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Short rotation willow coppice biomass as an industrial and energy feedstock

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ABSTRACT

In order to increase the yield of short rotation willow coppice cultivated on agricultural land and to improve the biomass quality as an industrial and energy feedstock, particular consideration should be devoted to proper location and to the cultivation of woody plants. This paper presents the yield of five new cultivars of willow coppice and the relationship between the chemical composition of biomass and the plant harvest cycle. The Tur cultivar has been shown to have the highest mean productivity of 21.5 t of d.m. ha^{-1} $year^{-1}$. In a three-year harvest cycle, the cultivar also gave biomass with the highest cellulose:lignin ratio (2.14). The significantly highest yield of dry biomass from the cultivars under study (20.5 t of d.m. ha^{-1} $year^{-1}$) was achieved in a three-year harvest cycle. It was lower by 3.4% on average in a two-year harvest cycle and lower by 17.2% in a one-year harvest cycle as compared to a three-year cycle. As the harvest cycle was extended, the biomass quality in terms of its chemical composition improved. The biomass obtained in a three-year cycle contained the highest amount of cellulose (44.6% of d.m.) and the lowest amount of lignin (21.8% of d.m.). The results indicate that the agrotechnical factors, including the cultivar and the harvest cycle, affect not only the yield, but also the qualitative features of short rotation coppice willow biomass.

1. Introduction

The amount of energy obtained from renewable sources in Poland has been growing in recent years (GUS, 2009). The share of such energy was equal to 7.1% in 2007, whereas according to the guidelines laid down in the EU climate and energy package, the share of renewable energy in the final consumption of energy in 2020 should be equal to 15%. In consequence, Poland has to double the amount of energy obtained from such sources within the next ten years. Of all the renewable energy sources, solid biomass, produced mainly as wood, is the most important one in Poland (91.6%). Therefore, increased interest in biomass utilisation in energy production may result in short supply of wood for industry. Poland's commitments to increase the share of biomass as a source of "green" heat and electricity (Ministry of Economy and Labour, 2005), have created concern that some sorts of wood (pulpwood) and wood waste (sawdust) will be used by the power sector, resulting in a deficit of material for cellulose and paper production, as well as boards made of processed wood. Since the National Forests do not plan to increase the established logging quotas, an urgent need exists to obtain material containing lignin and cellulose outside forests. Therefore, it is necessary to produce wood biomass from short rotation willow coppice, cultivated on agricultural land, which is an object of interest of many research centres in Poland (Stolarski, 2004; Stolarski et al., 2006; Grzybek, 2008; Kuś, 2008; Budzyński et al., 2009; Kuś and Faber, 2009; Podlaski et al., 2009).

Results of research centres abroad (Mc Adam, 1987; Warboys and Houghton, 1993) and conducted in Poland (Stolarski et al., 2005) have shown that wood from short rotation willow plantations on agricultural land can be used in the production of cellulose pulp, cardboard and paper. Willow chips can also be used in the production of chipboards for furniture production (Macpherson, 1995). It has also been shown that willow wood from field plantations can be used in energy, especially heat, production (Szczukowski et al., 1998, 2001, 2004; Stolarski, 2004; Stolarski et al., 2006). Lignocellulosic biomass is positively regarded as a raw material for the production of 2nd generation liquid fuels (Guidi et al., 2009).

The use of willow biomass, produced in different harvest cycles, in industry and in energy production requires knowledge of the achievable yield and its energy value to ensure a regular supply for industry and power plants. It is also very important to know the chemical composition of biomass as a feedstock for industry or energy production.

The aim of the study was to determine the yield and its energy value of new cultivars of willow coppice and to determine the

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chemical composition of wood produced in short rotation on agricultural land.

2. Materials and methods

2.1. Field research

The study was based on an exact, two-factorial experiment with willow coppice, located in the north of Poland in the Kwidzyn Lowlands in the village of Obory (53°43′ N, 18°53′ E), conducted from 2003 to 2006. The experiment was located on humus alluvial soil, classified as—Mollic Fluvisols, which is the optimal soil for willow cultivation. No mineral fertilisers were applied in the year when the experiment was established. The following doses of fertilisers were sown manually in the subsequent years of the experiment *N* – 90 kg ha^{-1}, P–18 kg ha^{-1}, K–66 kg ha^{-1}.

The first factor examined in the experiment were five willow cultivars, all of which were cultivated by University of Warmia and Mazury in Olsztyn: Duotur, species *Salix alba* L., Corda (*Salix alba* L.), Tur (*Salix viminalis* L.), Turbo (*Salix viminalis* L.) and UWM 046 (*Salix viminalis* L.). The other factor were three harvest cycles: every year, every two years and every three years.

Willow cuttings were planted in strips, in which two rows per strip were spaced with an interrow of 0.75 m, then an interrow of 0.90 m separating the next two rows in a strip with an interrow of 0.75 m, etc. The cuttings in a row were spaced every 0.50 m, which resulted in a density of 24 thousand plants per ha. The experiment was conducted in 4 replications on 60 plots, 23.1 m^2 each.

