WOOD RESEARCH
58 (4): 2013
651-662

BIOMASS PRODUCTION POTENTIAL OF DIFFERENT WILLOW VARIETIES (*SALIX* SPP.) GROWN IN SOIL-CLIMATIC CONDITIONS OF SOUTH-WESTERN SLOVAKIA

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(Received April 2013)

ABSTRACT

The research carried out in the 2009-2011 focuses on evaluation of biomass production potential of eight willow varieties (*Salix* L.) grown on arable land in the soil and climatic conditions of south-western Slovakia. The varieties included in the research were Jorunn, Jorr, Bjőrn, Klara, Lisa, Terra Nova, Loden and Dimitrios. During the research period (2009-2011), we observed climatic conditions of the research site, soil moisture, groundwater level and occurrence of diseases and pests. The production parameters determined in the study include the rooting of 0.20 m long cuttings of one-year old shoots, number, length, diameter and weight of shoots produced on rooted cuttings and weight of individual plants. There were very different climate conditions observed during the research period on the site. Years 2009 and 2011 were characterized by low amount of precipitation compared to the long-term average. On the contrary, the year 2010 was extremely rich in atmospheric precipitation, which exceeded the long-term average by 312.6 mm. The percentage of well-rooted cuttings ranged from 95 to 100 %, except of variety Terra Nova that reached only 56 %. There were statistically significant differences among varieties in the studied production parameters. Individual varieties produced 1.44 to 2.40 shoots per plant in the first year after the planting. In the second year, after the cutback, the number of shoots per plant ranged from 5.06 to 13.28 shoots. In the third vegetation year, the number of shoots decreased (weak shoots gradually died out) and ranged from 3.83 to 10.50. Strong statistical dependence was proven between shoot weight and length and/or shoot diameter. Studied willow varieties showed different levels of pests and diseases infestation. Varieties Dimitrios and Terra Nova were resistant to fungal diseases. Varieties Bjőrn, Klara and Lisa were attacked by rust (*Melampsora* sp.) on a small scale. The yield of dry biomass among the studied varieties ranged from 16.50 to 24.13 t.ha^{-1} at the end of the third vegetation year. The highest biomass yields were determined in varieties Bjőrn and Terra Nova (24.13 and 22.52 t.ha^{-1} respectively).

KEYWORDS: Production parameter, production potential, climate condition, biomass yield.

INTRODUCTION

The use of renewable energy sources is one of the priorities of Energy Security Strategy of Slovak Republic. Their use reduces dependence on imported fossil fuels, leads to reduction of greenhouse gas emissions and it is in accordance with sustainable and economic development of Slovak regions. The growing of energy crops such as *Salix* on agricultural land can also significantly contribute to the implementation of the Slovak energy security strategy. Biomass of this fast-growing woody crop can represent an important place in the fuel-energy base of Slovakia in the near future. Initial findings of the Salix cultivation in soil-climatic conditions of northern Slovakia were presented by Habovštiak and Daniel (2007), Daniel (2008), Daniel and Medvecký (2010). The first experimental results of energy willow (*Salix* L.) growing in soil-climatic conditions of south-western Slovakia were provided by Húska (2000). In following years (2006-2013), the research of production and energy potential of Swedish and Hungarian willow varieties has been conducted by Centre for Renewable Energy Research at the Department of Sustainable Development at the Faculty of European Studies and Regional Development at SUA in Nitra. The research is carried out on four research sites in south-western Slovakia (Kolíňany, Selice, Brodské and Chotín). The study results from these research sites are provided by Skladan (2010), Fazekaš (2011), Hauptvogl (2011), Demo et al. (2011), Bako (2012) and Tóthová (2012). Possibilities of growing energy crops and trees on unused agricultural land in Slovakia address Kotrla and Prčík (2011, 2012) also analyze biotic parameters of energy woody crops in floodplain forests of the lower reach of River Váh. Maga (2008), building on the works focused on the evaluation of production and energy potential of Swedish and Hungarian willow varieties in conditions of south-western Slovakia, deals with different ways of usage of the energy crops biomass.

The aim of the paper is to provide the research results of yield production potential of the newer willow varieties (*Salix* spp.) grown in soil-climatic conditions of south-western Slovakia in 2009-2011.

