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FEATURES OF BREEDING NEW WILLOW VARIETIES FOR CREATION OF ENERGY PLANTATIONS

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Abstract

An effective way to solve the problem of becoming energy more expensive can be found in the use of organic mass of growing woody plants, which are obtained from special energy plantations. Certain positive changes in energy policy in Ukraine in recent years have contributed to a marked increase in the percentage of alternative renewable energy in the energy balance of the country – from 0.5 % of the amount of consumed fuel and energy resources in 1998 to 5.8 % at present. In this paper we evaluated the possibility of obtaining new high-yield willow hybrids based on domestic and foreign cultivars for the creation of energy plantations in the conditions of Polesia and the Forest-Steppe of Ukraine. Breeding works were carried out as interspecific hybridization. Hybridization was conducted in spring 2018 on the cut branches in the laboratory and on branches inseparable from the bush, on which before the flowering female inflorescences was isolated to prevent uncontrolled pollination. The best of the two-year-old hybrid willow forms we have obtained in the course of our research reach a height of 3.0–3.2 m, which indicates their high biological potential and the potential for use in creating energy plantations.

Key words: cultivar, hybrids, interspecific crosses, plant biometric indicators, renewable resource, *Salix*, selection.

Introduction

Energy is becoming more and more expensive every year, and its quantity is constantly decreasing, so there is a need to ensure energy security of Ukraine, which leads to the search for alternative sources of raw materials for energy needs (Afonin and Fuchylo 2012a, 2012b; Geletukha 2015; Fuchylo and Sbytna 2017).

Representatives of willow species (*Salix* L.) are gaining popularity in Europe (Liberg 1994, El Bassam 2010, Fuchylo 2011, Caslin et al. 2012), the north of the US, and Canada as one of the promising biomass crops for use in bioenergy, biofuels and high value products in the chemical industry (Heller et al. 2003).

The main advantages of this culture are: genetic diversity for breeding and reproduction; short rotational growing period; high biomass capacity – significant potential for bioenergy generation; positive balance of greenhouse gases; carbon deposition in the aboveground and underground parts of the energy willow (Liberg 1994, Taylor at al. 2019).

Certain positive changes in Ukraine's energy policy in recent years have contributed to a significant increase in the percentage of alternative renewable energy in the country's energy balance – from 0.5 % of fuel consumed in 1998 (Geletukha and Martsenyuk 1998) up to 5.8 % nowadays (Chmeruk 2018).

About 5000 ha of energy plantations have been created in Ukraine now (Fuchylo et al. 2018). These are quite significant indicators, but they are not sufficient for a more complete solution of the problem of replacement of fossil energy by renewable energy raw materials, so it is very important for our country to expand the area of energy plantations and increase their productivity (Roik et al. 2015).

One of the effective ways to ensure high productivity of energy plantations of willow is the development of gene pools of this broad genetic base using Ukrainian and foreign material. The theoretical potential of Ukraine for the cultivation of energy willow and other energy plants is about 5 million ha of marginal land. Technical capacity is about 1.5 million ha. Economic potential is 2 billion USD. But a significant part of these lands belongs either to oligotrophic or oligomesotrophic hydrophytes or *vice versa* to xerophytes and mesoxerophytes, which in turn significantly complicates the creation of energy willow plantations on them. Existing cultivars are not very suitable for such a composition of lands. Expanding the genetic diversity of willows will solve these problems. Therefore, our goal is the selection of new high-yielding and resistant to negative factors varieties for specific soil and climatic conditions, and land categories (Smart et al. 2007, Afonin and Fuchylo 2012b, Fuchylo et al. 2016, Fuchylo et al. 2018).

The purpose of the study is to evaluate the possibility of obtaining new high-performance willow hybrids on the basis of domestic and foreign cultivars for the creation of energy plantations in the conditions of Polissia and Forest-Steppe of Ukraine.