The year when the experiment was set up (2003) was regarded as preliminary. During the first decade of February 2004, the willows from all the plots were mown and collected in order to stimulate the propagation and growth of stems in subsequent years. No data from that period were included in this paper. From the 2004 vegetation period onwards, plants were harvested three times following vegetation in 2004, 2005 and 2006. This paper presents the average biomass yield in three successive one-year harvest cycles. Two-year old plants were harvested once after the 2005 vegetation period and three-year old plants after the 2006 vegetation period.

Willows were harvested manually with a blade trimmer powered by a combustion engine. Immediately after the harvest, stems collected on all the plots were weighed and the fresh biomass yield was determined in tonnes per hectare. During the harvest, representative plant stems were collected from each plot to determine biomass humidity and its thermophysical and chemical characteristics.

2.2. Laboratory analyses

Just after harvesting fresh biomass was chopped and dried to constant weight at 105 °C. Subsequently, the biomass humidity was used to determine the dry biomass yield per hectare.

The dry biomass Higher Heating Value was determined by the dynamic method with an IKA C 2000 calorimeter (IKA Werke GmbH). The analyses were performed in three replications. Subsequently Lower Heating Value was determined for the fresh biomass. The Lower Heating Value of fresh biomass (GJ t^{-1}) and its yield per ha (t ha^{-1} year^{-1}) were used to calculated the energy value of the entire yield (GJ ha^{-1} year^{-1}).

Chemical composition of biomass was determined by commonly used analytical methods (Prosiński, 1984). The analyses were made at the Wood Technology Institute, Poznan. The wood was ground and sieved; the fraction of grain size from 0.5 to 1.0 mm was taken for analysis from each material. The following were determined:

- the content of cold-water-soluble substances, i.e. some minerals and carbohydrates, tannins, dyes, pectins, free acids and other,
- hot-water-soluble substances which – apart from the cold-water-soluble substances – include compounds formed by hydrolytic reconstruction of wood, mainly hemicelluloses,
- the content of substances soluble in ethanol–benzene mixture (1:1), referred to as extraction substances, which include such wood minor constituents as fats, waxes, resins,
- the content of substances soluble in alkalis (1% aqueous solution of NaOH), which provides information about the amount of hemicelluloses in wood, although certain amounts of cellulose and lignin are also in the extract,
- cellulose content by the Seifert method,
- lignin content by the Tappi method,
- pentosan content by the Tollens method.

Table 1
Significance of main effects and first order interactions for the biomass yield and its energy value.

Specification	Dry biomass yield (t ha^{-1} year^{-1})	Energy value of yield (GJ ha^{-1} year^{-1})
Variety	**	**
Harvest cycle	**	**
Variety × harvest cycle	**	**

** $p < 0.01$.

2.3. Statistical analysis

The experiment results were analysed statistically with the STATISTICA PL® software. Arithmetical means were calculated for the attributes examined in the experiment. The SNK (Student Newman–Keuls) multiple test, which links means of similar values, was used to establish homogenous groups with a level of significance $\alpha = 0.01$. The data were listed in tables and in figures, which present the mean values grouped in homogenous groups, with a standard error of mean (SEM).

3. Results

The dry biomass yield was significantly different within the main factors under examination and the interactions between them (Table 1, Fig. 1). Among the cultivars examined in the experiment, the highest yield was achieved in the Tur cultivar—21.5 t of d.m. ha^{-1} year^{-1} (Fig. 1) on average. The yield of the Duotur cultivar was similar. The second group included the Turbo and UWM 046 cultivars, whose yield was lower by 15% and 11%, respectively, than Tur. The lowest yield was achieved in the Corda cultivar—15.6 t of d.m. ha^{-1} year^{-1}.

The significantly highest yield in the harvest cycles under examination was achieved in a three-year harvest cycle—20.5 t d.m. ha^{-1} year^{-1} (Fig. 1). It was lower by 3.4% in a two-year cycle and lower by 17.15% in a one-year cycle as compared to the three-year cycle. The Tur cultivar did not corroborate the rule of dry biomass yield increase with increasing duration of the harvest cycle. Its yield was the highest in a two-year cycle—nearly 25 t d.m. ha^{-1} year^{-1}. Harvested every three years, the cultivar yielded nearly 2 t ha^{-1} year^{-1} less, whereas its yield was about 16.7 t d.m. ha^{-1} year^{-1} when it was harvested every year.

The energy value of the biomass obtained in the experiment from the *Salix* spp. cultivars varied, depending on the attributes under examination and the relationships between them (Table 1, Fig. 2). The highest significant energy value of fresh biomass of nearly 357 GJ ha^{-1} year^{-1} was achieved in the Tur cultivar (Fig. 2). The same group included the Duotur cultivar, although the energy