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# Willow biomass obtained from different soils as a feedstock for energy

Michał Krzyżaniak[a,*], Mariusz J. Stolarski[a], Stefan Szczukowski[a], Józef Tworkowski[a], Arkadiusz Bieniek[b], Mirosław Mleczek[c]

[a] Department of Plant Breeding and Seed Production, University of Warmia and Mazury in Olsztyn, Plac Łódzki 3, 10-724 Olsztyn, Poland
[b] Department of Soil Science and Soil Protection, University of Warmia and Mazury in Olsztyn, University of Warmia and Mazury in Olsztyn, Plac Łódzki 3, 10-724 Olsztyn, Poland
[c] Department of Chemistry, University of Life Sciences in Poznan, Wojska Polskiego 75, 60-625 Poznań, Poland

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ABSTRACT

Perennial energy crops, including willow, should be highly productive and the biomass should possess a high energy value, allowing farmers to obtain large amounts of energy per ha each year. The aim of this study was to determine the morphological traits, biomass productivity and quality of willow coppice grown on two different soil sites and harvested in a three-year cycle. The experiment was performed on a commercial willow plantation owned by the University of Warmia and Mazury in Olsztyn (the UWM). The plantation, located in north-eastern Poland, covered 4.7 ha. The study demonstrated that the UWM 043 cultivar grown in a three-year rotation system on Haplic Cambisols (Eutric) soil can produce plants over 8 m tall with shoots over 4 cm in diameter. On the other hand, plants of *Salix* spp. grown on much poorer soil are much shorter and have thinner shoots. Under optimal production conditions, it is possible to harvest in a three-year rotation system as much as 16.12 Mg ha$^{-1}$ year$^{-1}$ of dry biomass per year with moisture equal to 47.56%. The yield of the UWM 043 cultivar was significantly (40%) higher than that of the cultivar Turbo. The biomass of the UWM 043 clone proved to be better fuel owing to a higher bulk density, lower moisture, higher lower heating value and a lower content of nitrogen, sulphur and chlorine.

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## 1. Introduction

The agricultural land area in Poland is estimated to be about 18.7 million hectares (GUS, 2014). Four plant species: willow (*Salix* spp.), poplar (*Populus*), Virginia mallow (*Sida hermaphrodita* R.) and giant miscanthus (*Miscanthus* x *giganteus*), seem most likely to enter the biomass production market in Poland (Jeżowski, 2008; Krasuska and Rosenqvist, 2012; Jeżowski, 2008; Stolarski et al., 2014). Among all the perennials cultivated in Poland, naturally growing willow is the most promising crop (Krzyżaniak et al., 2014; Stolarski et al., 2014a). The area of its cultivation totaled about 6.2 thousand hectares, whereas all energy crops, including willow, were cultivated on an area of about 10 thousand hectares (Gajewski, 2010). It is predicted that in 2020 the land under energy crops would cover 2 million hectares, including about 500 thousand ha under perennial energy crops. Such a volume is required to meet the objectives outlined in the Directive 2009/28/EC on the promotion of the use of energy from renewable sources (European Commission, 2009; Kuś and Faber, 2009).

In Poland, *Salix* is represented by 28 species and numerous hybrids (Tomanek, 1994). There have been several studies conducted into the properties of new willow varieties intended for energy production. Research has been conducted in Sweden, the UK, the USA and in many other countries (Larsson, 1998; Lindegaard and Barker, 1996; Smart et al., 2005). In Poland, there is no single, central programme for research into the cultivation of SRWC willow, whereas the number of varieties registered with the Polish Research Centre for Cultivar Testing (15 Polish proprietary varieties) is a sign of interest in the subject (COBORU, 2014). Of the varieties mentioned, ten were registered by the research team of the Department of Plant Breeding and Seed Production of the University of Warmia and Mazury in Olsztyn.

The dominant system of Short Rotation Woody Crops (SRWC) cultivation on farmland is a short, three-year cycle (Kopp et al., 1997; Labrecque and Teodorescu, 2003; Kopp et al., 1997; Stolarski et al., 2014b). Soil preparation before the planting of willow cuttings comprises typical soil tillage treatments: deep ploughing, harrowing, mechanical and

* Corresponding author.
*E-mail address:* michal.krzyzaniak@uwm.edu.pl (M. Krzyżaniak).

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chemical weed control, mineral fertilization, etc. Another willow biomass production method is known as the Eko-Salix system. It consists of simplified, ploughless soil tillage and the planting of unrooted pole cuttings (Stolarski et al., 2011a).

Perennial energy crops, including willow, should be highly productive and the biomass should possess high energy value, allowing farmers to obtain large amounts of energy per ha each year. The productivity potential of perennial crops is highly varied and can range from a few to several tonnes of dry matter per ha annually. The yield depends on the soil quality, plant species and cultivar, crop management, planting density and rotation cycle (Labrecque and Teodorescu, 2005; Quaye and Volk, 2013; Stolarski et al., 2014a).

Apart from the biomass productivity obtained in a given year under given agro-climatic conditions, another important factor is the plantation life, on the basis of which we can estimate the accumulated biomass production of the plantation of studied perennial crop. Knowledge of the yields that can be expected on a commercial scale is crucial for clone selection and management optimization processes. Studies of this aspect of Short Rotation Woody Crops (SRWC) production have been done in Poland in recent years (Krzyżaniak et al., 2014; Stolarski et al., 2014a, 2013). The interaction of all of the above factors has a significant effect on both biomass productivity as well as the quality of energy feedstock, which is of paramount importance for the development of lignocellulosic crop production in the future.

