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SELECTED ASPECTS OF ENERGETIC UTILIZATION OF WILLOW BIOMASS

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Abstract. Civilizational development requires seeking for more and more modern methods of satisfying growing needs of the society. Living standards grow together with economic growth and, as a result, demand for energy grows as well. This fact is tantamount with the necessity to look for alternative energy sources. Otherwise, our civilization will soon have to face degradation of natural environment and shortage of conventional energy resources. Under Polish conditions, crucial role in utilizing renewable energy is played by biomass, and its importance is going to grow over the years. The present study has assessed productivity of three willow clones: Tur, Ekotur and Turbo, grown in short rotations on farmland.

Key words: renewable energy sources (RES), willow plantations

INTRODUCTION

Nowadays, human activity is the most significant influence on the shaping of climate. The process of intense climate change began in the middle of the 18th century at the time of Industrial Revolution, when the use of fossil fuels grew dramatically, causing climate warming and degradation of the environment. The concept of sustainable development was first introduced in 1987 by the World Commission on Environment and Development, and in Poland became known under the term of eco-development, i.e. activity based on three principles: economy, environmental protection and social acceptance [European... 2003]. The result of such activities on the supranational level was the 2nd United Nations Conference on Environment and Development in Rio de Janeiro in 1992, with the resulting document called Agenda 21, featuring the chapter "Protection and management of natural resources in order to ensure steady and sustainable development". In 1994, United Nations Framework Convention on Climate Change came into force, and after the introduction of amendments with respect to limiting emissions of harmful gases, a protocol to the Convention, known as Kyoto Protocol,

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was adopted on 11 December 1997. At the European Union level, first regulations regarding energy from renewable sources were published in 1997 as the White Paper of the European Commission, entitled “Energy for the Future: Renewable Sources of Energy”.

In November 2000, Green Paper: “Towards a European Strategy for the Security of Energy Supply” was produced, which supported the utilization of renewable energy sources in order to ensure energy security, environment protection and restructuring of rural areas. In 2006, yet another Green Paper: “A European Strategy for Sustainable, Competitive and Secure Energy” was published, specifying three main goals which ought to shape the energetic policy of Europe, i.e. permanence, competition and security. Fulfilling the first of these goals shall consist in utilizing renewable energy sources and other energy sources emitting insignificant amounts of pollution.

The first basic legislative act promoting renewable energy in the European Union was Directive... [2001], on the promotion of electricity produced from renewable energy sources in the internal electricity market. In 2009, the European Parliament and Council published Directive... [2009] on the promotion of energy from renewable resources, repealing [Directive... 2001, 2003].

Polish regulations regarding renewable energy sources were introduced in 1997, as the act of 10 April 1997 – The Energy Law [Journal... 1997], which established an obligation to take into account renewable energy sources in shaping state energy policy, as well as in developing local plans of providing energy to communes and in development plans of energy companies. Poland’s becoming a member of the European Community made it necessary for the country to fully adjust its regulations regarding renewable energy sources to EU regulations. On 2 April 2004 the law was passed on amending the acts: Energy Law and Environmental Protection Act, which made it possible to sell property rights to certificates of origin (so-called “green certificates”) confirming that a specific amount of electric energy has been produced from renewable sources, independently of the sale of electric energy. Another amendment, from 4 March 2004, obliged the sellers of electric energy to obtain and submit certificates of origin or pay a compensation fee. At the same time a document was developed – Energy Policy of Poland until 2025, which provided guidelines for monitoring and enhancing the agreed mechanisms of supporting development of renewable energy sources in order to make the national energetics more market-oriented and initiate changes following world trends. According to its principles, Poland’s goal by 2020 is to achieve a 15% share of electric energy from RES in the gross consumption of electric energy. After the introduction of Directive... [2009] a national plan of action was developed with reference to obtaining energy from RES on the basis of a template provided by the European Commission [Commission Decision 2009/548/EC of 30 June 2009]. Thus, the document Energy Policy of Poland until 2030 was developed. The forecast assures continued support for producers of renewable energy sources and retaining the so-called co-combustion as a form of RES utilized in Poland until 2020, taking into account limitations with regard to burning forest biomass. It also assumes development, in the sphere of energetics, of sources based on wind power and biomass. As of 15 October 2011, Energy Regulatory Office informed that 2847.4 MW of energy had been produced utilizing renewable sources: 1491MW had been obtained from windmills, 950 MW from hydroelectric power plants, 309.7 from biomass, and 96.7 MW from biogas power plants.

