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REGENERATION AND GROWTH OF WILLOW CLONES IN A BIOMASS PLANTATION

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Abstract

The study investigates the shoot regeneration ability of ten willow clones in an experimental plantation planted in the same initial density scheme (2.0 × 0.30 m). They were planted in lots with identical soil characteristics on the second terrace of the Danube River. The soil is Haplic Kastanozem with alkalinity (pH) between 7 and 8 and underground water below 8 m. The climatic conditions are typical for the continental climate of Northern Bulgaria. Development of new shoots was recorded in three consecutive years – from the seventh to the ninth year of their growth. The degree of preservation of the coppiced stumps, the number of shoots and their biometric data (height, basal diameter, fresh and dry weight, as well as their health status (live or withered), were recorded and compared. The results show that the shoot regeneration ability and the productivity of the various clones depend on the climatic conditions and the age of the plants. This shows that certain clones are more suitable for biomass production depending on the type of wood needed and the specific soil and climatic conditions of the designated planting area.

Key words: coppice, lignocellulosic crops, *Salix*, sprouts.

Introduction

The environmental and economic importance of wood biomass for the national energy balance requires an efficient and rational production of wood mostly in biomass plantations of suitable tree species planted on appropriate soils and cultivated using modern sylvicultural methods and techniques.

The suitability for production of biomass of the tree species depends on their biological characteristics – growth rate, propagation, yield, natural resilience, etc. A review of the literature revealed that woody crops for energy production include several forest tree species notably sharing the following characteristics: fast growth and high biomass yield, potential to be managed as a coppice and high management intensity (Guidi et al. 2013).

The species of genus *Salix* L. have a relatively fast growth rate, good shoot-regeneration ability and a high productivity. Combined with their outstanding ecological flexibility, genus diversity and resilience to adverse environmental conditions, these characteristics make them preferred tree species for biomass plantations (Zahariev 1977; Zaharinov and Naydenov 2012; Kalmukov 1995, 2013; Tsanov 1965, 1970, 1974).

The study aims to determine the regeneration and growth dynamics and the age-related productivity of ten willow clones in a biomass plantation.

Object and Methods

The observations were conducted in an experimental plantation of willow clones planted in 2005 in the nursery of the Experimental Station for Fast-growing Forest Species near the village of Vardim – 43°36'28.0" N, 25°29'30.5" E. The terrain is flat, on the second terrace of the Danube River. The soil is Haplic Kastanozem with alkalinity (pH) between 7 and 8 and underground water below 8 m. The surface soil layer is more than 50 cm deep, with low contents of nutrient nitrogen and phosphorus and sufficient content of potassium. The mechanical composition is heavy sandy-clayey, with good water-retaining capacity. The active moisture content in the one-meter layer is 217 mm, and in the two-meter layer is 452 mm. The average annual precipitation for the last 25 years is 510.9 mm. The average precipitation during the period (April – August) is 236.6 mm, which is 46.3 % of the average annual precipitation.

The cuttings were planted in spring, after a complete cultivation of the soil. The propagules were planted as standard cuttings from one-year shoots at a planting density of 2.0 × 0.30 m (16,667 cuttings per hectare). At the end of the first year the surviving saplings were counted and the sample was replenished in the following spring. Each year, prior to growing, they were coppiced and the cut shoots were removed from the plantation. The ridges were hoed manually and the furrows were disk-harrowed during the growing period. Of a total 130 willow clones, 10 were selected – 7 deciduous tree and 3 shrub (wicker) clones. Observations of the degree of rooting and growth during the first growing period and at the age of 6, 8 and 9 were made to collect empirical data. The degree of preservation of the stumps of the different clones, as well as the status and growth of shoots per stump, were monitored during the entire period. The length of the shoots was measured with an accuracy of 1.0 cm and their basal diameter – with an accuracy of 0.1 cm. The fresh and dry weight of the biomass produced annually by each clone was determined. The effect of the climatic conditions was determined through daily meteorological observations.

