

Clonal selection of *Salix* L. taxa perspective for biofuel production, evaluation of their dendrometric characteristics and accumulation of biomass in short rotation plantations

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Thirty seven clones were selected from the local Lithuanian flora, as well as from introduced and adapted willow taxa and studied in 1996–2004. Comparative analysis of dendrometric characteristics and dry biomass of stems of the taxa in the first and second rotations in short turnover plantations was carried out. Bush height, stem number and diameter, average dry weight per bush and its output are presented. The dendrometric characteristics and the dry biomass of willow stems were higher after the second rotation. *Salix dasyclados* 9977 and 04122, *S. viminalis* 'Americana' 06119 and 9972, and *S. viminalis* 9975 clones and natural hybrids *S. dasyclados* × *S. daphnoides* 00104 and *S. caprea* × *S. viminalis* 06117 were the most perspective for growing in short rotations and should be studied in future.

Key words: *Salix*, clonal selection, morphology, biomass, short rotation, intensive culture

INTRODUCTION

The search of the alternative energetic sources becomes quite an important question as prices of excavated energetic stock are on the rise. Wood is recognized to be the main self-renewing energetic source. It is an alternative and ecologically safe energetic material. One ton of wood dry material is equal to 450 litres of raw oil [1]. Species and clones of the genus *Salix* L. (e. g., *Salix viminalis*, *S. dasyclados*, etc.) are used for rapidly growing wood in shortly rotated sprouts. They produce a big amount of biomass in a short period of time [2, 3]. Species and clones of willows that are grown in energetic plantations have to fit some requirements [4]. The most important factors are the active risogenesis of planted slips, large biomass production, intensive growth after cutting during the first year, resistance to diseases, pests and frosts, adequacy to climatic conditions, etc. Nowadays, the clonal selection of *Salix* taxa perspective for biofuel is carried out in many countries with the aim to meet the requirements mentioned above.

The aim of this work was to evaluate biomass productivity of wood of some *Salix* L. species clones using clonal selection and to explain its dependence on bush age and dendrometric characteristics.

MATERIALS AND METHODS

The clonal selection of *Salix* L. taxa was carried out in 1996–2004 according to the criteria of clonal selection [5]. Clones of local Lithuanian flora (*Salix alba* ssp. *alba*, ssp. *coerulea*, *S.*

dasyclados, *S. daphnoides*, *S. caprea* × *S. viminalis*, *S. fragilis* × *S. alba*, *S. viminalis*, and *S. viminalis* × *S. purpurea*) were selected during scientific expeditions. *S. mollissima*, *S. schwerinii* × *S. dasyclados*, *S. schwerinii* × *S. udensis*, and *S. viminalis* 'Americana' clones that were adapted for growing in short rotations in Lithuanian field collections were selected as well. *S. viminalis* 'Tora', *S. schwerinii* 'Tordis' and *S. dasyclados* 'Gudrun' races, selected in Sweden, were obtained from the joint stock company "Jūsų sodui".

The selected clones were planted in the willow collection of the joint stock company "Vilda" (Alytus district). The collection was established in turfy sandy loam soil. The content of microelements and macroelements in the soil (mg/kg) was as follows: N-NO₃ – 15.9, K₂O – 86, P₂O₅ – 85, Ca – 1377, Mg – 250, Fe – 440, Zn – 1.5, Mn – 40, B – 0.6, and Cu – 1.1. Acidity (pH) of the soil was 6.2. Bushes were planted in rows in the field collection. The space between rows was 70 cm and between plants 50 cm. 28500 bushes were planted per one hectare. The length of the planted splits was 25 cm. The field was fertilized with potassium and phosphorus in autumn, while nitrogen was used in spring (the active substances were N₅₀, K₈₀ and P₆₀ (kg/ha)).

The dendrometric characteristics and biomass productivity of wood were evaluated at the end of vegetation or according to the cycles of usage after bush cutting each year.

Bush dendrometric characteristics and biomass productivity were studied employing standard techniques [6]. The obtained results were analyzed using statistical methods [7].

