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Comparison of the growth of fast-growing poplar and willow in two sites of Central Kazakhstan

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Abstract

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In temperate climatic conditions, plantations of poplar and willow species provide sustainable production of biomass. Short rotation coppice plantations on agricultural lands have a great potential to increase the amount of biomass available for the production of biofuels, bioenergy and bioproducts. We studied and measured the growth of poplar and willow clones in two experimental research sites in Batys and Astaninskiy in the steppe zone of Astana in northern Kazakhstan. We measured tree heights, stem diameters at breast height and crown diameter. The mean height of 6-years-old trees of the "Kazakhstanskiy" hybrid poplar was 4.03 m in the Batys site, which is 1.6 m less than the height of poplars from the Astaninskiy experimental site that were measured in autumn. The results of this study show different reactions of selected clones/cultivars of poplar and willow to climatic conditions of northern Kazakhstan as well as their usability for biomass production in plantations under limiting hydrological conditions.

Keywords: short rotation coppice; Salicaceae; Central Asia; plantation; biometric and soil parameters

In temperate climatic conditions, plantations of poplar and willow species provide sustainable production of biomass. Short rotation coppice (SRC) plantations on agricultural lands have a great potential to increase the amount of biomass available for the production of biofuels, bioenergy and bioproducts (Barontini et al. 2014). SRC plantations have an impact on biodiversity and influence the soil protection against water and wind erosion (Kort et al. 1998), especially when compared with annual crop monocultures (Weger et al. 2013).

In comparison with other tree species, poplars grow very fast and can grow on many types of sites, even on otherwise unfavourable places like former waste disposal areas (Weger, Bubeník 2011). They are among the most widely cultivated tree species because it is easy to propagate them through vegetative cuttings and are characterized by wide interspecific crossability (Dickmann, Stuart 1983; Eckenwalder 1996; Bradshaw et al. 2000; Dickmann 2001; Al Afas et al. 2008).

Poplar and willow species have proved to be an excellent source of biomass especially around the northern parts of the globe. Various European countries established SRC plantations of willow clones with varying success (Stolarski et al. 2015). Most recently, Poland initiated the creation of a huge plantation of hybrid poplars for biomass, which will be the largest poplar plantation in Europe at the present time (Stobra-

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wa 2014). Genetically improved hybrid poplar clones in Eastern Canada reach the sawlog size in 15 years with annual yields of 8–15 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ (Pliura et al. 2014). The conducted experiments in southern regions of Kazakhstan confirmed the high production potential of the selected hybrid poplars 62027-1 and hybrid poplar "Kazakhstanskiy" (Sarsekova, Zasada 2014). The reserves of the phytomass of fast-growing wood species make up 1.343 thousand t which are growing in Central Kazakhstan, on the base of the Republic State Enterprise "Zhasyl Aymak". (Sarsekova 2015). Besides, the implementation of works on the creation of a green zone of the city of Astana was carried out in accordance with the "Zhasyl El" Program, approved by the Government of the Republic of Kazakhstan. It defines the main goals and objectives for increasing tree-planting work, planting of settlements, and ultimately increases the forest cover territory (Kazakh Forest Inventory Enterprise 2008). The whole forestry cover of the territory of Kazakhstan makes up 4.6%. An extremely unequal distribution is characteristic of the forests of Kazakhstan. About 80% of timber reserves are in the northern and northeastern part of the country, with more than half of the coniferous forest reserves which grow in Eastern Kazakhstan. In order to ensure the efficient use of renewable resources and energy as a factor of sustainable economic development of the Republic of Kazakhstan a strategy by 2024 has been developed. This long-term strategy will include popularizing the ideas of rational and effective environmental management, introduction of new technologies, a new culture of production, the formation of an appropriate legislative framework for resource conservation, environmental protection, and solve problems that damage renewable resources, including taking measures to stop their predatory exploitation (Government of the Republic of Kazakhstan 2008). Poplars are very responsive to mineral and organic fertilizers applied into the soil. The application of fractional fertilizer into the soil of willows in the first three years increases the growth of seedlings in height and diameter by 183 and 140%, respectively. Subsequent fertilization allows to adjust nutrition and ratio between nutrients, thus achieving a better use of fertilizers and a more rapid impact on the growth of poplars (Sarsekova 2012). Based on the above-mentioned experiences we decided to study and measure the growth of poplar and willow clones in the territory of Astana (northern Kazakhstan).