Results and Discussion

During the nine years of the study the amount of precipitation both on annual basis and during the growing period varied. The highest annual precipitation was recorded in 2005 (the year when the cuttings were planted) – 940.0 mm and the lowest annual precipitation was recorded in the seventh year (2011) – 432.7 mm. The precipitation during the vegetation period (April – August) was highest in the ninth year (2013) – 400.6 mm and lowest in the fourth year (2008) – 165.2 mm. The precipitation during the vegetation period in 2012 (8th year) was 61.75 % of that in 2010 – 316.2 mm (6th year) and 48.72 % of that in 2013 (9th year) – see Table 1.

The intensity of shoot regeneration depends on the climatic conditions and the age of the saplings.

During the first year after the cuttings are planted, the degree of rooting depends on the characteristics of each clone, the quality of cuttings and certain subjective factors. This explains the differences in the degree of rooting. In the first year after the initial planting, the different

Table 1. Meteorological data for the period 2005–2014 at the test plantation in Vardim.

Year	Precipitation, mm			Average annual ambient temperature, °C	Absolute lowest ambient temperature, °C			
	annual	April – August			Jan.	Feb.	Nov.	Dec.
		mm	part of the annual, %					
2005	940.0	367.5	39.00	12.74	-5.0	-18.0	-	-
2006	445.0	204.8	45.27	11.49	-16.0	-13.0	-	-
2007	746.0	268.3	35.97	13.02	-6.0	-	-	-
2008	501.5	165.2	32.94	13.01	-16.0	-8.0	-	-
2009	562.2	178.9	31.82	12.70	-10.8	-2.3	-	-8.0
2010	720.5	316.2	43.90	11.70	-14.8	-9.0	-	-8.5
2011	432.7	351.1	81.14	11.80	-8.8	-7.5	-	-3.4
2012	517.8	195.2	37.70	13.01	-16.5	-23.0	-	-7.8
2013	690.8	400.6	58.00	12.90	-12.3	-5.0	-	-2.8
2014	757.1	450.8	59.56	12.70	-7.8	4.3	-1.8	-11.5
Average	631.4	289.86	45.91	12.52	-16.5	-23.0	-1.8	-11.5

clones had different number of shoots per stump. Most of the clones had up to three shoots, the number of shoots per stump varied according to the species. Four species had up to two shoots and only one species (*Salix excelsa* '84/8') had up to four shoots (Table 2).

Of the seven deciduous tree clones (rows 1 through 7 in the Table 2), the greatest number of shoots was recorded for *Salix alba Si* '2/64' and the smallest – for *Salix excelsa* '62/8'. The slowest growth rate was recorded for the *Salix alba* '351'. Of the 3 bush clones (rows 8 through 10 in the table) the highest growth rate during the first year was recorded for the *S. viminalis purpurea* 'X/43'. The highest growth rate of all clones during

Table 2. Biometric data for one-year-old biomass plantations of willow clones.

No	Clone	Different number of shoots per stump, %				Rooting, %	Shoots per ha	D_0, mm			H, m		
		1	2	3	4			av.	min	max	av.	min	max
1	*Salix alba* 'IX/4'	15.0	70.0	15.0		100	18182	27.5	15	44	2.71	1.70	3.20
2	*Salix alba* '351'	52.9	41.2	5.9		85	11818	16.8	6	25	2.20	1.45	3.00
3	*Salix alba Si* '2/64'	15.0	30.0	55.0		100	19545	21.9	12	33	2.50	1.60	3.10
4	*Salix Humboldtiana B.* '112'	5.0	5.0	90.0		100	18182	22.1	10	36	2.32	0.70	3.10
5	*Salix alba* '82/11'	57.9	42.1			95	12273	22.2	14	34	2.79	1.75	3.40
6	*Salix excelsa* '84/8'	36.8	36.8	21.0	5.4	95	16818	19.3	7	31	2.74	1.20	3.20
7	*Salix excelsa* '62/8'	61.1	38.9			90	11364	18.0	9	27	2.53	1.70	3.15
8	*Salix bregensis* 'IX/45'	47.4	52.6			95	13182	20.3	14	30	2.35	1.85	2.80
9	*Salix viminalis rubra* ‚X/3'	66.7	26.7	6.6		75	9545	19.5	10	32	1.94	1.70	2.65
10	*Salix viminalis purpurea* 'X/43'	60.0	40.0			100	12727	24.0	10	36	2.71	1.60	3.80

a b

Fig. 1. Plantations of the *Salix alba* ‘IX/4’: a) one-year-old; b) nine-year-old.

the first year was recorded for *Salix alba* ‘IX/ 4’ (Fig. 1).