AIM AND SCOPE OF THE STUDY

The aim of the study was to evaluate the productivity of three clones of a common osier (*Salix vinimalis*) i.e. Tur, Ekotur and Turbo, grown on arable land in short, one--year and three-year rotations.

The scope of the study encompassed specifying the number of plants within the area and the number of stems on particular plants. After cutting, the height of the plant as well as the diameter of a stem at breast height were measured, and the yield of fresh plant mass was established.

MATERIAL AND METHODS

Due to the growing importance of either forest or farmland biomass as a renewable energy source, the importance of energetic willow plantations grows as well. The characteristics of willow cultivation make it possible to establish plantations on land excluded from food production and partially polluted [Szczukowski and Tworkowski 2000, Szczukowski et al. 2001]. Problems connected with cultivation and utilization of willows for energetic purposes are studied by employees of the Department of Plant Breeding and Seed Production, University of Warmia and Mazury in Olsztyn, who conduct experiments aiming at the selection of such genotypes which, under proper habitat and climatic conditions, will become an alternative to conventional energy sources. It is estimated that the yields of carefully selected and intensively grown willow clones may be ten times higher than in a natural forest [Szczukowski et al. 2004]. Thus, it is important to learn how much dry mass may be obtained from a particular plantation under the conditions of intensive cultivation, as well as to estimate the calorific value of thus acquired wood [Szczukowski et al. 2004].

In the light of potential opportunities in the sphere of renewable energy resources, especially in connection with biomass, it seems justified to undertake studies aiming at the evaluation of productivity of three willow clones, i.e. Tur, Ekotur, and Turbo, grown in short rotations on post-agricultural land. The clones: Tur, Ekotur, and Turbo have been selected at the Department of Plant Breeding and Seed Production, University of Warmia and Mazury in Olsztyn. The experiment was conducted in the Kwidzyn Lowlands (Polish: Nizina Kwidzyńska), in the ice-margin valley of the Vistula River, on river muds. Field research was conducted over the area of 4 ha (100 m × 400 m). Plots of 10 m^2 were established with four repetitions (3 × 3 × 4 = 36 plots). The total area per every willow clone in a given growing cycle amounted to 44 ares. Within the area, the plots were established randomly so that every element of the whole had an equal chance to be in a sample with the same probability. The aim of featuring four repetitions was to increase the degree of representativeness of a particular feature. The plots of 1.50 m × 6.66 m were established with the aid of a measure and provided with a plate indicating the number of a particular field. Planting density per unit of area (1 ha) was established before the cutting of shrub willow stems took place, and the number of stems on a plant was also established. Then measurements were conducted of stem diameter at the height of 1.3 m. The number of rootstocks was estimated over each 10 m^2 plot, as well as the number of stems sprouting from each rootstock. Only live stems with height exceeding 1.5 m were taken into account. The diameter of stems was measured with a caliper, with the accuracy of 1 mm, while their length was measured with the accuracy of 1 cm.

The cutting of willow stems in one-year and three-year cycles was conducted by hand, using a chain saw Stihl FS 400 equipped with a cutting metal disc with sharp teeth, 200 mm in diameter. Such a carefully selected and suitably powerful saw, as well as the fact that it was operated by a qualified worker, facilitated the process of cutting and protected both the stems being cut and the rootstocks left on the plantation against injury. The stems were cut practically at the ground level, therefore it was important to use a new cutting disc whenever the old one became blunt. Following cutting, the biomass yield from each plot was estimated with the accuracy of 1 kg and then the stems were shredded into woodchips by SKORPION 120 SD drum wood chipper with a hydraulic propulsion system. The obtained wood chips may be used as energy material.

RESULTS

Data provided below constitute mean value of measurement results from four repetitions for each clone in a particular acquisition cycle. The mean number of plants on the plantation equaled 37.02 thousand plants per ha^{-1}, which indicated 92.54% success of cultivation. The highest number of plants per 1 ha was observed in the case of Turbo clone (37.50 thousand plants). The number of plants was slightly lower in the case of Ekotur clone (37.15 thousand plants), whereas in the case of Tur clone the number of plants was the lowest and amounted to 36.40 thousand plants per ha^{-1}. The highest number of plants per 1 ha was identified in the case of a three-year acquisition cycle: 38.20 thousand plants, whereas the lowest number of plants was observed in the case of a one-year cycle: 35.83 thousand plants per ha^{-1}. Out of all three clones, Turbo clone was characterized by the highest number of plants per 1 ha (i.e. 39.50 thousand plants) in the three-year acquisition cycle and the lowest number of plants per 1 ha in the one-year acquisition cycle (i.e. 35.50 thousand plants per ha^{-1}; Table 1).