Materials and Methods

Pollen for pollination of female flowers was obtained by germinating branches prepared to open anthers and placed at room temperature (20–22 °C) at a relative humidity of 40–50 %. Under these conditions, the pollen mass matures within 2–3 days. The pollen was shaken from branches onto paper, placed in test tubes, and stored in a refrigerator until crossbreeding. Thus, pollen of male plants of Basket willow (*S. viminalis* L.) varieties 'Ternopilska' and 'Sven' and Fragile willow (*S. fragilis* L.) of the variety 'Adam' (Ukrainian Institute … 2020) were obtained (Melezhyk and Maurer 2016a, 2016b). Table 1 shows list of cultivars selected for research.

Table 1. List of species and cultivars selected.

Order number	Name	Sex	Origin
1	*S. alba* L.	female	Ukraine
2	*S. fragilis* L.	female	Ukraine
3	*S. viminalis* 'Tora'	female	Sweden
4	*S. alba* 'Lisova pisnia'	female	Ukraine
5	*S. viminalis* 'Tordis'	female	Sweden
6	*S. dasyclados* Wimm.	female	Ukraine
7	*S. viminalis* 'Inger'	female	Sweden
8	*S. fragilis* 'Adam'	male	Ukraine
9	*S. viminalis* 'Ternopilska'	male	Ukraine
10	*S. viminalis* 'Sven'	male	Sweden

Hybridizations were conducted in spring 2018 on the cut branches in the laboratory and on branches not separated from the bush, which before the flowering was isolated female inflorescences to prevent uncontrolled pollination.

White willow (*S. alba* L.), Wool-twig willow (*S. dasyclados* Wimm.), Fragile willow (*S. fragilis* L.), three varieties of Swedish breeding on the basis of the basket willow – 'Tora', 'Tordis' and 'Inger' and a hybrid of White and Fragile willow 'Lisova pisnia' were used as female plants (Melezhyk and Maurer 2018).

The time of pollination of female flowers was determined by the condition of the pestles. Pollination of pre-isolated inflorescences was carried out immediately before the beginning of their bloom, when the blades of the uterus receptacles have acquired their inherent size, shape and colour. The pollination was carried out with a soft brush, which was pollen collected and evenly distributed over the inflorescence and immediately isolated with paper bags. When the seeds ripen, the branches with insulators were cut. The seeds were separated by grinding in a sieve with a hole diameter of 2 mm and immediately sown in plastic containers on a well-moistened soil-sand mixture. Within 1–2 h after sowing, the seeds have turned bright green – through the thin shell, chlorophyll-bearing seedlings can be seen. The seedlings appeared in 24–36 h. When the plants reached stages 3–4 of true leaves (mid-June), they were transplanted into larger-capacity plastic containers where they were gradually adapted to grow outdoors. By the end of the first growing season, 70 % of the planted seedlings died, despite the fact that the automatic irrigation system was constantly working and shading of the area was created. Thus, we have obtained individuals of ten hybrid combinations, among which selected plants with intensive growth, resistant to disease and pests and adapted to local climatic conditions. According to the results of wintering, plants that were well tolerated in the unfavourable winter period were selected (Gorielov et al. 2014).

The selected plants were planted in open soil according to the scheme 0.5×0.7 m in November 2018. During the growing season, 4 manual soil inspections were carried out, which contributed to the complete destruction of weeds and intensive growth of seedlings.

Periodic determinations of the height and diameter of hybrid plants and the processing of the obtained results were carried out according to conventional methods (Dospekhov 1973, Fuchylo et al. 2018).

Results

Studies have shown that after the end of the first growing season of almost 200 obtained hybrids (100 %) remained 69 (34.5 %). Their height ranged from 2.4 to 48.5 cm, and the diameter near the root neck – from 1.0 to 4.0 mm. Among the offspring of hybrids where three or more plants were preserved, the highest average height had *S. viminalis* hybrids. 'Tordis' × *S. viminalis* 'Ternopilska' – 39.0 cm and *S. viminalis* 'Tordis' × free pollination – 28.0 cm. Their average diameters were 3.1 and 2.2 mm, respectively. Table 2 shows morphometric characteristics of hybrid willow plants before planting in open ground and at the end of the second growing season.