Short rotation woody crops should be established on poor, marginal or contaminated soils, and shall not compete with the production of edible crops. Nevertheless, farmers producing biomass will seek the highest yield from a unit area.

It was hypothesized that biomass productivity for two selected cultivars would differ between cultivars and the cultivars productivity would be different on two soil types. In view of the above, the purpose of the present research has been to determine the morphological traits, biomass production and quality from two willow cultivars grown on a commercial scale at two different stands on loam and loamy-sandy soil.

## 2. Material and methods

### 2.1. Characteristics of the experimental area

The years 2009–2011, when the research was carried out, were similar in the mean air temperatures (from 7.1 to 8.4 °C) (Fig. 1). The total rainfall in each year was higher during the growing season than the analogous values calculated for the multi-year period (Fig. 1). In turn, the average annual precipitation in 2009 and 2010 was higher, and in 2011 it was lower than the multi-year average. The rainfall distribution was variable. In each year, April was drier than the multi-year average, which could inhibit the early growth and development of willow plants.

The study area is characterized by gently undulating land, where differences in relative height were less than 15 m. The experiments were located on an eastward slope with a 10% gradient. The tests were carried out at two sites located on different soils. The first SRWC willow stand is located on loam soil: Haplic Cambisols (Eutric) (IUSS Working Group WRB, 2007) developed from loam with underlying clay loam at the depth of 88 cm. The second site was on Brunic Arenosols (Dystric) (WRB 2007) formed from loamy sand deposited on sand (Table 1).

The actual moisture (% of the volume) at both sites was strongly differentiated. In the loam soil site it was within 20.9–30.7% vol. In the loamy sand soil site there was less water (7.2–10.1% vol.). At A and Bw levels of the loam soil site, water was easily available to plants (pF 2.0–3.0), whereas at the bedrock level it was poorly accessible (pF 3.0–4.2). In the loamy sand site, water was poorly accessible to plants (pF 3.0–4.2) at all levels.

**Table. 1**
Characteristics of soil texture.

| Horizon | Depth (cm) | Percent of fraction of diameter (mm) | | | | Textural group |
|---|---|---|---|---|---|---|
| | | >2.0 | 2.0–0.05 | 0.05–0.002 | <0.002 | |
| Loam soil | | | | | | |
| A | 0–30 | 0 | 42 | 47 | 13 | Loam |
| Bw | 30–88 | 0 | 45 | 45 | 10 | Loam |
| C | 88–150 | 0 | 30 | 51 | 19 | Clay loam |
| Loamy sand soil | | | | | | |
| A | 0–28 | 0 | 85 | 10 | 5 | Loamy sand |
| Bv | 28–65 | 0 | 74 | 22 | 4 | Loamy sand |
| C | 65–150 | 0 | 88 | 11 | 1 | Sand |

A – humic horizon; Bw – horizon enriched with non-alluvial iron deposits; Bv – in situ iron enrichment; C – bedrock.

The soils at the experimental sites were characterized by extremely different air and water conditions. There were few macropores in the loam soil site, whereas the loamy sand soil site was poor in micropores. Consequently, the loamy sand soil site suffered from periodic water deficits, which had an adverse effect on the growth and development of plants, an event unobserved at the other site.

### 2.2. Establishment and management of the plantation

In the third decade of April 2008, a commercial willow plantation was established on 4.7 hectares of land at the Research Station in Łężany, owned by the University of Warmia and Mazury in Olsztyn (the UWM) (N: 53°58′ E: 21°8′). The preceding crop was winter triticale grown in a crop rotation system. After the triticale was harvested, in late autumn 2007, deep winter ploughing to the depth of 35 cm was done with a subsoiler. In spring 2008, soil smoothing was carried out and willow cuttings of the UWM 043 and Turbo cultivars bred at the UWM in Olsztyn were planted. Each cultivar was planted on two types of soil and on separate plots, which in total covered 2.35 ha of land. Cuttings, 25 cm in length and 0.9–1.1 cm in diameter, were planted manually from 20 to 22 April 2008 at a density of 18,000 cuttings per ha. A strip cropping system was used. The distance between double rows was 1.5 m and the distance between single rows in a double row was 0.75 m. The distance between cuttings in a row was 0.5 m. During first week after planting, weeds were controlled chemically (Guardian Complete MIX 664 SE: 3.5 l $ha^{-1}$ with acetochlor and terbuthylazine: 300 g $l^{-1}$). The one-year-old shoots were harvested after the 2008 growing season to increase the number of shoots from each stump in the following year. Mineral fertilizer was applied in the first decade of April 2009 in doses corresponding to N 100, $P_2O_5$ 30 and $K_2O$ 60 kg $ha^{-1}$.

The results of the study since 2009 are presented, in which the first factor consists of cultivars of willow species *Salix viminalis*: UWM 043 and Turbo. The second factor is the type of soil site: loam and loamy sand.

For each stand and cultivar, experimental blocks measuring 60 m × 150 m were designed, on which plots measuring 3.0 × 10.0 m (30 $m^3$ each) were randomly chosen in four replications (Fig. 2).

After three years, in the first decade of January 2012, the plant density of three-year-old willow stands per 1 ha and the number of living shoots with height >1.5 m were counted on the designated plots. Next, the density of plants per hectare was calculated from plots. The following biometric measurements were performed on 10 plants within the plot: the stem height and diameter of stems at 0.5 m height of the stem. In order to obtain more detailed yield determination, in the first decade of January 2012, three-year-old

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