MATERIAL AND METHODS

In order to carry out the research aimed at evaluating of the production potential of 8 willow varieties in drier climate conditions of south-western Slovakia, a field trial was established on land belonging to university farm in Kolíňany in 2009. The site is flat, located at 180 m above sea level at the foot of slight slope without elements of surface water erosion. The soil is moderate (loam), pH values range from 7.18 to 7.35, humus content is 1.16 to 2.50 %. The area belongs to warm, very dry and lowland climate region. According to Špánik and Šiška (2008) the long-term mean annual air temperature (1951-1980) is 9.9°C and long-term annual rainfall (1951-2000) is 547.6 mm.

Following registered willow varieties (*Salix* spp.) were included in the research: Jorunn, Jorr, Bjőrn, Klara, Lisa, Terra Nova, Loden and Dimitrios.

The first research activity was the establishment of stands of the individual varieties. In the middle of April 2009, cuttings of one-year old shoots 0.2 m long in dormant state were planted to a depth of 17 cm, so the 3 cm of the cuttings remained above the soil surface. The cuttings were

planted in double-rows in three replicating plots. The distance between the double-rows was 2 m and distance between the rows within the double-row was 1 m. The distance between individual plants in the row was 0.75 m. This spacing represents 8.889 plants ha^{-1}.

Thirty days after the planting, rooting of the cuttings were surveyed. Percentage of well-rooted cuttings was determined based on the number of living individuals out of the total planted cuttings. Unrooted cuttings were replaced by new ones.

Number of shoots produced on each planted cutting was observed at the end of the first growing year.

In March 2010, before the beginning of the second growing period, cutback (technical cut) of one-year old shoots was realized. The shoots were cut at 5 cm above the soil surface, thus creating conditions for the formation of more shoots in the next growing period. After the cutback, mineral fertilizers were applied (100 $kg.N.ha^{-1}$, 75 $kg.K.ha^{-1}$ and 35 $kg.P.ha^{-1}$).

Following measurements and evaluations of soil and production parameters were made during the three growing periods:

Monitoring of soil moisture content was done by dielectric method. For this purpose, four probes (sensors) were installed into the soil, evenly distributed throughout the experimental site. The soil moisture was monitored at depths of 0.1, 0.2, 0.3, 0.4, 0.6 and 1.0 m using measuring equipment PR2 (Profile probe) and data reader HH2 (Moisture meter) during all growing seasons. Data were statistically evaluated by two-factor analysis of variance (ANOVA), where one factor was the soil depth and the second factor the date of measuring.

At the end of each growing season, number of shoots, shoot length and diameter and weight of individual plants was observed on selected individuals. The shoot length was determined by telescopic meter nEssfix 8 m (Nedo). The shoot diameter was measured by electronic callipers. The shoot diameter was determined at 0.5 m above the soil surface in the first growing period and at 1.0 m above the soil surface in the second and third growing period. The obtained data were evaluated by analysis of variance (ANOVA).

The biomass yield was determined each year by combination of destructive and non-destructive method, since we were limited by the total number of planted cuttings for each variety. Removing larger number of individuals could disrupt the structure of the stand in following growing periods. The destructive method consisted of cutting two individuals from each of the three replicating plots. After the cutting, the weight of each shoot and the total weight of each plant were determined. Biomass samples were oven-dried at 105°C and dry weight of individuals was determined. The procedures for determining the biomass yield were the same in all growing periods. The obtained data were statistically evaluated by two-factor analysis of variance (ANOVA).

From the occurring diseases, the biggest attention was paid to the degree of rust (*Melampsora* sp.) infestation. In 2010, the rate of rust infestation was investigated in the first decade of September and in 2011 in the second decade of August. The rate was evaluated by a scale ranging from 0 to 5 (Aylott et al. 2008, Matthew et al. 2008). According to the scale, 0 represents no occurrence and 5 means very strong infestation.

Correlation between the biomass weight and other growth parameters was evaluated by correlation and regression analysis. Overall evaluation of the achieved values of the production parameters was done by cluster analysis.

RESULTS AND DISCUSSION

During the three-year research period (2009-2011) the precipitation and temperature conditions in individual months showed significant differences and deviations from long-term averages. Months with very low precipitations, which could affect the production process occurred in each experimental year. In 2009, the total annual precipitation was 571.3 mm and particularly poor months were April, May and September. On the other hand, year 2010 was extremely rich in rainfall. The total rainfall was 860.2 mm, which represents 312.6 mm over the long-term average. Particularly high amounts of rainfall were observed in April (86.0 mm), May (158.0 mm) and June (131.3 mm). The total precipitation in 2011 was 420.4 mm, which is 127.2 mm less than the long-term average. Hall (2003) defines the total rainfall during the growing period needed for optimal biomass production of fast growing woody crops as 550 mm.