After two years of research, it was found that the resulting two-year hybrids have a height of 120.0 to 320.0 cm.

Table 2. Morphometric characteristics of hybrids before planting in open ground.

Order number	Hybrid combination (female × male)	2018				2019			
		Height, cm		Root neck diameter, mm		Height, cm		Root neck diameter, mm	
		M	m	M	m	M	m	M	m
1	*S. alba* L. × *S. fragilis* 'Adam'	16.0	0.24	3.0	0.10	320.0	12.00	16.8	0.96
2	*S. dasyclados* Wimm.× *S. fragilis* 'Adam'	16.5	-	3.1	-	320.0	-	16.0	-
3	*S. viminalis* 'Inger' × *S. viminalis* 'Ternopilska'	48.5	4.35	3.9	0.36	280.0	21.00	13.2	1.24
4	*S. fragilis* L. × *S. viminalis* 'Ternopilska'	18.0	0.80	3.6	0.14	240.0	14.00	12.4	1.00
5	*S. viminalis* 'Tora' × *S. viminalis* 'Ternopilska'	22.0	1.20	3.3	0.22	310.0	24.00	14.2	1.15
6	*S. viminalis* 'Tora' × *S. viminalis* 'Sven'	24.0	0.65	2.4	0.10	275.0	13.00	13.8	0.94
7	*S. viminalis* 'Tordis' × *S. viminalis* 'Ternopilska'	39.0	2.20	3.1	0.12	215.0	15.00	12.0	1.06
8	*S. alba* 'Lisova pisnia' × free pollination	22.0	1.25	3.8	0.24	320.0	21.00	16.0	1.12
9	*S. alba* 'Lisova pisnia' × *S. fragilis* 'Adam'	22.0	1.30	4.0	0.26	240.0	18.50	13.2	1.14
10	*S. viminalis* 'Tordis' × free pollination	28.0	0.60	2.2	0.10	315.0	19.00	16.0	1.10
	Average value	25.6	1.38	3.2	0.18	283.5	17.50	14.4	1.08

Note: M – mean value, m – mean value error.

The best among the studied hybrids had a height of 320.0 cm *S. alba* × *S. fragilis* 'Adam' (hybrid 1/16), *S. dasyclados* × *S. fragilis* 'Adam' (hybrid 2/2) and *S. alba* 'Lisova pisnia' × free pollination hybrid 4/9), 315.0 cm – *S. viminalis* 'Tordis' × free pollination (hybrid 5/3), height 310.0 cm small *S. alba* × *S. fragilis* 'Adam' (hybrid 1/13) and *S. viminalis* 'Tora' × *S. viminalis* 'Ternopilska' (hybrid 3.7).

These promising plants will be cloned and their vegetative offspring will be tested in test cultures with the prospect of obtaining clone variety status.

The study of the growth characteristics of the obtained hybrids during the second growing season showed that the intensity of increasing their height reaches maximum values in the period from mid-June to mid-August (Fig. 1).

The diameter near the root collar during the second year of vegetation increased almost similar to the height, but the intensity of this process was higher in most hybrids in the first half of summer (Fig. 2). This applies in particular to almost all hybrids that are 300 cm or more in height.

