significant positive correlation was observed between the content of hydrogen and carbon content (Table 2).

Willow biomass was found to contain low amounts of sulphur (Table 3). The highest content in dry matter was determined in February and March (0.26 g kg^{-1} DM) and the lowest was in September (0.17 g kg^{-1} DM). The sulphur content was positively correlated with nitrogen content (Table 2). The nitrogen content in dry matter of the samples under analysis ranged from 3.45 to 4.64 g kg^{-1} DM; the average value was equal to 4.05 g kg^{-1} DM (Table 3).

DISCUSSION

The yield of willow wood dry biomass, obtained in experimental conditions in Poland, is highly variable and ranges from a few to as much as 30 Mg of dry wood per 1 hectare per year (STOLARSKI 2008, KUŚ, MATYKA 2009, KUŚ, MATYKA 2010, STOLARSKI et al. 2011, 2013). The yield of willow biomass, harvested on a commercial plantation was low as compared to the experimental plantations. This was a result of poor cultivation site, lack of fertilisation and an extensive method of running the plantation. Moreover, a higher loss of biomass is incurred in mechanical harvesting on commercial plantations than in experiments. It has been found in this experiment that about 6% of the biomass is left in the field when willow is harvested with a biobaler WB 55 with a mulcher head. Moreover, many plants were cut at the height of as much as about 0.5 m above the ground level (Figure 2). The percentage of willow biomass left on the ground was much lower than when willow was harvested at natural sites, where the value was equal to 38% (SCHROEDER et al. 2009, SAVOIE et al. 2010). High yield of willow biomass was also achieved on experimental plantations in Sweden and UK, but they could not be reproduced on commercial plantations (BULLARD et al. 2002, MOLA-YUDEGO 2011). Whereas annual biomass production from natural willow rings in Canada ranged from 1.9 to 16.2 Mg ha^{-1} year^{-1} DM for the 12 sites that were between 9 and 34 years old (MIRCK, SCHROEDER 2013).

The economics of short rotation willow crops are strongly influenced by yield, production, and harvesting costs and the delivered price for biomass (BUCHHOLZ, VOLK 2013). Harvest and transport of willow biomass is the most costly and energy-consuming stage of production; it may generate from 39% to 60% of the total cost of biomass production. The cost of harvest depends on the harvest method, situation in the local area, scope of transport, the amount of equipment involved (tractors, trailers) and the yield per unit area (SEIXAS et al. 2006, VOLK et al. 2006, SPINELLI et al. 2009, FIALA, BACENETTI 2012). Therefore, new possibilities are being sought of reducing the cost of willow biomass production (ERICSSON et al. 2009). According to THARAKAN et al. (2005), an increase in yield by 18% can reduce the cost of biomass supply to the end consumer by 13%. On the other hand, a 25% increase in harvest productivity and effectiveness can reduce the cost of willow biomass supply by 7.50 USD Mg^{-1}. MOREOVER, GIGLER et al. (1999) report that the choice of the right technologies along the production chain can reduce the cost of willow chips production by 45%. Similar conclusions have been arrived at by ROSENQVIST et al. (2013), who reported that – based on the currently available knowledge and technology – increasing the area of willow coppice cultivation can reduce the production cost by approx. 10% on average. However, with advancing knowledge and technology of *Salix* spp. cultivation, the production cost can be reduced by about 35%. Incidentally, the highest cost reduction potential is possible (in the order as mentioned below) at the stage of biomass harvesting, plantation management, plantation set-up and weed control.

The biomass harvesting productivity, achieved with a biobaler WB 55 in this study, is similar to the findings of other authors. The productivity of willow harvesting in natural habitats ranged from 4 to 7 Mg h^{-1} (Savoie et al. 2010), but it was higher (8-13 Mg h^{-1}) when willow biomass was harvested on plantations (Lavoie et al. 2008). On the other hand, according to the manufacturer's data, the productivity of a biobaler WB 55 amounts to 19-20 Mg h^{-1}, with the actual value being equal to 16.2 Mg h^{-1}. Among the factors which must be taken into account is the type of terrain, because a biobaler can produce up to 40 bales an hour in a cultivation area and 15-18 bales in natural environments. The yield on a willow plantation was lower (18 bales h^{-1}) due to insufficient power of the tractor (129 kW), because the recommended power ranges are from 147 to 184 kW. The productivity of biomass harvesting with a biobaler WB 55 was comparable to that of other machines used in two-stage harvesting. For example, tests with an Empire 2000 have shown that the average yield of dry matter achievable with the machine is equal to 6.7 Mg h^{-1}, with a maximum harvesting speed of 8 km h^{-1} (Seixas et al. 2006). Moreover, it must be emphasised that willow harvesting with a biobaler WB 55 requires one operator and bales are produced in the process. On the other hand, an Empire 2000 can be operated by one person, but such a method of harvesting may be inefficient and hence cooperation of two people is a better solution. Moreover, the biomass is harvested as loose bunches of shoots.

