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Research paper

Willow biomass and cuttings' production potential over ten successive annual harvests

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A B S T R A C T

Willow nursery plantations for cuttings' production, which provide planting material for new, improved varieties, can be set up in greater densities and must be harvested in one-year cycles. Therefore, the aim of this study was to determine the effect of planting density on the survival rate, yield and production potential of cuttings of two varieties and three clones in ten successive one-year harvest cycles. The experiment was conducted in the years 2004–2013 in northern Poland. Significant differentiation regarding the biomass yield and the number of cuttings was demonstrated not only between the planting densities, but also between the varieties/clones and the interactions between those factors. The final survival rate was close to 85% with a planting density of 12 000 $ha^{-1}$and 24 000 ha^{-1}. However, the survival rate was half that at the highest planting density. The varieties and clones differed in their morphological features, which affected their yield, both as chips and cuttings number. The best results were achieved for the UWM 095 clone and the Tur variety. The yield varied over the next ten years, but it was not found to decrease as the plantation aged. An increase in planting density from 12 000 ha^{-1} to 24 000 ha^{-1} resulted in greater yield, but a further increase to 48 000 $ha^{-1}$and 96 000 ha^{-1} did not bring such effects. The production of cuttings could bring more than 20 times higher potential income compared to the production of chips for energy purposes.

1. Introduction

The production of willow biomass on short rotation woody crops (SRWC) plantations has been an object of development studies in many European countries [1–5] and in the USA and Canada [6–8]. The selection of the right species and variety is one of the major factors which impacts the yield of willow biomass [2,7,9,10]. Other factors of key importance include soil conditions [2,11] and the type and dose of fertilisers used [1,12], although some studies have shown the impact of this factor on the yield to be limited [13–15]. Other factors which have an impact on willow yield include weather conditions and agricultural procedures [16–18], as well as planting density and harvest frequency [19,20].

The recommended planting density for willow on commercial plantations for biomass production ranges from 10 000 to 20 000 ha^{-1}, and the plants are usually harvested in three-year cycles. It was found that a higher yield per year of plantation use is usually achieved in longer harvest cycles (3–4 years) than in shorter cycles (1–2 years) [9,20,21]. However, willow plantations set up for the production of cuttings (nursery plantations) to provide planting material for new, improved varieties in sufficient quantity and of good quality, can be set up in greater densities and they must be harvested in one-year cycles. It must also be stressed that nursery plantations must be permanently ready to supply cuttings to the market and must be harvested every year, even if there is no demand for planting material. In such cases, it is important that the quantity of biomass is as large as possible. It is also believed that harvesting willow in one-year cycles with higher planting densities results in high biomass yield and is technologically closer to traditional cultivation of annual plants, if only in that it gives annual income from the sale of biomass. It is also technologically easier to harvest willow in one-year cycles than, for example, in three-year cycles. Moreover, cultivation procedures can be carried out on the plantation every year after the harvest, which helps to keep plants in good health. Knowledge of effective

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production of willow biomass in successive one-year harvest cycles is indispensable in order to plan the biomass production potential and the number of cuttings from nursery plantations. Therefore, the aim of this study was to determine the effect of planting density on the survival rate, morphological features, yield and production potential of cuttings of two varieties and three clones of willow in ten successive one-year harvest cycles.

2. Materials and methods

2.1. Location and factors of the field experiment

The field experiment was set up in spring, in early April 2003. It was located in northern Poland, in the Kwidzyn Valley, in the village of Obory (53°43′ N, 18°53′ E) near Kwidzyn. The Kwidzyn Valley is the northern section of the Lower Vistula Valley, between Kotlina Grudządzka and Żuławy Wiślane. It is 40 km long and 6–9 km wide. The bottom of the valley lies 15 to 7 m above sea level and its slopes rise to 50–60 m above its bottom. Alluvial soils are typical of the surface of the entire area of the Lower Vistula Valley. The quality and agricultural usability of these soils is affected by their variable granulation and organic matter content. Factors taken into account when choosing the site for the experiment included the condition of the vegetation in the area. Although care was taken to select as uniform a site as possible, some variability of the soil conditions (which are typical of soils in river valleys) could not be avoided. The experimental site was relatively flat with a slight elevation. Elevation differences in the area did not exceed 1 m. Humic heavy alluvial soil, complete, formed from silty clay, occurred in the majority of the experiment site, especially where cuttings were planted at a density of 24 000 and 48 000 ha^{-1}. An enclave of sandy subsoil, with soil described as alluvial soil proper, medium compact and shallow, on loose sand, was identified in part of the experiment site, especially in the area where cuttings were planted at a density of 12 000 and 96 000 ha^{-1}. This soil had much lighter granulometric composition. Moreover, surface layers at this site were underlain at a small depth (from 37 cm) by loose sand, which testifies to the previous presence of a shallow bottom in the river valley. The aero-hydrographic conditions of this soil were much worse, including capillary ascension, compared to very heavy alluvial soil. It resulted in a shortage of water for willows during periods with no precipitation. All of this made willows grown in this part of the site more susceptible to weather conditions and it had an adverse effect on growth and plant development when the distribution of rainfall was not favourable.

