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Research paper

Economic comparison of growing different willow cultivars

Mariusz J. Stolarski [a,*], Håkan Rosenqvist [b], Michał Krzyżaniak [a], Stefan Szczukowski [a], Józef Tworkowski [a], Janusz Gołaszewski [a], Ewelina Olba-Zięty [a]

[a] Department of Plant Breeding and Seed Production, Faculty of Environmental Management and Agriculture, Centre for Renewable Energy Research, University of Warmia and Mazury in Olsztyn, Plac Łódzki 3, 10-724, Olsztyn, Poland

[b] Department of Crop Production Ecology, Swedish University of Agricultural Sciences, Ullsväg 16, Box 7043, 750 07, Uppsala, Sweden

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A B S T R A C T

The aim of this study was to assess the cost, income and revenue of chips produced from seven new willow cultivars harvested in three-year harvest rotations. In the base scenario, the willow biomass yield varied greatly from one cultivar to another and the cost of producing chips ranged from 89.1 € Mg^{-1} d.m. to 57.1 € Mg^{-1} d.m. for UWM 155 and UWM 006, respectively. The highest revenue in the base scenario (537 € ha^{-1} $year^{-1}$) was achieved in the plantation with the highest-yielding cultivar UWM 006.

A sensitivity analysis showed that the change in the biomass price and change in energy content of willow biomass had a much greater effect on the final revenue than a change in the yield level. When the price increased by 10%, the revenue from growing different cultivars increased by 33–92%, whereas when the yield increased by 10%, the revenue from growing different cultivars increased by 13–20%. Shortening the transport distance from 50 to 25 km increased the final revenue by 14–36%. An increase in the transport distance to 100 km decreased the final revenue by 28–73%, and when the transport distance increased to 200 km, only the production of UWM 006 and UWM 043 cultivars brought any positive revenue. It is important to find willow varieties with a high energy content because a higher yield of Mg d.m. per hectare will cause the costs per hectare increase but the costs per Mg d.m. and GJ will decrease.

1. Introduction

Solid biomass is the main source of renewable energy in the EU-28 (47%). In Poland, this type of biomass accounts for 82% of all the renewable energy sources [1]. Currently, biomass is obtained mainly from forestry and from the wood industry. Biomass obtained by cutting grass and pruning municipal vegetation, as well as sorted organic waste, is being used increasingly frequently. Biomass as feedstock for energy generation can be obtained from agricultural residues (i.e. corn stover, sugarcane bagasse, husk, etc.) or dedicated perennial crops, such as giant miscanthus, poplar and willow [2–6].

It is noteworthy that future demand for non-forest biomass in Poland (i.e. mainly from agriculture) will steadily increase due to the regulation of the Polish Ministry of Economy [7], which requires that the portion of biomass from energy crop plantations or from waste and residues from agricultural production and the agricultural processing industry should not be lower than 80% in 2015. This also includes cereal grain which fails to meet quality standards, as well as other biodegradable waste in the total biomass, supplied for combustion in energy sources with an electrical power output exceeding 5 MW in which biomass is co-burned with other fuels. This portion is projected to increase in consecutive years to reach 85% in 2018. However, the weight portion of non-forest biomass in cogeneration systems and units in which biomass will be burnt exclusively (in systems with electrical power exceeding 20 MW) will be 20% in 2015 and will reach 50% in 2019 [7]. Therefore, the production of biomass as feedstock for energy generation on short rotation woody crops (SRWC) plantations still remains a challenge for agriculture. Crops grown in the SRWC system include poplar, willow and black locust. These issues have been studied in Europe [8–11] as well as in the USA and Canada [12–14].

Among all the perennial crops cultivated in Poland, naturally-growing willow enjoys the greatest interest, since willow cultivation technology is better known than the cultivation technology of other perennial energy crops and because power-production

* Corresponding author.
E-mail address: mariusz.stolarski@uwm.edu.pl (M.J. Stolarski).

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stations prefer woody biomass as a feedstock for combustion. Depending on the data source, the cultivation of willow in Poland is estimated to occupy an area of 5–9 thousand ha [15,16]. Willow is grown on the largest area in Sweden (about 12,000 ha) [10].

The cost-effectiveness of biomass production is strongly correlated with the plant yield. The yield of willow can reach as much as 30 Mg ha^{-1} year^{-1} d.m., when cultivated on good soil and under favourable weather conditions [8,17], although this is lower in agricultural practice (5–15 Mg ha^{-1} year^{-1} d.m.) [18–21]. The lower yield in agriculture is caused by different factors, including the cultivation of such plants on lower quality land, which is less usable for the cultivation of edible crops [22]. The choice is frequently dictated by economic factors. Farmers concentrate high-yield production of edible crops on high quality soils and defective or marginal soils are left for the production of less demanding plants. Therefore, willow cultivars should be sought which ensure satisfactory biomass yield and income, even on lower quality soils. Therefore, the aim of this study was to assess the cost and cost-effectiveness of chips production from seven new willow cultivars harvested in a commercial plantation in three-year harvest rotations.