Volumetric soil moisture measured during the experimental years points to the heterogeneity of soil moisture at the site. Statistically highly significant differences were found among individual plots as well as among the dates when the measurements were carried out.

The assessment of the soil water in 2010 was based on the point of reduced water availability, which was determined in the range from 24.6 to 28.4 % of the volumetric soil moisture. The results show that in most cases the average volumetric soil moisture values in the individual depths of the soil profile exceeded the value of the reduced water availability during growing period. Thus it can be concluded that the studied willow varieties did not suffer from water shortages in 2010. The high amount of rainfall during the growing season had a significant share on this fact. In 2011, the values of volumetric soil moisture were on average lower than in 2010. These values were influenced mainly by lower rainfall during the growing season. However, as the values of volumetric soil moisture in deeper soil layers were higher than the point of reduced water availability, we do not assume any significant influence on the production process due to water shortages.

Rytter and Hanson (1996) considered the soil depth of 400-450 mm as determining in terms of the amount of water needed for the production process, due to the largest number of active roots absorbing water and nutrients located in this layer.

The number of well-rooted cuttings investigated 30 days after the planting was high among the individual varieties with one exception. The varieties Jorunn, Jorr, Bjőrn, Klara, Lisa and Loden reached 100 % and Dimitrios 95 % of well-rooted cuttings. The lowest value, only 56 %, had Terra Nova. The mortality of plants from original number of well-rooted cuttings occurred only in variety Dimitrios (17 %) at the end of the first growing period. Bergkvist et al. (1996) and Kiernan et al. (2003) consider 80 % rootedness for economically acceptable threshold.

The average number of shoots produced on cuttings planted in the first and second growing season (after the cut back) and at the end of the third growing season (2011) is shown in Tab. 1.

Tab. 1: Average number of shoots produced on planted cuttings in the first year (2009), in the second year after the cut back (2010) and changes in the number of shoots at the end of the third year (2011).

Growing period	Varieties							
	Jorunn	Jorr	Björn	Klara	Lisa	Terra Nova	Loden	Dimitrios
	Average number of shoots							
2009	1.94	2.39	2.00	1.56	1.44	2.40	1.50	1.71
2010	13.28	13.22	8.06	10.06	5.06	9.30	10.22	6.07
2011	10.50	10.42	6.00	8.502	3.83	8.29	9.00	5.80

As can be seen from Tab. 1, the number of shoots produced on cuttings ranged from 1.44 to 2.40 in the first year after the planting. In the second year after the cut back, the number of produced shoots ranged from 5.6 (Lisa) to 13.28 (Jorunn). There was a decrease in the shoot numbers in the growing period of 2011 compared to 2010 in all varieties. Differences in the number of shoots among the varieties are statistically highly significant. Verwijst et al. (2012) indicate that diameter and length of planting material can affect the number of shoots and consequently the total biomass yields. During the three-year growing cycle, the cumulative mortality of willow shoots reaches up to 90 % of the original number of shoots (Verwijst 1991). According to Cannell (1989) the shoot mortality is higher in individuals with more shoots, which may be associated with greater foliage cover and lower light distribution into the crop stand.

The average shoot lengths of the studied varieties in the individual growing periods are shown in Tab. 2 and the shoot diameters in Tab. 3.

Tab. 2: Average length of shoots (cm) of the studied willow varieties in the individual growing periods.

Growing period	Varieties							
	Jorunn	Jorr	Björn	Klara	Lisa	Terra Nova	Loden	Dimitrios
	Average length of shoots (cm)							
2009	188.77	191.51	202.75	193.46	225.58	136.42	157.48	185.29
2010	271.00	277.68	288.78	327.36	300.87	268.53	267.73	288.82
2011	378.29	419.11	444.63	511.10	560.62	466.90	396.09	442.71

Tab. 2 shows that the average length of shoots ranged from 136.42 cm (Terra Nova) to 225.58 cm (Lisa) at the end of the first growing season. Variety Lisa had the longest shoots also in the next two growing periods. According to Rytter (2001), the shoot growth of individual genotypes in the first year is affected mainly by the ability of willow to create a root system able to supply the plant with nutrients and water. This ability was in our experiment limited by the dry period after the planting.

Tab. 3: Average diameters of shoots (mm) of the studied willow varieties in individual growing periods.