Table 1. Number of *Salix* sp. plants, $10^3 \cdot ha^{-1}$
Tabela 1. Liczba roślin *Salix* sp., tys. szt.$\cdot ha^{-1}$

Clone Odmiana	Cutting frequency – Częstotliwość zbioru pędów					
	every year co rok	plant loss ubytki roślin %	every 3 years co 3 lata	plant loss ubytki roślin %	average średnio	average plant loss średnio ubytki roślin %
Turbo	35.50	11.25	39.50	1.25	37.50	6.25
Tur	36.00	10.00	36.80	8.00	36.40	9.00
Ekotur	36.00	10.00	38.30	4.25	37.15	7.13
Average Średnio	35.83	10.42	38.20	4.50	37.02	7.46

The percentage difference between actual crop stand and theoretical crop stand (40 thousand plants per × ha^{-1}), is also shown in Table 1. The least plant loss was observed in the case of Turbo clone in the three-year acquisition cycle, where the difference between the actual and theoretical crop stands amounted to just 1.25%. In the case of Ekotur and Tur clones, the comparison of actual and theoretical crop stands revealed plant loss amounting to 4.25% and 8% respectively. The highest plant loss was observed in the case of Turbo clone in the one-year cycle, as it amounted to 11.25%, while for both Tur and Ekotur clones it amounted to 10%.

The average number of stems per plant amounted to 3.3 (Table 2). It was the highest in the case of Turbo clone (4.52 stems), and the lowest in the case of Tur clone (3.35 stems), whereas Ekotur clone was characterized by the presence of two stems per plant. The highest average number of stems, i.e. 4.6, was identified on rootstocks used in the one-year cycle. The longer was the cycle, the lower became the number of stems per rootstock and in the three-year cycle it amounted to 2.0 stems. The highest average number of stems per plant was identified in the case of Turbo clone cut in the one-year cycle (i.e. 6.6 stems). This value was over 2.5 times higher than in the case of Ekotur clone cut in the one-year cycle. In the case of Turbo and Tur cut in the three-year cycle the plants were characterized by the presence of a similar average number of stems, amounting to 2.4 and 2.1 respectively. At the same time, in the case of Ekotur clone the lowest average number of stems was identified, amounting to 1.5 stems per rootstock.

Table 2. Number of stems per plant
Tabela 2. Liczba pędów na roślinie

Clone Odmiana	Cutting frequency – Częstotliwość zbioru pędów		
	every year co rok	every 3 years co 3 lata	average średnio
Turbo	6.6	2.4	4.5
Tur	4.6	2.1	3.35
Ekotur	2.5	1.5	2.0
Average Średnio	4.6	2.0	3.3

Average plant height in the experimental plantation amounted to 4.77 m (Table 3). On average, Ekotur clone was characterized by the longest stems (4.99 m), followed by Tur clone (4.87 m) and Turbo clone (4.44 m). Plants cut in the three-year cycle were the highest, i.e. 6.36 m on average. In the case of plants cut in the one-year cycle the average height amounted to 3.17 m. The most significant difference between plant heights was identified in the three-year crop cycle, between Ekotur and Turbo clones. The difference amounted to 1.26 m, with Ekotur being the higher of the two (Table 3).

Average value of stem diameter measured at the height of 1.3 m amounted to 14.2 mm. It was the highest in the case of Ekotur clone, reaching 16.7 mm. In the case of Turbo and Tur clones the diameters were 13.2 and 12.7 mm respectively. For plants cut in the three-year cycle the average diameter was 20.4 mm, whereas for plants cut in the one-year cycle it was 8.1 mm. The analysis of obtained results led to the conclusion that

Table 3. Height of *Salix* sp. plants, m
Tabela 3. Wysokość roślin *Salix* sp., m

Clone Odmiana	Cutting frequency – Częstotliwość zbioru pędów		
	every year co rok	every 3 years co 3 lata	average średnio
Turbo	3.20	5.67	4.44
Tur	3.25	6.48	4.87
Ekotur	3.05	6.93	4.99
Average Średnio	3.17	6.36	4.77

Ekotur clone was characterized by the thickest stems, reaching up to 25 mm in diameter in plants cut in the three-year cycle, whereas the stems of Turbo clone were the thinnest, with the diameter of 17.8 mm. Meanwhile in the one-year production cycle the thickest stems at breast height were identified for Turbo clone, with the average diameter of 8.6 mm. Tur clone was characterized by the thinnest stems in the one-year production cycle, with the average diameter of just 7.3 mm (Table 4).