MATERIAL AND METHODS

We studied two clones of hybrid poplar Kazakhstanskiy and Kyzyl-Tan from the Aigeiros poplar section and *Salix alba* Linnaeus on two research areas (358 m a.s.l.), Batys (51°10'48"N, 10.088 ha) and Astaninskiy (71°26'45"E, 9.371 ha) located in northern Kazakhstan. Kazakhstan mostly consists of steppe land occupied by hills and plateaus. The Kazakh steppe covers almost one third of the territory of the country, occupied by grasslands and sandy areas. The "Astaninskiy" site is characterized by suitable forest soil which provides the cultivation of quite stable and viable plants of most tree species of the local flora. The soil of this site is characterized by average salinity. The "Batys" site is characterized by the soil of limited suitability for forest cultivation but thanks to the high agricultural technology it is possible to grow salt-tolerant species. Most of these lands are reserved for protective afforestation. Climate conditions of the two sites are nearly the same. Both research areas are located in the green zone of the city of Astana. Hybrid poplars Kazakhstanskiy and Kyzyl-tan were obtained by crossbreeding the poplar clone *Populus berolinensis* K. Koch with *Populus deltoides* Marsh. These clones were obtained by the breeder and professor P. Besschetnov (Besschetnov 1969). We also studied the species *S. alba*.

The climate of Astana is continental. The average long-term snow cover is 300 mm with an average of 30 days per year with snowfall. The wind mainly blows in a southwestern direction. Average temperature in July is 20°C, maximum daily temperatures reach 42°C. The average maximum temperature in July (30°C and above) is observed during 11–12 days. The annual rainfall is 300 mm. Soils of the green zone of Astana are Vertisols. Land use is classified as artificial forest. Groundwater depth ranges between 5 and 10 m and near lakes and marshes between 1.5 and 5 m. For the investigation of the soil status six soil samples were taken at three depths, 0–0.2, 0.2–0.4 and 0.4–0.6 m, to investigate soil properties at the research sites. In examining the characteristics of the soil, its texture, hygroscopic moisture, humus, pH, organic carbon, percentage of salts and dry residues were measured.

Plantations were established in a six-row design. Distance between rows is 4 m. A schematic layout of experimental plot is S-P-P-P-P-S (S for *Salix* Linnaeus, P for *Populus* Linnaeus). The distance between poplars in a row is 1.5 m and between willows 1.0 m. The number of planted poplars is 1,116 individuals, the number of planted willows amounts to

Table 1. Number of measured trees (*n*) in experimental research sites

Clone	Research site			
	Batys		Astaninskiy	
	n	observation period	*n*	observation period
Kazakhstanskiy hybrid poplar	405	autumn 2015	240	spring and autumn 2015
Kyzyl-Tan hybrid poplar	144	autumn 2015	–	–
Salix alba Linnaeus	231	autumn 2015	240	spring and autumn 2015
Total sample	780		480	

550 trees per hectare. Plantations were established with annual saplings of cuttings. Straight shoots with well-developed and mechanically intact buds were used for propagation cuttings. Cuttings were cut from the middle part of the shoots of one-year trees because the top shoot is very thin and there are few nutrients as well as they can be damaged by frost. Cuttings were 20–25 cm long with a diameter between 0.8 and 1.0 cm. Plantations were weeded between rows and around the research site twice in the first two years. The site was irrigated twice during the first year, once during the next year and then it was no longer irrigated. Irrigation rates were 20 l per tree. In the case of poplar it was calculated that 446 m^3 of water was used in the first year and 223 m^3 in the second year. For willow the water consumption amounted to 220 m^3 in the first year and in the second year it was 110 m^3. On the whole four plantations were observed, in "Astaninskiy" it was 1 plantation of 6-year hybrid poplars and *S. alba*, in "Batys" 3 plantations of 4–6-year crops of hybrid poplars and *S. alba*. All measured trees are presented in Table 1.

Trees were studied using a conventional method (Anuchin 1983). We calculated and measured biometric parameters such as averages of tree heights, DBH and crown diameter. Analyses of the measurement results were performed using a program based on ANOVA (Dospehov 1985). We calculated survival rates of the planted trees separately for each clone/cultivar. The survival rate was based on the condition rating assigned to the tree: good, fair, or poor trees were rated as alive and absent, dead, shrub, stump, or sprout trees were rated as dead (Vogt et al. 2014).

RESULTS

Results of soil sample examination are presented in Table 2.

The maximum content of humus in soil samples from 0–0.2 m in Astaninskiy site ranged between 8.14 and 10.11%, in Batys site 3.9–4.6%. Soil pH in Astaninskiy location ranged from 7.8 to 8.73 while it was 7.13–7.95 in Batys location.

Results of biometric measurements are presented in Table 3.