Growing period	Varieties							
	Jorunn	Jorr	Björn	Klara	Lisa	Terra Nova	Loden	Dimitrios
	Average diameter of shoots (mm)							
2009	11.55	12.23	12.74	12.57	14.34	11.42	12.26	8.74
2010	12.85	14.32	16.81	16.30	17.80	16.75	15.40	16.84
2011	14.28	16.72	23.01	21.68	25.32	21.94	19.66	22.04

Similarly to the length of shoots, the variety Lisa reached the highest values also in the shoot diameters (Tab. 3). When compared the shoot diameters in the second and third growing year, it can be concluded that the growth trend of the diameter in 2010 had been similar to 2011. The order of the shoot diameters increase was the same in the second and third growing period in all varieties. In comparison with 2009, the largest increase in the shoot diameters was recorded in the variety Dimitrios in 2011. The analysis of individual categories of shoot diameters shows that the highest numbers of shoots were in the smallest diameter categories (around 40 %) but their share on the total biomass represents only a small percentage (less than 10 %). We found an opposite trend in the thickest shoots. Their numbers were low, but they share on the total

biomass weight was high. The increase of the shoot diameter and length in the studied varieties varied among the individual growing periods. A significant difference was observed mainly between the first and second growing season. While in the first year the biomass production was affected in particular by dry period after the planting, in the second year, on the contrary, by extremely high amount of precipitation. We found a strong correlation between the shoot length and diameter in the individual varieties during the three research years. The number of shoots had a statistically significant effect on their length and diameter only in 2009, when there was a decrease in the average shoot length and diameter with the rising number of shoots on individual plants. According to Hytönen et al. (1987) and Ballard et al. (2000), the weight of individuals increases by power series in dependence of the shoot length and diameter.

The average weight of dry biomass obtained by individual willow varieties is given in Tab. 4.

Tab. 4: Yields of dry biomass of individual willow varieties in the second and third growing period.

Growing period	Average weight of dry biomass	Varieties							
		Jorunn	Jorr	Björn	Klara	Lisa	Terra Nova	Loden	Dimitrios
2010	1 plant (kg)	1.57	1.67	2.08	2.04	1.55	1.63	1.59	0.94
	(t.ha^{-1})	13.92	14.86	18.48	18.17	13.79	14.52	14.11	8.34
2011	1 plant (kg)	2.74	3.91	5.43	4.79	4.38	5.07	4.08	4.28
	(t.ha^{-1})	16.50	17.37	24.13	21.27	19.46	22.52	18.14	19.01

Tab. 4 shows that the yield of dry biomass at the end of the third growing period is similar in varieties Lisa, Dimitrios and Loden and varies from 18.14 t.ha^{-1} to 19.46 t.ha^{-1}. The highest biomass yields were achieved by varieties Bjőrn and Terra Nova that yielded 24.13 t.ha^{-1} and 22.52 t.ha^{-1} respectively. The biomass yield achieved by varieties Bjőrn, Klara and Terra Nova in the third year (2011) represents an increase by 3.10-8.0 t.ha^{-1} compared with the second year (2010). Theoretically, if the percentage of well-rooted cuttings was 100 %, the yield of these varieties would be more than 10 t.ha^{-1}, which Buchholz and Volk (2011) consider to be very profitable. Lindegaard et al. (2001) consider 10-12 t.ha^{-1} year as the economic threshold for growing of energy willows. Experimental results from the northern England show that biomass yields increase with the planting density (Wilkinson et al. 2007).

The rust infestation of the studied willow varieties had different levels of intensity. The varieties Terra Nova and Dimitrios were not attacked by the rust at all. Varieties Bjőrn, Klara and Lisa were attacked slightly (values 1-2). The level of infestation of varieties Jorunn, Jorr and Loden was moderate (value 3). Diseases caused by rust (*Melampsora* spp.) can cause yield losses of up to 40 %. The use of fungicide is not very viable option in willow plantations due to economic and environmental impacts (Hanley et al. 2011). Thus, the rust attacks of willow stands can be eliminated by breeding of rust resistant genotypes and by growing a mixture of different varieties (Christersson et al. 1993, Tothová 2010, Labrecque and Teodorescu 2005, McCracken et al. 2001).

The set of the production parameters was evaluated by cluster analysis. The output of the cluster analysis is a classification of the 8 studied varieties into 4 groups based on the similarity of results achieved by the production parameters. The first group includes variety Jorunn, the second group variety Jorr, the third group varieties Bjőrn, Klara and Terra Nova and the fourth group varieties Lisa, Dimitrios and Loden.