Table 4. Stem diameter of *Salix* sp. plants at 1.3 m high, mm
Tabela 4. Średnica pędów *Salix* sp. na wysokości pierśnicy, mm

Clone Odmiana	Cutting frequency – Częstotliwość zbioru pędów		
	every year co rok	every 3 years co 3 lata	average średnio
Turbo	8.6	17.8	13.2
Tur	7.3	18.2	12.7
Ekotur	8.5	25.0	16.7
Average Średnio	8.1	20.4	14.2

The average weight of fresh wood mass per 1 $ha^{-1}\cdot year^{-1}$ amounted to 33.46 tonnes. The highest average yield in comparison to other clones was identified in the case of Tur clone and amounted to 38.92 $t\cdot ha^{-1}\cdot year^{-1}$. In the case of Turbo clone the corresponding value amounted to 35.96 $t\cdot ha^{-1}\cdot year^{-1}$, whereas in the case of Ekotur clone it amounted to just 25.50 $t\cdot ha^{-1}\cdot year^{-1}$. The highest yield was observed in the case of plants cut in the three-year cycle and amounted to 35.83 $t\cdot ha^{-1}\cdot year^{-1}$, whereas for the plants cut in the one-year cycle the corresponding value amounted to 31.08 $t\cdot ha^{-1}\cdot year^{-1}$. Tur clone was characterized by a comparatively steady growth of plant mass, yielding similar amounts of fresh mass in particular cycles. The lowest yield, amounting to 15.25 $t\cdot ha^{-1}\cdot year^{-1}$, was observed in the case of Ekotur clone in the one-year acquisition cycle, whereas for Turbo and Tur clones, also in the one-year acquisition cycle, the yield amounted to 39.00 $t\cdot ha^{-1}\cdot year^{-1}$ (Table 5).

Table 5. Yield of fresh wood mass of *Salix* sp. at harvest, $t \cdot ha^{-1} \cdot year^{-1}$
Tabela 5. Plon świeżej masy roślin *Salix* sp. w okresie zbioru, $t \cdot ha^{-1} \cdot rok^{-1}$

Clone Odmiana	Cutting frequency – Częstotliwość zbioru pędów		
	every year co rok	every 3 years co 3 lata	average średnio
Turbo	39.00	32.92	35.96
Tur	39.00	38.83	38.92
Ekotur	15.25	35.75	25.50
Average Średnio	31.08	35.83	33.46

DISCUSSION

Finding optimal conditions for development of willow plantations with a shortened yield cycle requires that extensive research be conducted in order to select clones characterized by high productivity, provided that planting density, as well as production cycle and cutting frequency have also been properly adjusted. In order to achieve this it is necessary to specify habitat preferences and nutritional requirements of particular willow clones, as well as to find out what cultivations will be needed. Acquaintance with productivity levels possible to achieve under particular habitat conditions will supplement the required knowledge and help future investors make decisions connected with establishment of willow plantations.