The Kazakhstanskiy hybrid poplar in Astaninskiy site had greater heights than in Batys site. Survival rate of the Kazakhstanskiy hybrid poplar was 89.4% with the mean height of 5.63 m. In Batys site, survival rate of the Kazakhstanskiy hybrid poplar after three years of growth was 71.4% and the mean height was 1.58 m compared to 58.5% survival rate and mean height of 1.34 m in Kyzyl-Tan. Growth in the height of *S. alba* for the growing season in Batys site was lower than in Astaninsky site. Survival rate of *S. alba* after 5 years of growth in Batys site was 87.8% and the mean height of 2.18 m was reached. In Astaninskiy site, survival rate of the 6-years-old plantation of *Salix alba* was 90.4% and the mean height was 4.24 m.

DISCUSSION

The mean height of Kazakhstanskiy hybrid poplar in the southern regions of Kazakhstan on weakly saline soils with 8–10 irrigations (700–800 $m^3 \cdot ha^{-1}$) during the growing season was 1.83 ± 0.01 m in the first year after planting. Mean height at the age of two years was 3.86 ± 0.01 m. Three-years-old plants reached the mean height of 5.72 ± 0.01 m. Mean height of Kyzyl-tan in the first year was 1.767 ± 0.01 m. Mean height at the age of two years was 3.56 ± 0.01 m. Three-years-old plants had the mean height of 5.48 ± 0.01 m (Besschetnov 1969).

The mean height of Kazakhstanskiy hybrid poplar reached 4.03 m in the Batys experimental site, which is 1.6 m less than in 6-years-old poplars from the Astaninskiy experimental site that were measured in autumn. Both values of height are much lower than the values measured for 3-years-old poplar growth from late 1969 in the southern regions of Kazakhstan. Plantations of 8-years-old poplars in Diwandareh (Kurdistan province, western Iran) were observed. The highest total mean

Table 2. Basic soil parameters and content of organic matter in the plantations of the experimental research sites Astaninskiy and Batys

Sample	Depth (m)	Hygroscopic moisture (%)	pH (KCl)	Humus (%)	CO_2 (%)	Sum of salts (%)	Dry residue (%)	Soil layer
Astaninskiy								
	0–0.2	10.11	8.73	3.45	0.16	0.085	0.09	L
1	0.2–0.4	10.4	8.44	3.33	0.67	0.104	0.11	L
	0.4–0.6	8.76	8.37	1.43	0.84	0.096	0.1	CL
	0–0.2	9.08	7.87	5.64	0.13	0.134	0.14	CL
2	0.2–0.4	9.49	7.91	3.68	0.16	0.113	0.12	CL
	0.4–0.6	10.01	7.92	3.62	0.13	0.092	0.09	CL
	0–0.2	8.14	7.8	3.21	0.2	0.106	0.11	L
3	0.2–0.4	8.31	7.86	3.09	0.23	0.103	0.11	L
	0.4–0.6	6.97	7.92	2.09	0.21	0.116	0.12	L
Batys								
	0–0.2	3.9	7.95	3.62	0.13	0.098	0.1	SL
1	0.2–0.4	4.02	7.92	3.6	0.16	0.06	0.06	SL
	0.4–0.6	4.35	7.64	2.02	0.13	0.057	0.06	L
	0–0.2	4.31	7.93	3.98	0.13	0.064	0.07	SL
2	0.2–0.4	5.64	7.58	2.33	0.16	0.09	0.09	SL
	0.4–0.6	3.45	7.32	1.27	0.11	0.054	0.05	L
	0–0.2	4.6	7.13	3.5	0.23	0.08	0.08	L
3	0.2–0.4	4.51	7.48	2.02	0.2	0.075	0.08	L
	0.4–0.6	3.99	7.4	1.02	0.16	0.051	0.05	SL

L – loam, CL – clay loam, SL – sandy loam

height was in Taze-Abad No. 2 stand (14.69 m) while the lowest was observed in Bishe Ola stands (6.37 m) (Alijanpour et al. 2014). During long-term measurements of natural cottonwood stands in the Lower Mississippi River Valley mean heights of 6.7 m were measured in 5-years-old poplars (Stanturf et al. 2001). This increment is more than twice higher than in Batys site.

Comparable results were obtained in the genetically similar poplar clone NL-B-132b of *Populus* × *canadensis* Moench that reached the mean height of 1.3 m three years after establishment on a site reclaimed from brown coal surface mining in the Czech Republic (50°38'1.244"N, 13°56'59.754"E). The site had unfavourable soil and climatic conditions and the experiment was neither irrigated nor fertilised (Weger, Bubeník 2011). Black poplar did not perform well only in very unfavourable conditions regarding soils and temperatures, the black poplar "NE-42" clone demonstrated greater adaptability and performed well even under unfavourable conditions (Benetka et al. 2014).