The first group is characterized by above-average numbers of shoots, moderate rust infestation (value 3) and lower biomass production. The second group is characterized by average

production parameters. The third group includes varieties with high biomass production that makes them suitable for commercial use. The level of rust infestation in this group had lower values (0-2). The fourth group is characterized by fewer shoots, but high values of average shoot heights and diameters. The variety Dimitrios was not attack by the rust and variety Lisa was attacked only slightly (value 1). These characteristics make also the varieties Dimitrios and Lisa potentially suitable for commercial cultivation in soil and climatic conditions of Slovakia.

CONCLUSIONS

The three-year research aimed at evaluating of production parameters of 8 willow *(Salix* sp.) varieties in the soil-climatic conditions of south-western Slovakia took place in various moisture and temperature conditions during the individual growing periods. The first (2009) and third (2010) growing period was characterized by low precipitation volume in comparison with the long-term average. On the contrary, the second growing period (2010) was extremely rich in precipitations and exceeded the long-term average by 312.6 mm.

The different rainfall conditions during the growing periods affected also values of the volumetric soil moisture. The lowest values of the volumetric soil moisture were measured at the depth of 0.1 m. The soil layers deeper than 0.6 m had the moisture values above the point of reduced water availability during the whole growing season in 2010 and 2011. This was caused also by high groundwater level that varied from 0.42 m (in spring) to 2.03 m below the soil surface at the end of the growing period. High groundwater level allowed the capillary flow into the root zone of the studied varieties.

The percentage of well-rooted cuttings, 30 days after the planting, was 100 % in the varieties Jorunn, Jort, Bjőrn, Klara, Lisa and Loden, 95 % in the variety Dimitrios and 56 % in the variety Terra Nova.

The mortality of originally well-rooted cuttings was observed only in the variety Dimitrios (17 %).

Production parameters such as the number of shoots, shoot length and shoot diameter were varietal dependent. There were statistically significant differences confirmed among the varieties and the parameters varied in the individual years. The lowest number of shoots per plant was observed in the first growing year, when the number ranged from 1.44 to 2.40 shoots. After the cut back, in 2010, the average number of new shoots increased and ranged from 5.6 (Lisa) to 13.28 (Jorunn). At the end of the third year, the average number of shoots per plant decreased due to the mortality of the weakest shoots and ranged from 3.83 to 10.50.

The average length of shoots ranged from 136.42 cm to 225.58 cm at the end of the first year (2009). At the end of the third year (2011) the values ranged from 378.29 cm (Jorunn) to 560.62 cm (Lisa).

The evaluation of the individual categories of shoot diameters shows that the most numerous are shoots in the smallest diameter category (40 %), but their represent relatively small percentage of the total biomass (less than 10 %). On the contrary, the thickest shoots had the lowest numbers but their share on the total biomass weight is the biggest. Strong correlation was found between the height and diameter of shoots in individual varieties. The number of shoots significantly affected the length and diameter of the shoots only in 2009, when there was a decrease in the average shoot length and diameter with the growing number of shoots per plant.

The biomass yields of the most varieties achieved similar values at the end of the third growing period. The exceptions were varieties Jorr and Jorunn that provided significantly the

lowest biomass yield. Varieties Bjőrn, Klara and Terra Nova had the highest biomass yield.

The intensity of the rust (*Melampsora* sp.) infestation varied among the studied varieties. There was no occurrence of the rust on varieties Terra Nova and Dimitrios, varieties Bjőrn, Klara and Lisa were attacked by the rust only on a small scale and varieties Jorunn, Jorr and Loden had the highest degree of infestation. The rust caused various levels of leave necrosis on the individual varieties.

The studied varieties were divided into 4 groups by cluster analysis, taking into account particularly the production parameters. According to the production potential and vulnerability to the rust attack, the best varieties are those that are included in the third group. The most productive varieties of this group are Terra Nova, Bjőrn and Klara, which were not attacked by rust at all, or only slightly. The high biomass production makes these varieties suitable for commercial cultivation in soil-climatic conditions of south-western Slovakia. Varieties Dimitrios and Lisa, belonging to the fourth group, are also potentially suitable for commercial cultivation in our conditions because of their resistance to the rust infestation.

ACKNOWLEDGMENT

The work was supported by the Slovak Research and Development Agency (Grant No. APVV-0131-07).

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