The special interest is presented by landings of fast-growing willow, that require the selections of sorts which countries adapted to the ground-climatic terms. This is considered on the basis of the presence of large areas of unoccupied marginal land (more than 5 million ha), as well as the high level of Ukraine's poten-

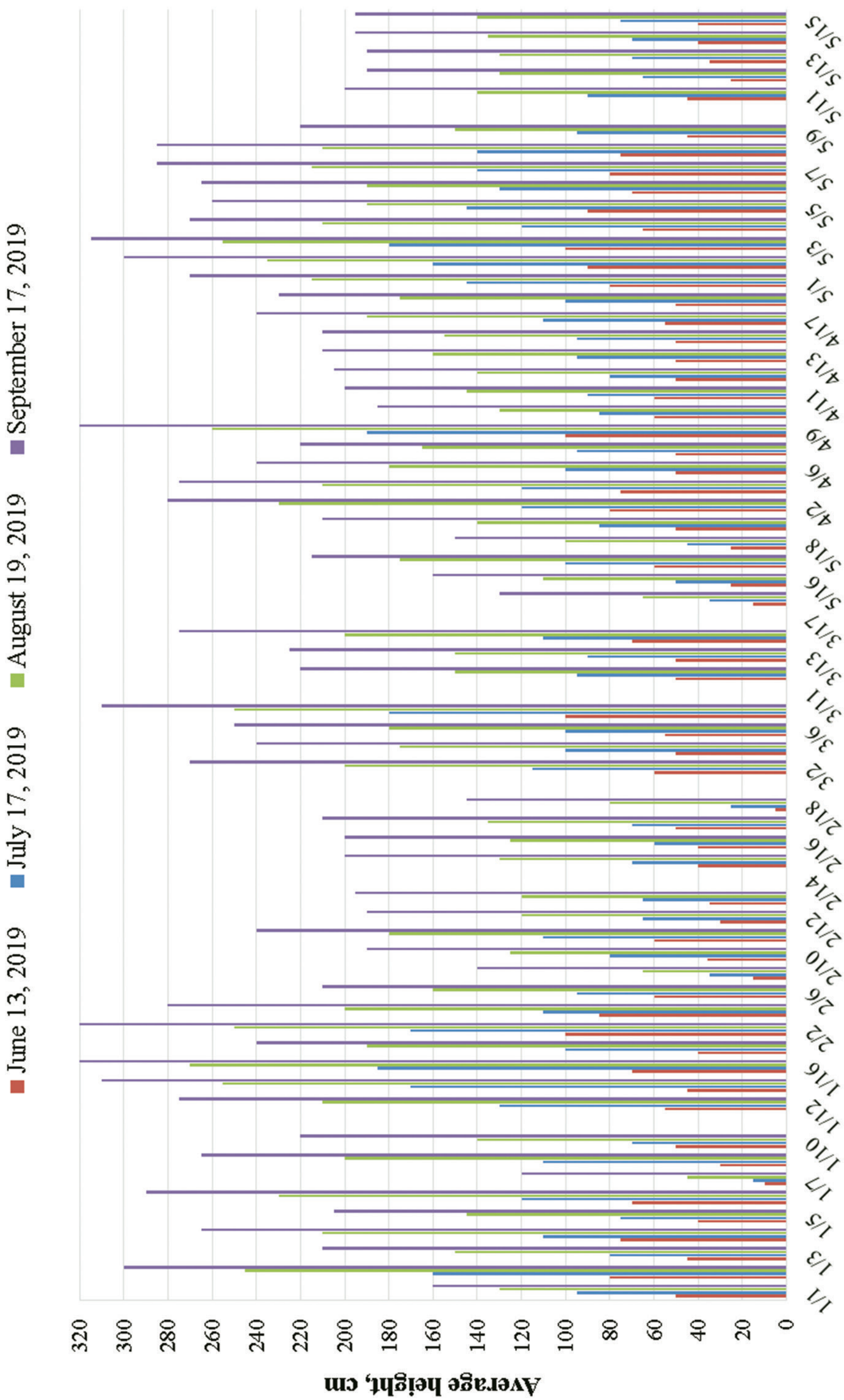

Fig. 1. Growth in height during the second growing season.