The average diameter at the stump of this clone’s shoots was 27.5 mm, and the largest absolute diameter was 44 mm (Table 1). Its productivity was 11.83 t/ha of green biomass and 4.67 t/ha of dry biomass (Table 3).

All 10 clones had fast initial growth of their shoots (Table 3). As the stumps aged, the survival rates of the various clones began to decline at various degrees for the different species. The fastest rates of decline were recorded for the shrub species and especially for the *S. viminalis purpurea* ‘X/43’ (Table 3). The number of shoots increased until the sixth year of the plantation and after that started to decline gradually. Of all shrub species the *S. viminalis rubra* ‘X/3’ had the highest number

a b

Fig. 2. Plantation of the shrub clone *S. viminalis rubra* 'X/3' in year one (a) and year nine (b) with annual coppicing.

Table 3. Biometric data dynamics of biomass plantations of various species of willow.

No	Clone	Stump age, yrs	Sur-vival, %	Shots, number per ha	Dimensions		Yield, t/ha	
					D_0 av., mm	H av., cm	fresh	dry
1	*Salix alba* ‘IX/4’	1	100	18,182	27.50	271	11.83	4.67
		6	88	296,153	12.00	207	68.40	
		8	84	185,577	15.60	243	39.48	
		9	80	216,667	9.70	219	45.14	31.27
2	*Salix alba* ‘№351’	1	85	11,818	16.80	202	2.70	1.17
		6	88	437,179	8.54	187	37.84	
		8	88	289,103	8.40	180	22.15	
		9	88	415,705	6.70	152	19.77	9.77
3	*Salix alba Si* ‘2/61’	1	100	19,545	21.90	160	9.56	4.22
		6	64	358,974	10.64	205	57.10	
		8	58	258,333	8.10	168	24.66	
		9	50	307,051	8.10	163	25.08	12.56
4	*Salix alba Humboldtiana* ‘B-112’	1	100	18,182	22.10	232	7.23	2.91
		6	86	192,948	13.00	215	45.94	
		8	80	175,000	14.50	237	55.13	
		9	80	248,718	9.30	195	45.38	21.43
5	*Salix alba* ‘82/11’	1	95	12,273	22.20	279	5.27	2.36
		6	78	175,000	14.36	255	45.41	
		8	78	60,897	10.10	193	6.83	
		9	76	107,692	10.00	206	6.97	3.49
6	*Salix excelsa* ‘84/8’	1	95	16,818	19.30	274	5.23	2.67
		6	86	192,948	12.33	233	39.28	
		8	78	143,590	10.10	199	17.41	
		9	78	204,167	10.10	199	19.92	10.97
7	*Salix excels*a ‘62/8’	1	90	11,364	18.00	253	2.91	1.45
		6	86	372,115	9.31	200	53.75	
		8	86	124,679	10.40	196	17.27	
		9	82	222,436	9.60	165	20.07	12.06
8	*Salix bregensis* ‘IX/45’	1	95	13,182	20.30	235	4.29	1.94
		6	68	305,128	11.96	220	49.40	
		8	66	187,821	10.60	204	14.25	
		9	64	299,359	7.80	180	11.94	6.18
9	*Salix viminalis rubra* ‘X/3’	1	75	9,545	19.50	194	5.48	2.55
		6	52	708,333	8.22	192	40.64	
		8	46	499,679	7.70	174	26.30	
		9	38	565,385	6.60	145	17.05	8.46
10	*Salix viminalis purpurea* ‘X/43’	1	100	12,727	24.00	271	7.69	3.32
		6	36	548,077	8.89	189	53.27	
		8	36	233,013	7.60	148	19.66	
		9	32	277,564	5.40	129	8.30	3.97