In two locations of northeastern Poland were established field trials with two *S. alba* clones Duotur and Corda. Field trials were weeded in the first two years and fertilized (40 kg N·ha^{-1}, 9 kg P·ha^{-1}, 33 kg K·ha^{-1}) in the second and third growing seasons After four years of growth Duotur clone had the mean height of 4.79 ± 0.24 m while Corda clone reached the mean height of 4.49 ± 0.24 m (Stolarski et al. 2011). Probably because of not so favourable climatic conditions *S. alba* in Batys site had the mean height of 0.84 ± 0.15 m after 4 years of growth.

CONCLUSIONS

The results of this study show different reactions of selected clones/cultivars of poplar and willow to climatic conditions of northern Kazakhstan as well as their usability for biomass production in plantations under limiting hydrological conditions. Preliminary results also show that the growth of hybrid poplar may be enhanced by applying biomicro-fertilizers and stimulants. In order to improve the yields of biomass per unit of surface area, it is important to focus on the proper selection of new poplar and willow genotypes especially from species well adapted to more arid regions with conditions similar to those in northern Kazakhstan. From the experience in the Czech Republic and other Central European countries it can be expected that the growth of poplars will increase in the following years, when their root systems are more developed.

Table 3. Results of measurement of biometric parameters of fast-growing trees in experimental research sites Astaninskiy and Batys

Parameter	Site	Average	Age of trees (yr)	Sum of squared deviations	No. of samples	Max–min
Kazakhstanskiy hybrid poplar						
Height (m)	Astaninskiy	4.67 ± 0.581	6 (s)	2,657.6	120	5.60–2.85
		5.63 ± 0.507	6 (a)	3,835	120	6.40–3.70
	Batys	4.03 ± 0.145	6	2,260.4	139	5.16–2.88
		3.09 ± 0.260	5	1,153.9	120	4.10–2.40
		1.58 ± 0.159	4	368.17	146	1.86–1.29
Diameter at 1.3 m height (mm)	Astaninskiy	26.5 ± 6.376	6 (s)	4,290.76	120	33.5–19.5
		43.3 ± 12.09	6 (a)	2,425.3	120	57.7–42.0
	Batys	39.4 ± 4.075	6	2,714.02	405	49.3–29.5
		25.4 ± 4.556	5	2,215.04	405	32.3–18.5
		22.3 ± 2.972	4	1,040.86	405	27.8–16.8
Crown diameter (m)	Astaninskiy	1.70 ± 0.324	6 (s)	359.4	120	1.95–1.25
		2.18 ± 0.316	6 (a)	582.3	120	2.63–2.15
	Batys	1.33 ± 0.231	6	253.3	405	1.67–1.00
		1.13 ± 0.250	5	160.8	405	1.41–0.85
		1.18 ± 0.157	4	206.9	405	1.59–0.77
Kyzyl-Tan hybrid poplar						
Height (m)	Batys	1.34 ± 0.205	4	264.62	144	1.69–0.99
Diameter at1.3 m height (mm)	Batys	21.2 ± 2.622	4	973.94	144	26.9–15.6
Crown diameter (m)	Batys	1.06 ± 0.185	4	166.7	144	1.37–0.65
***Salix alba* Linnaeus**						
Height (m)	Astaninskiy	3.64 ± 0.389	6 (s)	1608	120	4.50–2.75
		4.24 ± 0.551	6 (a)	190.7	120	6.35–3.65
	Batys	2.18 ± 0.268	5	434.2	90	2.25–1.15
		1.05 ± 0.151	4	103.7	141	1.53–0.67
Diameter at 1.3 m height (mm)	Astaninskiy	19.4 ± 3.429	6 (s)	1,344.83	120	27.5–11.0
		39.4 ± 5.763	6 (a)	3,535.80	120	48.5–30.0
	Batys	17.0 ± 3.526	5	1,051.0	90	32.0–13.0
		15.4 ± 2.149	4	478.72	141	19.0–11.0
Crown diameter (m)	Astaninskiy	1.44 ± 0.351	6 (s)	263.6	120	1.75–1.13
		1.82 ± 0.363	6 (a)	413.3	120	2.30–1.34
	Batys	1.23 ± 0.236	5	141.2	90	1.55–0.90
		1.08 ± 0.237	4	172.4	141	1.42–0.75

s – measurements carried out in spring, a – measurements carried out in autumn

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