RESULTS AND DISCUSSION

Dendrometric characteristics and productivity evaluation of annual and biennial bushes. It is a usual practice to cut short rotation willows after three or four years of growth. Energetic plantations of willows used for an intensive culture (turnover cycle 1–2 years) are under discussion [8]. They are called of 'ultrashort-rotation' or 'wood grass' systems. The comparative dendrometric and biomass productivity of stems of 16 *Salix* L. taxa and their clones was measured in order to evaluate the cycle of one-year turnover (the age of stumps was four years) (Table 1). The data showed that different taxa of willows and their clones had different dendrometric and productivity characteristics. The height of annual bushes varied from 196.7 to 393.3 cm, the number of stems from 3.1 to 14.2 per stump, the diameter of stems from 0.6 to 1.7 cm, the average dry weight of stems from 180.0 to 445.8 g per bush. There is an opinion [2] that energetic plantations of willows are economically profitable when the average increase of biomass reaches 8 t/ha of dry material per

vegetation season. *S. dasyclados* 9877 clone reached the highest amount of dry stems (12.70 t/ha), while *S. purpurea* × *viminalis* 9702 and 9709 clones produced 10.49 and 10.30 t/ha, respectively, *S. viminalis* 9872 – 8.19 t/ha, and *S. viminalis* 'Americana' 9601 – 8.64 t/ha. The output of dry biomass of the taxa and clones studied positively correlated with their main dendrometric characteristics: bush height, stem number per bush, their diameter and branching.

Summarized results of dendrometric characteristics of the 12 willow taxa and their clones showed that all indices of biennial bushes were much higher (Table 2). The biological and genetic characteristics of clones and races influenced the results. The *S. schwerinii* 'Tordis' clone grew up most intensively and its stems reached the highest height in two years (the height of bushes was 545.4 cm and the diameter of stems 2.6 cm), *S. viminalis* 'Tora' (529.7 and 2.9 cm, respectively), *S. viminalis* 'Americana' 06119 (445.6 and 1.6 cm), *S. dasyclados* 9977 (424.3 and 2.5 cm), *S. dasyclados* 04122 (352.7 and 2.4 cm), *S. caprea* × *S. viminalis* (340.4 and 2.2 cm). They accumulated the largest amount of

Table 1. Dendrometric and productivity characteristics of annual bushes of *Salix* L. taxa and their clones during the fourth year of growth (one-year rotation)