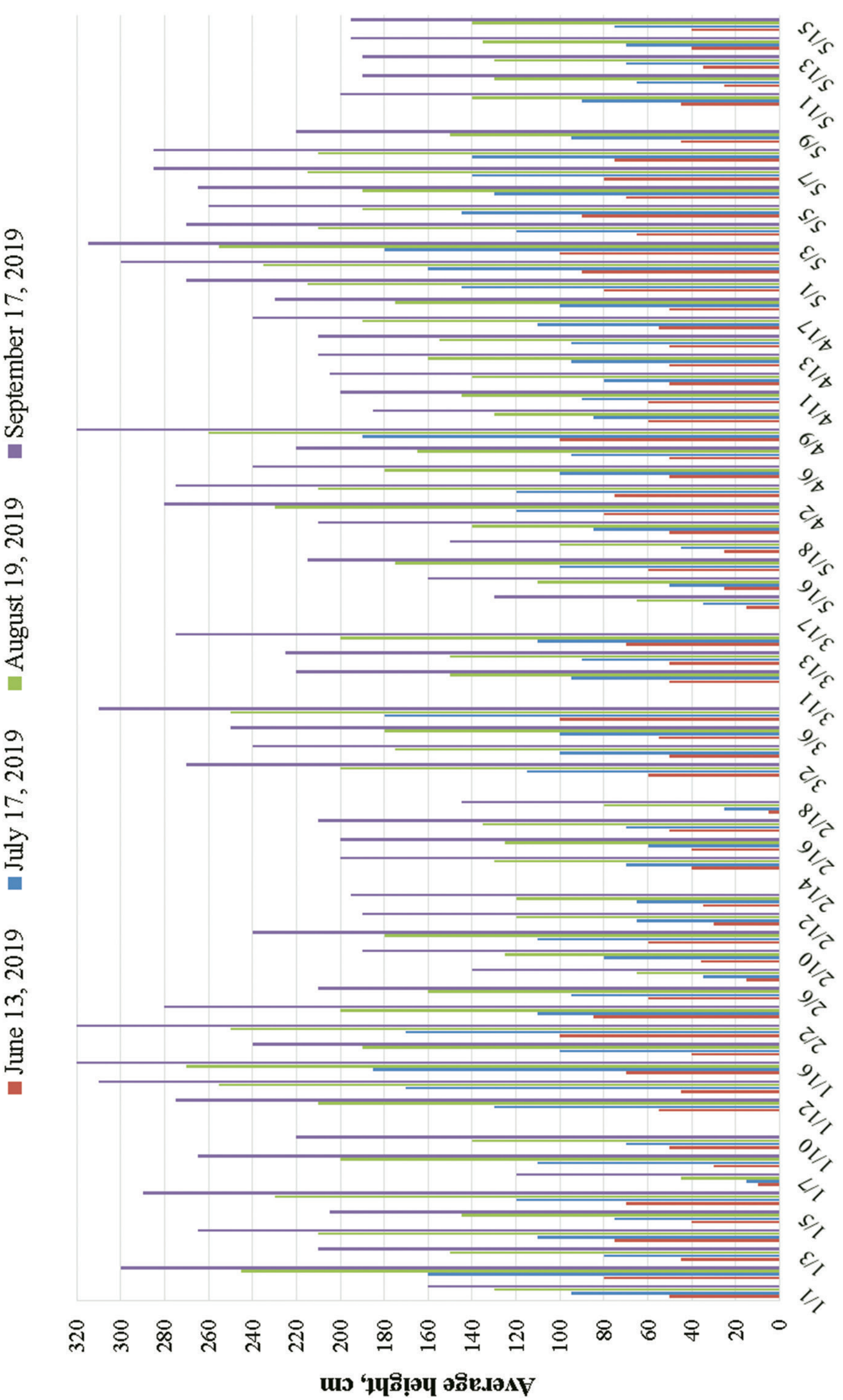

Fig. 2. Growth in stem diameter near the root collar during the second growing season.

tial for growing energy crops.

So, hybridization of the most productive willow varieties with native species will allow to receive cultivars that will yield high biomass yields and have a high growth rate while maintaining resistance to specific growing conditions. By bringing willow varieties to different regions of Ukraine, we will be able to significantly accelerate the growth of energy plantations throughout the territory, not just in some areas.

