**THE ASSESSMENT OF PHYSIOLOGY PARAMETERS OF WILLOW PLANTS AS A CRITERION FOR SELECTION OF PROSPECTIVE CLONES**

**ABSTRACT:** Bioenergy production based on short rotation coppice willow plantations (SRC) is an effective direction both for economic and environment profit. The yield of willow wood can amount to 10-15 tons per hectare of dry biomass per year and the cost of thus obtained energy is lower in comparison with other energy crops. In order to achieve high yield and profitability, the use of special willow clones is necessary. Species most often used in selection for biomass production are shrub type willows: *Salix viminalis, Salix dasy-clados* and *Salix schwerini*, while the clones tested in this paper were also of tree species *Salix alba*. The productivity and some physiology characteristics of Serbian selection clones of *Salix alba* (Bačka, Volmianka and Drina) and Swedish selection clone Jorr (*Salix viminalis*) were investigated in greenhouses and in field conditions. As the result of testing three clones of *Salix alba* – Bačka, Volmianka and Drina, having special preferences and adaptability to different environmental conditions, these were included in State register of Republic of Belarus in 2013. In our experiment it was also satisfactory that specific properties of willows (intensity of transpiration and photosynthesis, water use efficiency and others), were conserved both in greenhouses and in field conditions. This factor gives opportunity to select prospective clones of willows at an early stage of ontogenesis for further testing.

**KEYWORDS:** bioenergy, willow, selection, varieties, physiology parameters

**INTRODUCTION**

Bioenergy production based on short rotation coppice plantations (SRC) is widely introduced in some European countries, USA and Canada [Rodzkin et al., 2012]. Willows have a special place among energy crops due to their high potential in productivity and broad tolerance to environmental factors.

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The average yield of willow wood is 10–15 tons per hectare of dry biomass per year [McElroy 1986], which results in a lower cost of energy obtained from willow wood compared to other crops [Keolian 2005].

The assessments of cost of energy crops production on the basis of total costs and risk assessment were done in Sweden [Rosenqvist and Nilsson 2007], where the cost of energy from willow biomass was 4–5 Euro/GJ, from poplar 5–6 Euro/GJ, from hemp 8–9 Euro/GJ, from reed 6.5–6 Euro/GJ, from silver-grass 7.9–8.5 Euro/GJ and from triticale 6.7–7.1 Euro/GJ. In Poland, the assessment of cost of energy crops has shown that the highest profit was from willow wood [Krasuska 2011]. According to Polish agricultural market, energy crops can be as competitive as cereal crops.

In order to achieve high yield and profitability, the use of special willow clones is necessary. In the former USSR the special breeding program of willow clones selection started in 1960s and 1970s [Skvortsov 1968]. The willow biomass was used for baskets, furniture, as building material and for other purposes [Levitskiy 1965]. As prospective candidates, hybrid varieties of willow Jarvim, Omvim, (Salix schwerinii), Chillin-3, (Salix viminalis x Salix chilkoans), Jikin-7, (Salix viminalis x Salix purpurea) were selected, and during field testing the highest biomass production was obtained by varieties of Salix schwerinii.

Selection of willow for energy purposes started after 1970’s. The following species of willow were most actively used for selection: Salix viminalis, Salix dasyclados, and Salix schwerinii. These species were characterized as high productive with a large number of sprouts and fast sprout re-growing. They belong to bush types of willow [Caslin et al., 2012; Tuck et al., 2006]. But along with these characteristics for selection, it is necessary to assess other features. For example, Salix dasyclados is characterized by lower requirements regarding oxygen and nutrients supply when comparing to Salix viminalis. Salix purpurea and Salix acutifolia successfully grow under condition of water shortage, as opposed to Salix nigra which can resist extra flooding, and so on [Parfenov 1986]. Taking in consideration that willow wood can grow on different types of soil, influence by a number of environmental factors, it is necessary to broad of base of willow species and hybrids for selection [Tahvanainen and Rytkonen 1999; McKay 2011; Rodzkin et al., 2013]. In this article, the results of our study of selection of willow Salix alba are presented.

MATERIAL AND METHODS

The clones of Salix alba were selected at the Institute of Lowland Forestry and Environment in Novi Sad, and clone Jorr (Salix viminalis) is Swedish selection. The experiments were carried out in greenhouses in Mitscherlich pots and under field conditions in the International park “Volma” (Republic of Belarus). Soil properties are presented in Table 1. The field experiment was
designed as 25 m² plots in 4 repetitions with 1.40x0.70 m spacing. The following physiological characteristics of willow plants were measured: water use efficiency (WUE), transpiration (E), photosynthesis (A), and stomatal conductance (GS). The results were measured by means of LC pro+ Portable Photosynthesis System (ADC BioScientific Ltd. company).