2. Materials and methods

2.1. Field experiment

This study was conducted on a commercial willow plantation (53°59′ N, 21°05′ E) with an area of 10.5 ha, owned by the University of Warmia and Mazury in Olsztyn. The plantation was situated mainly on soil created from slightly loamy sand and light loamy sand. Three cultivars and four clones of willow were planted on the plantation; later in the study they were regarded as cultivars. All cultivars were bred at the Department of Plant Breeding and Seed Production of the University of Warmia and Mazury in Olsztyn. Start, Tur, Turbo, UWM 006, UWM 043 – of the species *Salix viminalis,* UWM 035 – of the species *Salix pentandra*, UWM 155 – of the species *Salix dasyclados*. The variety definitions registered in Polish Research Centre for Cultivar Testing (COBORU) are forms that possess legal status and are protected by law, while clone designates a form that is not registered in COBORU and is not protected by law.

Willows were planted at the density of 18 thousand cuttings ha^{-1}. Willow cuttings were planted mechanically (step planter) in strips, with two rows in a strip spaced every 0.75 m, then 1.50 m of space separating the next 2 rows in a strip with 0.75 m space between them, with plants in each row spaced every 0.50 m.

Three-year-old willows were harvested with a Class Jaguar 830 harvester. Chips were collected from the harvester with three units, each one consisting of a tractor and a transport trailer. Subsequently, the trailers with chips produced from different cultivars were weighed and the fresh biomass yield in tonnes per ha was determined for each cultivar.

2.2. Economic analysis

In this paper, the production cost of each of the seven willow cultivars describes the economic compensation needed by the farmer to grow the energy crop. The methods used for calculating or estimating these costs are described below.

2.2.1. The cost of cultivation

The cost of cultivation includes all costs associated with growing the willow crop. The main costs refer to establishment, fertilisation, harvest, field and road transports, weed control administration, brokerage, overheads and wind-up (when terminating the cultivation). Many of the cost items include both labour and machinery costs, the latter of which refer to contractor costs. The costs of plantation establishment, crop cultivation and harvest were based on data obtained from this experiment. We assume that all cultivars are fertilised and transported 50 km after harvest to a collection point. In the calculations for the entire period of plantation use it was assumed that no top dressing was applied in the first year of the willow vegetation. However, before the beginning of the second year of growth and after each harvest, nitrogen was applied on average at: 100 and 160 kg ha^{-1} N, respectively. Phosphorus and potassium fertilisation was applied also 7-fold and was 0.8 kg P and 4 kg K, respectively, per ton DM in the yield of willow cultivars. It was also assumed that Roundup was applied four times during the entire plantation period, with the first dose of 2 dm^3 per ha and the subsequent three doses were 4 dm^3 each per ha. The road transport cost of willow chips from the field to the conversion plant was based on the typical rates for the region where the plantation was located. Table 1 presents data obtained during the work and studies conducted on the willow plantation used in the analysis.

2.2.2. Calculation

The calculations were made using a model developed by Rosenqvist [23]. This model combines the present value method and the annuity method, thus making it possible to compare the economics (including production costs) for different crops. The model employs a total-step calculation method, in which all disbursements over the estimated lifespan of the plantation are discounted. The annual cost of cultivation for a crop was calculated by multiplying all disbursements by their present value factor and the annuity factor of the discount rate (according to the equation below).

$$\text{Annual cultivation cost} = \frac{r}{1-(1+r)^{-n}} \sum_{T_{t-0}} (1+r)^{-t} \cdot A_t$$

n = length of the calculation period (lifespan) in years
r = discount rate (5%)

Table 1
Data from the willow plantation and the costs used to conduct the analyses.

Item	Unit	Value	Number of operations
Plantation lifespan	years	21	–
Harvest cycle	years	3	–
Number of harvests	–	7	–
Planting density	Cuttings ha^{-1}	18,000	–
Interest rate	%	5.0	–
Workforce	€ h^{-1}	4.58	–
Chips price	€ MWh^{-1}	17.568	–
Chips price	€ GJ^{-1}	4.88	–
Cuttings	€ ha^{-1}	659.0	–
Common costs in enterprise	€ ha^{-1}	15.0	–
Brokerage	€ Mg^{-1} d.m.	2.0	–
N fertiliser	€ kg^{-1}	0.9	7
P fertiliser	€ kg^{-1}	1.4	7
K fertiliser	€ kg^{-1}	0.72	7
Roundup	€ dm^{-3}	7.62	4
Stubble harrowing	€ driving^{-1}	25.10	2
Ploughing	€ driving^{-1}	58.27	1
Harrowing	€ driving^{-1}	16.85	2
Spraying	€ driving^{-1}	11.54	5
Fertilizer spreading	€ driving^{-1}	16.76	7
Planting	€ ha^{-1}	111.3	1
Mechanical weed control	€ ha^{-1}	24.38	2
Chemical weed control	€ ha^{-1}	94.0	1
Liquidation of plantation	€ ha^{-1}	268.0	1
Harvesting of willows	€ Mg^{-1} d.m.	24.2	7
Field transport	€ Mg^{-1} d.m.	10.3	7
Road transport 50 km, loading	€ Mg^{-1} d.m.	9.6	7