The biobaler WB 55 is inferior in terms of productivity as compared to combine harvesters used in single-stage willow harvesting. For example, an Austoft 7700 combine harvester can produce 20 t of fresh matter per hour, while a Claas Jaguar combine harvester can produce 30 tonnes of fresh willow chips per hour (Seixas et al. 2006). On the other hand, the productivity of poplar harvesting with a Claas Jaguar 880 with a GBE2 header ranged from 42.2 to 64.2 Mg h^{-1} and it was equal to 55.4 Mg h^{-1} on average (Fiala, Bacenetti 2012). Furthermore, the average productivity of a Krone harvester with a Wood Cut 1500 header is estimated at 60 Mg h^{-1}; moreover, it is fitted out with one circural saw, which cuts shoots of up to 1,500 mm in diameter (Spinelli et al. 2011).

However, willow harvesters are mainly intended for large plantations and they are expensive. For example, a Claas Jaguar 880 harvester costs about 250,000 € and the amount should be increased by the price of a GBE2 header - about 90,000 € (Fiala, Bacenetti 2012). On the other hand, a biobaler WB 55 costs about 135,000 € and it can be used on small and large plantations. The machine can be used to harvest nearly all types of biomass, for example from willow, poplar, aspen, alder and forest undergrowth. Bales can be transported to a processing plant immediately or stored in the field for future use. Biomass bales do not lose their value during prolonged storage, even if the material was very humid when harvested. Among the advantages of the technology is the fact that bales dry naturally, without the risk of auto-ignition, which increases their lower heating value. The shape and content of bales reduces the cost of biomass transport to a processing plant (standard means of transport can be used). It has been found in this study that the quality of willow biomass, harvested in a two-stage process with a biobaler WB 55 machine, as solid fuel, improves with extending the period of storage. This resulted mainly from reduced moisture content and increased biomass lower heating value. Furthermore, it has been found before that natural drying of willow shoots results in moisture content decrease and lower heating value increase (Stolarski et al. 2011). It has also been shown that storing uncut willow biomass does not pose any problems and it can improve the fuel quality. This actually results from the fact that no high losses of biomass resulting from its decay are observed in bales, and the moisture content in shoots can decrease from an initial value of 52-55% to 15-20% after six months of storage (Jirjis 2005). Considerable reduction of moisture content in whole shoots after several months of storage has also been achieved in earlier studies (Gigler et al. 2000). It is the improvement of quality of willow biomass harvested in a two-stage process and possibility of regular supplies to an end consumer that make the technology interesting. This applies especially when one compares it to single-stage willow harvesting with a combine harvester, when wet chips are produced, which have to be utilised within a short time.

CONCLUSIONS

Willow harvesting with a unit consisting of a 129 kW tractor and biobaler WB 55 was conducted efficiently. Willow biomass bales, collected from the field with a front end loader, retained their shape and form throughout the study period. Therefore, they can be used for at least 9 months for combustion or further processing. With an extended duration of storage, the quality of willow biomass as an energy raw material improved. The moisture content in the baled biomass decreased steadily depending on the weather conditions. No adverse processes were observed which could have made the material quality deteriorate. Bales can be left outdoors throughout the spring and summer period, but they must be covered or brought under a roof at the end of summer to prevent a moisture content increase. It has been found based on the observations made during the study period that the advantages of a biobaler WB 55 are the easy and efficient harvesting of plants on a plantation and bales can be used for energy production as needed. However, there is also a disadvantage – the cutting system damaged the willow rootstock. New shoots from the rootstocks may have been high, but further studies of willow harvesting by this method must be conducted to confirm it.

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