Transpiration, water deficit, water retained abilities, morphology parameters of willow plants were measured under field conditions by weighing the leaves on the torsion balance [Grodzinskij 1973]. The soil of experimental plot was sandy loam (Table 1). The density of willow planting was 16,000 per hectare.

Table 1. Agrochemical characteristics of soil

<table>
<thead>
<tr>
<th>Experimental plot</th>
<th>Soil characteristics</th>
<th>Structure</th>
<th>Humus %</th>
<th>P₂O₅, mg/kg</th>
<th>K₂O, mg/kg</th>
<th>pHKCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volma</td>
<td>Sandy clay</td>
<td>2.2</td>
<td>76.2</td>
<td>96.9</td>
<td>6.05</td>
<td></td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Due to its tree form, *Salix alba* was not actively used in the selection for SRC plantations. The reason could be in the risk of insufficient number of sprouts after the first year cutting. Our results showed that the average number of new sprouts after cutting of *Salix alba* varied from 3.5 to 3.9, *Salix viminalis* – 3.1–4.1, and *Salix dasyclados* – 3.9–4.2 (Table 2). These characteristics indicated that clones of *Salix alba* were competitive to other species of willow. The Serbian candidate clones of *Salix alba* were estimated both in greenhouses and under field conditions. The high potential of willow clones selected within *Salix alba* species was also recorded for the conditions of Russia [Parfenov 1986] where yield of hybrids *Salix fragilis* x *Salix alba* was higher than yield of *Salix viminalis* and ranged from 7 to 10 tons of dry biomass per hectare.

One of the problems in selection of perennial crops is the duration of the process, where testing of prospective clones lasts for several years until final selection of the best cultivar. In our experiments was investigated the ability of willow clones to keep their parameters both in greenhouses and under field conditions. The key factor for willow production is the water regime of plants. Willows belong to the group of phreatophytes, having an increased demand for water during vegetation. Therefore, the focus on water regime in willow plants is obligatory in the investigation.
Figure 1. Seedlings of *Salix alba* after cutting at experimental plot “Volma” in 2013.

The results of comparison of Serbian selection of *Salix alba* candidate clones (Drina, Volmianka and Bačka) with widely used Swedish clone Jorr, regarding the intensity of transpiration in greenhouse, is presented in Figure 2.

Figure 2. Intensity of transpiration of willow clones in greenhouse.

The highest transpiration was observed for clone Bačka, while the lowest transpiration rate was with clone Volmianka. The transpiration of clone Jorr (*Salix viminalis*) was moderate, when compared with other clones, as presented in Figure 2.
As already mentioned, energy willow plantations can be grown under different environmental conditions, including areas with low water supply, for example post-mining peatlands, degraded peaty soils, etc. Therefore, a very important factor for willow clones is the water use efficiency (WUE). The results of water use efficiency (WUE) in greenhouse experiment are presented in Figure 3.

The best results of WUE were recorded for clone Volmianka (*Salix alba*). As it was identified earlier, this clone had the lowest level of transpiration. Clones of willow tested in greenhouses during early stage of ontogenesis were also tested under field conditions. Results of measurements of intensity of transpiration are presented in Figure 4.
Diurnal dynamics of transpiration showed that the lowest level of transpiration, the same as in greenhouse experiment, was observed for clone Volmianka, while the highest transpiration was recorded for clone Bačka. The results of diurnal dynamics of transpiration showed one peak (typically at midday) for all clones. Our results are in accordance with the results of transpiration dynamic presented in other publications [Kostjuchenko 2009].

Water retention ability represents a physiology indicator related to water use efficiency. The results of this parameter are presented in Figure 5.

![Figure 5](attachment:figure5.png)

*Figure 5. The dynamic of water loss by leaves of willows under field conditions*

As presented in Figure 5, the minimal level of water loss was observed for clone Volmianka. It indicates that this clone can economize water and spend it efficiently under field conditions, which was also identified in greenhouse experiment. Plants of willow clone Bačka showed maximal discharging of water both in field and in greenhouse.

Results of water deficit dynamics (Figure 5) correlate with water deficit parameters in willows. Minimal water deficit on average was recorded for clone Volmianka, while maximal was recorded for clone Bačka. These results indicate that clone Volmianka has the best water retention capability and low water deficit parameters, resulting in better drought resistance and tolerance to unfavorable environmental conditions.