The study presented in this paper was based on a two-factorial field experiment. The first experiment factor were two willow varieties: Tur (*Salix viminalis* L.), Turbo (*S. viminalis* L.), and three willow clones: UWM 046 (*S. viminalis* L.), UWM 095 (*S. alba* L.) and UWM 200 (*S. alba* L.) – all of them bred at the Department of Plant Breeding and Seed Production of the University of Warmia and Mazury in Olsztyn.

Four densities of cuttings planting were the second factor: 12 000 ha^{-1}, 24 000 ha^{-1}, 48 000 ha^{-1} and 96 000 ha^{-1}. Cuttings were planted in a strip system. The distance between double rows was 90 cm and the distance between single rows within a double row was 75 cm (Fig. 1). The planting density was regulated by plant spacing in a row. It was 100 cm for the lowest density (12 000 ha^{-1}) and it decreased with increasing plant density to reach 50 cm, 25 cm and 12.5 cm, respectively. The experiment was conducted in four replications on a total of 80 plots with an area of 23.1 m^2 each. The plants grew in four rows on each plot.

The year when the experiment was set up (2003) was taken as the initial year and no data from that year was included in the study. Early in February 2004, one-year-old willows from all the

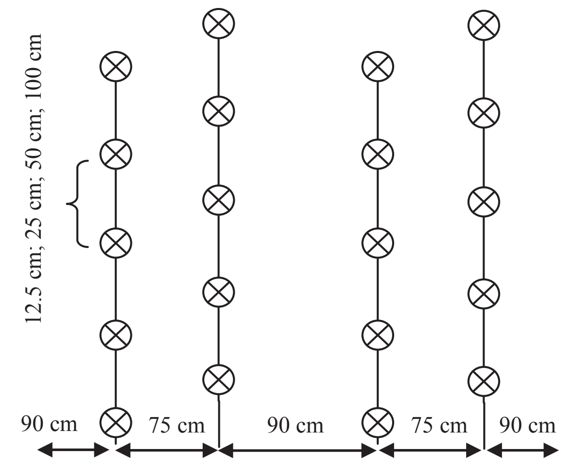

Fig. 1. Diagram of a system of strip planting of cuttings.

plots were harvested in order to stimulate branching and growth of shoots in the following years. The current study was based on data for ten successive plant growth periods. 1 - 2004; 2 - 2005; 3 - 2006; 4 - 2007; 5 - 2008; 6 - 2009; 7 - 2010; 8 - 2011; 9 - 2012; 10 - 2013. One-year-old willow shoots grew on stumps which were between two and eleven years old. Plants were harvested in the winter of the following year, i.e. in February 2005–2014, respectively.

2.2. Preparation of the site and conducting the experiment

Alfalfa was sown as a forecrop. Roundup 360 SL at 5 dm^3 ha^{-1} was applied before the experiment was set up, near the end of August 2002, in order to destroy alfalfa and weeds. Subsequently, on the final days of September 2002, cultivation measures were carried out with a disc harrow in order to grind plant biomass. Winter ploughing at the depth of 30 cm was performed on the final days of October 2002. The field was harrowed twice in early spring of the year of establishing the experiment (2003). The soil herbicide Azoprim 50 WP was applied at 3 kg ha^{-1} immediately after the cuttings were planted. Moreover, the plantation was weeded twice during the plant growth season of 2003 in order to control the secondary weed infestation. The cultivation measures were carried out on the final days of June and early days of August. No mechanical cultivation of willows was carried out in the remaining years of the experiment. A herbicide was sprayed on the soil after each harvest before the next growing season started. Moreover, on early days of May in 2009–2013, the plants were sprayed with a perethroid insecticide (Fastac 100 EC) at 150 cm^3 ha^{-1} in order to control the growth of pests. No mineral fertilisers were applied in the year of setting up the plantation. Fertilisers were sown manually every year in the subsequent years of the experiment: N 90 kg ha^{-1}, P 18 kg ha^{-1}, K 66 kg ha^{-1}. Nitrogen was sown as ammonium nitrate at 50 kg ha^{-1} at the start of a growing season. The remaining amount of nitrogen (40 kg ha^{-1}) was applied at the end of May. Phosphorus was applied as triple superphosphate and potassium - as potassium salt - before a growing season started. Willow coppice was observed during the growing seasons for any infestation with pests and diseases.

2.3. Survival rate and biometric measurements

After each growing season (2004–2013), the plant density was determined in each plot. This was used to determine the survival rate after each growing season. The heights and diameters of the