| Taxon and its clone | Height of bush, cm | Number of sprouts per bush | Diameter of sprouts at the bottom, cm | Dry mass of stems per bush, g | Dry mass of stems t/ha |
|--|--------------------|----------------------------|---------------------------------------|-------------------------------|------------------------|
| <i>Salix viminalis</i> 9822 | 296.7 ± 5.2 | 7.1 ± 0.6 | 0.9 ± 0.05 | 233.1 ± 23.6 | 6.64 ± 0.67 |
| <i>S. viminalis</i> 9817 | 330.1 ± 6.4 | 6.3 ± 0.3 | 0.8 ± 0.04 | 195.8 ± 12.8 | 5.58 ± 0.36 |
| <i>S. viminalis</i> 00108 | 228.0 ± 6.4 | 6.6 ± 0.5 | 0.6 ± 0.02 | 180.0 ± 25.7 | 5.13 ± 0.73 |
| <i>S. viminalis</i> 9872 | 300.1 ± 9.5 | 10.3 ± 0.4 | 0.9 ± 0.03 | 287.5 ± 14.2 | 8.19 ± 0.40 |
| <i>S. viminalis</i> 'Americana' 9811 | 320.6 ± 4.2 | 9.0 ± 0.6 | 0.9 ± 0.04 | 293.3 ± 20.3 | 8.35 ± 0.57 |
| <i>S. viminalis</i> 'Americana' 9601 | 248.7 ± 3.6 | 10.1 ± 0.8 | 0.9 ± 0.01 | 303.2 ± 45.3 | 8.64 ± 1.29 |
| <i>S. dasyclados</i> 9877 | 393.3 ± 7.8 | 4.8 ± 0.9 | 1.7 ± 0.02 | 445.8 ± 31.2 | 12.70 ± 0.88 |
| <i>S. dasyclados</i> 0099 | 231.4 ± 6.4 | 6.2 ± 0.4 | 1.5 ± 0.07 | 271.8 ± 30.4 | 7.74 ± 0.86 |
| <i>S. mollissima</i> 9868 | 196.7 ± 3.8 | 5.8 ± 0.5 | 1.0 ± 0.04 | 196.6 ± 20.3 | 5.60 ± 0.57 |
| <i>S. schwerinii</i> × <i>S. udensis</i> 9873 | 313.0 ± 8.3 | 3.1 ± 0.2 | 1.2 ± 0.06 | 249.0 ± 8.2 | 7.09 ± 0.23 |
| <i>S. schwerinii</i> × <i>S. dasyclados</i> 9873 | 323.3 ± 9.7 | 3.7 ± 0.3 | 1.5 ± 0.04 | 294.5 ± 16.3 | 8.39 ± 0.46 |
| <i>S. alba</i> ssp. <i>alba</i> 00113 | 228.7 ± 4.6 | 14.2 ± 0.8 | 1.0 ± 0.01 | 200.3 ± 19.1 | 5.70 ± 0.54 |
| <i>S. alba</i> ssp. <i>coerulea</i> 9736 | 213.0 ± 8.0 | 8.7 ± 3.5 | 0.7 ± 0.04 | 195.6 ± 15.1 | 5.57 ± 0.43 |
| <i>S. purpurea</i> × <i>S. viminalis</i> 9709 | 313.7 ± 6.1 | 12.3 ± 0.4 | 0.9 ± 0.04 | 362.2 ± 7.7 | 10.30 ± 0.21 |
| <i>S. purpurea</i> × <i>S. viminalis</i> 9702 | 296.7 ± 10.5 | 10.9 ± 0.1 | 0.8 ± 0.03 | 368.2 ± 4.3 | 10.49 ± 0.12 |
| <i>S. daphnoides</i> f. <i>angustifolia</i> 9904 | 236.3 ± 11.8 | 5.0 ± 0.2 | 1.0 ± 0.06 | 186.0 ± 15.0 | 5.30 ± 0.42 |

Table 2. Dendrometric characteristics and evaluation of dry stem weight of biennial bushes of *Salix* L. taxa and their clones in short rotation plantations (stump age three years)

| Taxon and its clone | Height of bush, cm | Number of sprouts per bush | Diameter of sprouts at the bottom, cm | Dry mass of stems per bush, kg | Dry mass of stems t/ha |
|--|--------------------|----------------------------|---------------------------------------|--------------------------------|------------------------|
| <i>Salix viminalis</i> 06116 | 330.0 ± 7.1 | 11.4 ± 1.3 | 1.6 ± 0.0 | 0.65 ± 0.05 | 19.9 ± 1.4 |
| <i>S. caprea</i> × <i>S. viminalis</i> 06117 | 340.4 ± 7.8 | 4.2 ± 0.2 | 2.2 ± 0.1 | 0.95 ± 0.10 | 28.5 ± 2.9 |
| <i>S. viminalis</i> 'Americana' 06118 | 434.7 ± 11.4 | 9.5 ± 0.3 | 1.3 ± 0.0 | 0.80 ± 0.05 | 22.8 ± 1.4 |
| <i>S. viminalis</i> 'Americana' 06119 | 445.6 ± 11.6 | 8.7 ± 0.5 | 1.6 ± 0.1 | 0.90 ± 0.05 | 25.6 ± 1.4 |
| <i>S. viminalis</i> 'Tora' | 529.7 ± 25.7 | 2.9 ± 0.2 | 2.4 ± 0.2 | 1.05 ± 0.10 | 29.0 ± 2.9 |
| <i>S. schwerinii</i> 'Tordis' | 545.4 ± 7.7 | 2.6 ± 0.1 | 2.6 ± 0.1 | 0.90 ± 0.05 | 25.9 ± 1.4 |
| <i>S. dasyclados</i> 9977 | 424.3 ± 6.2 | 7.0 ± 0.2 | 2.5 ± 0.0 | 0.86 ± 0.05 | 24.5 ± 1.4 |
| <i>S. dasyclados</i> 04122 | 352.7 ± 4.3 | 7.9 ± 0.5 | 2.4 ± 0.0 | 0.90 ± 0.05 | 25.7 ± 1.4 |
| <i>S. dasyclados</i> 'Gudrun' | 367.7 ± 2.7 | 6.0 ± 0.5 | 2.3 ± 0.0 | 0.59 ± 0.05 | 16.9 ± 1.4 |
| <i>S. dasyclados</i> 04123 | 347.5 ± 5.2 | 7.2 ± 0.3 | 1.9 ± 0.0 | 0.65 ± 0.05 | 19.9 ± 1.4 |
| <i>S. dasyclados</i> 04124 | 336.5 ± 5.2 | 5.0 ± 0.6 | 2.0 ± 0.1 | 0.59 ± 0.05 | 16.8 ± 1.4 |
| <i>S. fragilis</i> × <i>S. alba</i> 04138 | 384.8 ± 6.9 | 3.9 ± 0.1 | 2.2 ± 0.1 | 0.89 ± 0.04 | 25.3 ± 1.1 |