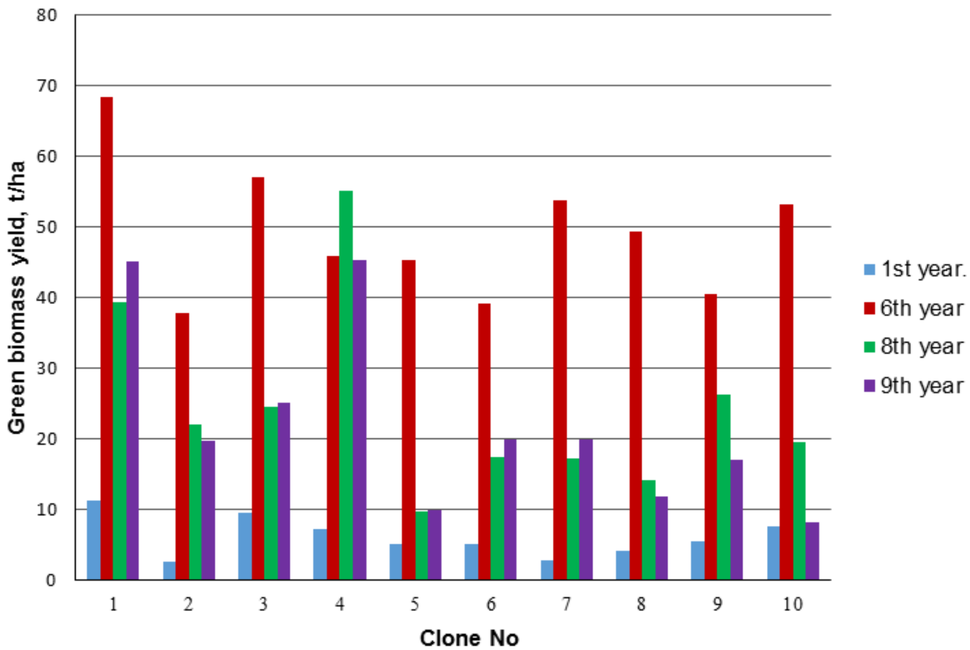

Fig. 3. Green biomass yield of the ten clones at different ages.

of shoots per hectare for the whole period of the study after the first year (Table 2).

In the eight year of the study (2012), all clones had the smallest number of shoots compared to the number of shoots in the sixth and the ninth year due to the adverse climatic conditions in that year: low amount of precipitation, particularly during the vegetation period, preceded by cold winter (Table 1). The largest number of shoots and productivity were recorded in the sixth year. The diameter growth in that year is proportional to the number of shoots. As the clones got older the basal diameter of the shoots decreased (Table 3).

As the clones got older, their productivity increased at various rates until the sixth year and after that began to decrease. Similar results have been reported by Arevalo et al. (2007), Aravanopoulos (2010) and Hangs et al. (2011). The best overall productivity throughout the study was calculated for *Salix alba* 'IX/4′, followed by *Salix alba* 'Si 2/61′. The productivity (yield) of *Salix alba Humboldtiana* 'B-112′ was relatively stable throughout the study and did not decrease after the sixth year unlike the other clones.

The yield of the shrub clones peaked in their sixth year and after that declined. During the first and the sixth year the highest yields were recorded for *Salix viminalis purpurea* 'X/43′ and during the eighth and the ninth year the highest green biomass yield was recorded for *Salix viminalis rubra* 'X/3′ (Fig. 3).

Conclusions

As a result of this research, the following conclusions were made:

– Deciduous tree and shrub willows

have specific shoot regeneration characteristics, growth rates and yields, which depend also on their age and cultivation and the climatic conditions.

– When the shoots are coppiced annually, their shoot regeneration ability declines after their sixth year.

– As the stumps get older, the survival rate declines.

– All ten clones showed a markedly fast initial growth of their shoots.

– The increase of the shoot diameter depends on the age of stump, the number of shoots per stump and the amount of precipitation during the growing period. The best thickness growth rates of the shoots of all clones were recorded in the first year.

– Of all 10 clones the best yield for the whole period of study was recorded for *Salix alba* 'IX/4' clone.

– Despite their lower survival rate, shrub clones had biomass yield comparable to that of the deciduous clones.

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