The amount of yield depends mainly on successfully combining such factors as willow genotype, type of soil in a particular location, planting density and cutting frequency. Planting density applied in the discussed experiment, amounting to 40 thousand plants/ha, turned out to suit the selected willow clones. This was shown by the proper pace of plant growth as well as high productivity. Such planting is suitable for willow plantations established on small farms, since it allows for utilization of agricultural equipment available on the farm [Szczukowski et al. 2004], and thus the cost of exploiting the willow plantation is lower. Planting density of up to 60 thousand plants/ha is justified when the cutting is planned to take place in the one-year or two-year cycle, whereas in the case of the three-year rotation planting density of thousand plants/ha is sufficient [Stolarski et al. 2002]. A comparison of the obtained results with those of an experiment conducted by Szczukowski et al. [2004], which was aimed at specifying the productivity of six shrub willow clones cut in the one-year cycle in the Kwidzyn Lowlands in the course of six subsequent years, led to an observation that the number of plants over the plantation area in professor Szczukowski's experiment became lower at each subsequent crop cycle, decreasing from 38.7 thousand plants in the first year to 35.7 thousand plants in the sixth year. In the analysed case, in the third year, the average number of plants of three willow clones cut in the one-year cycle amounted to 35.83 thousand plants/ha. An analysis of planting of particular clones cut in the one-year cycle showed that Tur and Ekotur clones were characterized by nearly the same values. In the case of Turbo clone the number was lower by 500 plants/ha. In comparison to results obtained from the experiment conducted by Szczukowski et al. [2004], a significantly lower number of stems per plant was observed: the number was lower by the average of 3.2 stems. In the experiment discussed in this paper, this average value was lowered by the value of this parameter for Ekotur clone, which was twice lower than in the case of Turbo clone. All three clones were characterized by quick pace of growth in the vegetation season in the year following cutting. Furthermore, in the case of each of the three clones, the willow plants were higher in comparison to data featured by Szczukowski et al. [2004], in whose experiment the average height amounted to 2.83 m. Obtained results show that Turbo and Tur clones are suitable for willow plantations with a shortened, one-year acquisition cycle. As for Ekotur clone, its cutting in the one-year cycle has not yielded good results, since the number of stems sprouting from rootstocks was lower than in the case of the remaining two clones, and the plants representing this particular clone were also the shortest.

According to Jeżowski [2003], introduction of energy plants cultivation entails many favourable economic, environmental and social aspects. However, the most important is the fact that biomass is a renewable resource, and obtaining energy from it does not negatively affect natural environment, contrary to obtaining energy from fossil fuels, as the processing of the latter degrades the environment by accelerating the greenhouse effect. It ought to be highlighted that the utilization of biomass for obtaining energy is the most effective way of fulfilling Poland's obligations resulting from the United Nations Framework Convention on Climate Change, as well as the country's obligations resulting from European Union membership, that is increasing the share of energy obtained from RES in the national energy balance to 7.5% by 2010 and to 15% by 2020. Furthermore, apart from increasing energetic security, the utilization of biomass will result in decentralization of energy production. This will be connected with the creation of many workplaces in rural areas, since major producers of willow biomass are located in such areas. A development of energetics utilizing renewable resources in Poland is a guarantee of these producers' success. At the same time, the amended Energy Law Act, adjusted to the provisions of [Directive 2009/28/EC] and promoting the utilization of energy originating from renewable resources, obliges business entities to purchase electric and thermal energy obtained from RES. Local biomass power stations which are built in many administrative communes necessitate establishing energy plantations. Such plantations may be an alternative cultivar on land excluded from food production, at the same time becoming a source of additional income for a farmer. However, in order to create suitable conditions for full development of renewable energy sector in Poland still many barriers have to be brought down, which, in spite of undertaking many efforts in this sphere, have not been successfully eliminated as yet.

CONCLUSIONS

1. The results obtained for the clones Turbo and Tur, grown in the ice-margin valley of the Vistula River in a one-year cycle, have shown that these clones are suitable for growing in willow plantations.

2. Fast-growing willow species grown in plantations located on arable land in the ice-margin valley of the Vistula River may be an important source of renewable fuel.

3. It is necessary to continue the studies on productivity of willow biomass obtained from a willow plantation and utilized as a renewable energy source.

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WYBRANE ASPEKTY ENERGETYCZNEGO WYKORZYSTANIA BIOMASY WIERZBOWEJ

Streszczenie. Rozwój cywilizacji wymaga poszukiwania coraz nowocześniejszych sposobów zaspokajania rosnących potrzeb społeczeństwa. W wyniku zwiększającego się standardu życia wynikającego ze wzrostu gospodarczego rośnie także zapotrzebowanie społeczeństwa na energię. Jest to równoznaczne z koniecznością poszukiwania alternatywnych jej źródeł. W przeciwnym razie w bardzo szybkim tempie nastąpi degradacja środowiska naturalnego oraz deficyt surowców konwencjonalnych dostarczających energię. W polskich warunkach czołową rolę w energetyce odnawialnej odgrywa biomasa, której znaczenie będzie rosło z każdym rokiem. W pracy określono produktywność trzech odmian wierzby: Tur, Ekotur i Turbo, uprawianych w krótkich rotacjach na gruntach rolniczych.

Słowa kluczowe: odnawialne źródła energii, plantacje wikliny

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