Table 3. Dendrometric characteristics and evaluation of dry stem weight of *Salix* L. taxa and their clones in short rotation plantations (the age of bushes of the second rotation was three years and of stumps six years)

| Taxon and its clone | Height of bush, cm | Number of sprouts per bush | Diameter of sprout, cm | | Dry mass of stems per bush, kg |
|---|--------------------|----------------------------|------------------------|-----------------|--------------------------------|
| | | | at the bottom | at height 1.3 m | |
| <i>Salix alba</i> ssp. <i>alba</i> 0098 | 414.0 ± 6.4 | 9.1 ± 0.9 | 2.5 ± 0.3 | 1.6 ± 0.1 | 3.4 ± 0.1 |
| <i>S. dasyclados</i> 0099 | 416.2 ± 7.3 | 7.5 ± 0.3 | 2.7 ± 0.2 | 1.9 ± 0.1 | 3.7 ± 0.1 |
| <i>S. dasyclados</i> × <i>S. daphnoides</i> 00104 | 405.5 ± 5.7 | 5.4 ± 0.2 | 3.4 ± 0.1 | 2.9 ± 0.1 | 4.5 ± 0.1 |
| <i>S. viminalis</i> 00109 | 431.0 ± 5.1 | 8.7 ± 0.3 | 2.0 ± 0.2 | 1.6 ± 0.1 | 3.1 ± 0.0 |
| <i>S. viminalis</i> 00108 | 395.5 ± 3.2 | 6.5 ± 0.3 | 2.7 ± 0.1 | 1.8 ± 0.1 | 1.8 ± 0.0 |
| <i>S. viminalis</i> × <i>S. purpurea</i> 0095 | 475.0 ± 3.3 | 7.6 ± 0.2 | 2.0 ± 0.1 | 1.4 ± 0.1 | 1.7 ± 0.0 |

Table 4. Dendrometric characteristics and evaluation of dry stem weight of *Salix* L. taxa and their clones in short rotation plantations (the age of bushes of the second rotation was four years and of stumps seven years)

| Taxon and its clone | Height of bush, cm | Number of sprouts per bush | Diameter of sprout, cm | | Dry mass of stems per bush, kg |
|---|--------------------|----------------------------|------------------------|-----------------|--------------------------------|
| | | | at the bottom | at height 1.3 m | |
| <i>Salix schwerinii</i> × <i>S. dasyclados</i> 9971 | 541.9 ± 12.7 | 3.5 ± 0.1 | 3.9 ± 1.1 | 2.8 ± 1.0 | 2.9 ± 0.1 |
| <i>S. viminalis</i> 'Americana' 9972 | 540.9 ± 6.7 | 10.9 ± 0.7 | 2.6 ± 0.6 | 1.6 ± 0.2 | 4.9 ± 0.4 |
| <i>S. viminalis</i> 'Americana' 9976 | 506.6 ± 3.3 | 6.9 ± 0.4 | 2.4 ± 1.1 | 1.5 ± 0.7 | 2.2 ± 0.1 |
| <i>S. viminalis</i> 9975 | 566.6 ± 2.7 | 5.5 ± 0.1 | 3.2 ± 1.4 | 2.2 ± 0.8 | 3.7 ± 0.2 |
| <i>S. viminalis</i> 9974 | 459.1 ± 5.6 | 5.0 ± 0.3 | 3.3 ± 1.1 | 2.1 ± 0.7 | 2.6 ± 0.2 |
| <i>S. purpurea</i> × <i>S. viminalis</i> 9707 | 460.1 ± 2.6 | 13.0 ± 0.7 | 2.1 ± 0.1 | 1.5 ± 0.1 | 3.2 ± 0.3 |
| <i>S. dasyclados</i> 9977 | 582.0 ± 6.0 | 5.4 ± 0.3 | 3.6 ± 1.4 | 2.4 ± 1.0 | 3.3 ± 0.3 |