Results of morphology characteristics of clones showed higher productivity of *Salix alba* clones compared to clone Jorr (*Salix viminalis*), Table 2.
All results of testing of three Serbian varieties of willow selected from *Salix alba*, characterized by intensive growth and sprout re-growing, were included in State register of Republic of Belarus in 2013. Every variety has special preferences and can be adapted to different environmental conditions. Bačka showed higher productivity than other clones during the testing. Volmianka is characterized by special water regime and this clone can be successfully adapted to the areas with low water supply. Drina, as it was identified in our experiments, accumulates heavy metals to biomass less than other clones. This clone can be used for reclamation of areas polluted by heavy metals (e.g. along the roads, near the livestock breeding complexes, etc.) [Rodzkin *et al.*, 2010; Rodzkin and Pronko 2010].

Table 2. *Morphology characteristics of willow clones under field conditions*

<table>
<thead>
<tr>
<th>Clone</th>
<th>Year</th>
<th>Parameter</th>
<th>Height of plants, cm</th>
<th>Stem diameter mm</th>
<th>Number of sprouts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jorr</td>
<td>2012</td>
<td>206</td>
<td>12.5</td>
<td>-</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>401</td>
<td>25.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bačka</td>
<td>2012</td>
<td>226</td>
<td>14.0</td>
<td>-</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>428</td>
<td>28.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Volmianka</td>
<td>2012</td>
<td>225</td>
<td>13.6</td>
<td>-</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>417</td>
<td>26.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Drina</td>
<td>2012</td>
<td>197</td>
<td>13.5</td>
<td>-</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>387</td>
<td>27.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LSD 0.05</td>
<td>2012</td>
<td>9.2</td>
<td>0.53</td>
<td>-</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>14.6</td>
<td>1.12</td>
<td>-</td>
<td>0.28</td>
</tr>
</tbody>
</table>
CONCLUSIONS

According to prognoses of World Energy Council, energy consumption will increase twofold until 2050. Over 40% of energy demands will be covered by renewable energy resources, including bioenergy with 32%. It is obvious that development of bioenergy production will have the priority, which includes crop remains, energy cultures, animal waste and energy biomass plantations like poplars, willows, black locust and eucalyptus.

Results of our testing of *Salix alba* L. clones (Bačka, Drina and Volmianka) and *Salix viminalis* L. clones (Jarr) showed good adaptability in Belarus. Water regime of investigated clones shows differences in transpiration and water use efficiency, with clone Bačka surpassing other investigated clones, while clone Volmianka showed the highest potential for drought conditions.

REFERENCES


Levitskiy II (1965): *Iva i ee ispol'zovanie*, «Lesnaya promyshlennost», Москва, p.100


ИСПИТИВАЊЕ ФИЗИОЛОШКИХ ПАРАМЕТРА ВРБА КАО КРИТЕРИЈУМ ЗА СЕЛЕКЦИЈУ ПЕРСПЕКТИВНИХ КЛОНОВА

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РЕЗИМЕ: Производња биоенергије у засадима са кратким турнусима (SRC) врба ефикасан је првац истраживања, како са економског, тако и са аспекта заштите животне средине. Принос дрвне масе код врбе може достићи 10–15 тona по хектару суве биомасе годишње и трошковима добијене енергије нижим у поређењу са другим енергетским културама. У циљу постигања високог приноса и профитабилности треба користити посебне клонове врбе. Најчешће врсте коришћене у избору за производњу биомасе су украсни типови врбе као што су: Salix viminalis, Salix dasyclados и Salix schverini док су у овом раду испитивани клонови врбе: Salix alba. Продуктивност и неке физиолошке карактеристике српске селекције клонова Salix alba (Бачка, Волминака и Дрина) и шведски клон Jorr (Salix viminalis) су испитивани у стакленицима и у теренским условима.
Тестирања три клона *Salix alba* – (Бачка, Волмианка и Дрина) који имају посебне склоности и прилагођене су на различите услове животне средине тестирани су такође у условима Белорусије и ти клонови су укључени у државни регистар Републике Белорусије у 2013. У нашим експериментима, са наведеним клоновима, испитивана су следећа својства врбе (интензитет транспирације и фотосинтезе, ефикасност коришћења воде и других показатеља), како у стакленицима, тако и у спољним условима. Овакав приступ даје могућност да се изаберу перспективни клонови врбе у раној фази онтогенезе те се могу користити за даља тестирања.

КЉУЧНЕ РЕЧИ: биоенергија, врба, селекција, сорте, физиолошки параметри