Discussion

Cross-species willow hybridization to bring new emerging cultivars is widely used in leading countries in the world. With state support, in 1990, a breeding program for the fast-growing willow at the Long Ashton Research station in the UK, based on a collection created by Kenneth Stott, replaced by Kevin Lindegard, started. In 1997 Svalof Weibull Willow Cultivation Industrial Breeding Program began in Sweden, under the direction of Stig Larson (Karp et al. 2011, Sharma et al. 2017).

The breeding of new varieties of willow in North America was initiated at the University of Toronto which research focused on local willow species. Beginning in 1983, it was the first attempt at extensive crossing with willow species from US collections, which provided important information and the ability to obtain interspecific hybrids. At present, SUNY College of Environmental Science and Forestry is developing new willow hybrids.

According to the book ‘Genetic Improvement of Bioenergy Crops (Vermerris 2008), the most productive and commercially successful willow cultivars can be distinguished. Table 3 shows list of willow hybrids as commercial bioenergy crops.

Table 3. Willow hybrids bred and selected as commercial bioenergy crops.

Breeding country	Cultivars	Parental species and hybrids
Sweden Svalof Weibull	'Orm', 'Jorr', 'Jorunn'	*S. viminalis*
	'Tora', 'Bjorn'	*S. schwerinni* × S. *viminalis*
	'Torchild', 'Tordis'	(*S. schwerinni* × *S. viminalis*) × *S. viminalis*
	'Sven', 'Olof', 'Asgerd'	*S. viminalis* × (*S. schwerinni* × *S. viminalis*)
	'Loden', 'Gubrun'	*S. dasyclados*
	'Inger'	*S. trianda* × *S. viminalis*
Great Britain	'Endeavour'	*S. viminalis* × *S. schwerinnii*
	'Discovery'	*S. viminalis* × (*S. schwerinni* × *S. viminalis*)
	'Resolution'	(*S. viminalis* × (*S. schwerinni* × *S. viminalis*)) × (*S. viminalis* × (*S. schwerinni* × *S. viminalis*))
	'Tera Nova'	(*S. trianda* × *S. viminalis*) × *S. linderstipularis*
	'Ashton Stott'	*S. viminalis* × *S. burjatica*
	'Nimrod'	(*S. schwerinni* × *S. viminalis*) × *S. linderstipularis*
	'Quest'	*S. viminalis* × (*S. schwerinni* × *S. viminalis*)
USA SUNY-ESF	'Fish Creek', 'Onondaga', 'Alle-gany'	*S. purpurea*
	'Millbrook', 'Oneida'	*S. purpurea* × *S. miyabeana*
	'Sherburne', 'Canastota'	*S. sachalinensis* × *S. miyabeana*
	'Otisco', 'Tully Champion', 'Owasco'	*S. viminalis* × *S. miyabeana*

Having analyzed the experience of international and domestic experts with our results, we have concluded that during breeding of new fast-growing willow cultivars, hybrids from crossing native species such as white and three-willow with the most productive varieties of foreign and domestic breeding are the most productive.

Conclusion

The use of hybridization in the process of obtaining highly productive and sustainable forms of willow has a great potential, in particular – to improve the productivity of energy plantations. The best of the two-year-old hybrid willow forms we have obtained in the course of our research reach a height of 3.0–3.2 m, which indicates their high biological potential and potential for use in the creation of energy plantations. After further research, the best of them will be submitted for registration in the National Register of Plants. According to the results obtained, it is advisable to use white, woolly, willow, 'Lisova pisnia' hybrid, Swedish breed 'Tora' and 'Tordis' to obtain growing hybrids of willow during crosses as female plants. As pollinators, the varieties of *S. viminalis* 'Ternopilska' and the cultivar of our breeding *S. fragilis* 'Adam' have positively proved themselves.

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