stem dry weight as well. *S. viminalis* 'Tora' surpassed the other clones and accumulated 29.0 t/ha, *S. caprea* × *S. viminalis* 06117 – 28.5 t/ha, *S. schwerinii* 'Tordis' – 25.9 t/ha, *S. dasyclados* 04122 – 25.7 t/ha, *S. fragilis* × *S. alba* 04138 – 25.3 t/ha, and *S. dasyclados* 9977 – 24.5 t/ha. The local Lithuanian willow species and their clones *S. dasyclados* 04122 and 9977, hybrids *S. caprea* × *S. viminalis* 06117 and *S. fragilis* × *S. alba* 04138 are promising for short turnover energetic plantations according to two-year dry weight accumulation and need future research.

Dendrometric dry stem weight characteristics of *Salix* L. taxa and their clones at the end of the second rotation of the third and the fourth cycles. Studies of dendrometric and stem weight characteristics of six willow taxa and their clones (second rotation, bush age three years) showed that they were much higher and more productive in comparison with the first rotation bushes (Table 3). It is quite obvious when comparing the average biomass of stems per bush and other characteristics. They are characterized by an optimal number of stems per bush, a much larger diameter of stems and a better branching. The hybrid of the local flora *S. dasyclados* × *S. daphnoides* 00104 seemed to be the most perspective for growing in short rotation plantations among the six willow taxa and their clones studied.

The results of the studies of seven *Salix* L. taxa and their clones (the second rotation, bush age four years) are presented in Table 4. The data showed that their most important dendrometric characteristics and accumulated biomass were higher. *S. viminalis* 'Americana' 9972, *S. viminalis* 9975, *S. dasyclados* 9977 and *S. purpurea* × *S. viminalis* 9707 were the most productive willows among the taxa studied.

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**BIOKURO GAMYBAI PERSPEKTYVIŲ SALIX L.
TAKSONŲ KLONINĖ ATRANKA, JŲ DENDROMETRINIŲ
SAVYBIŲ IR MASĖS SUKAUPIMO ĮVERTINIMAS
TRUMPOS APYVARTOS ŽELDINIUOSE**

S a n t r a u k a

1996–2004 metais iš Lietuvos natūralios floros ir Lietuvoje auginamų adaptuotų introdukuotų gluosnių taksonų atrinkti 37 klonai. Atlikti pirmos ir antros rotacijos trumpos apyvartos želdinių šių taksonų paly-

ginamieji dendrometriniai ir stiebų sausos biomasės susikaupimo tyrimai. Pateikta krūmų aukščio, stiebų skaičiaus, stiebų skersmens, krūmo stiebų vidutinė sausa masė ir jos išeiga. Nustatyta, kad antros rotacijos tirtų gluosnių taksonų ir jų klonų dendrometriniai ir stiebų sausos masės rodikliai yra didesni. Kaip perspektyvūs tolimesniems tyrimams ir auginimui trumpos apyvartos želdiniuose rekomenduotini šie kloninės atrankos būdu gauti gluosnių taksonų klonai: *Salix dasyclados* 9977 ir 04122, *S. viminalis* 'Americana' 06119 ir 9972, *S. viminalis* 9975 ir natūralūs hibridai *S. dasyclados* × *S. daphnoides* 00104, *S. caprea* × *S. viminalis* 06117.