Promising introduced Black Cottonwood species for bioenergy and forage production

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Abstract. The winter-hardy introduced North American Populus trichocarpa Torr. & Gray is of particular interest. The results of the study of some clones of poplar on the experimental sites of the Voronezh region are presented. It was found that the rootability of standard stem cuttings of poplar was 98-100%. The survival of plants during the first 3-5 years varied from 75 to 100%. The growing season in different years was 135-146 days. The yield of standard cuttings on root-cutting plantations under favorable conditions and optimal age varied in different clones from 592 000 to 1 380 000 pieces per ha. The wood stock at the age of economical exploitability (~25 years) reached 400 m³/ha, while the stock of local balsam poplar at the same age reached 220 m³/ha. The green mass of leaves contained 0.22-0.28 feed units/kg. In addition, the content of digestible protein, calcium, phosphorus, carotene, crude protein, crude fat, crude fiber, nitrogen-free extractives and ash was determined. In general, studied clones of P. trichocarpa can be used in short rotation coppices for bioenergy and feed production, as well as in reclamation plantings. Clones of the poplar can be used in hybridization with black poplars to increase their winter hardiness.

1. Introduction
Studies of the poplars’ cultivation conducted in the last 80-90 years in the Russian Federation by Albensky A, Bogdanov P, Starova N, Besschetnov P etc. have shown that the representatives of the balsam poplars’ section have the highest winter hardiness. That conclusion was confirmed by our field tests in Central Chernozem region [1-5]. Abroad, among the winter hardy balsamic poplars, the Populus trichocarpa Torr.&Gray [syn. P. balsamifera ssp. trichocarpa (Torr.&Gray) Brayshaw], or Black Cottonwood is well known as naturally occurring in North America [6,7].
In recent years, the high winter hardiness of Populus trichocarpa has been confirmed in Sweden [8,9]. Several winter-hardy cottonwood cultivars have been selected from native plantings in North America, including those known as ‘Fritzi Pauley’ (ex-SP-126) and ‘Scott Pauley’ (ex-SP-127). Both cultivars were selected by S Pauley in Washington State [10]. The first of them is female, has a beautiful trunk shape and rapid growth. In Europe it’s used as a female parent tree in hybridization to increase the winter hardness of black poplars [11]. For the first time in the Central Chernozem region of European Russia, Voronezh researchers (Veresin M and Tsarev A, 1974; Tsarev A, 1985) collected and conducted field testing of 25 clones of various species and hybrids of balsamic poplars to test winter hardiness and growth [1-5]. Some interest among the tested poplars was also aroused by P. trichocarpa as a winter hardy and fast-growing species of balsamic poplars at a young age.

In northern European countries great importance is attached to the adaptation of poplar clones to northern climatic conditions. They’ve been testing a large number of Europe commercial poplar clones throughout the continent with the aim of large-scale forestry development using fast-growing poplars in short-rotation coppice. And in these studies, one of the first places belongs to P. trichocarpa and other balsamic poplars [12]. In Sweden, for example, full-factor experiments were conducted to study the growth, production and distribution of biomass and the conservation of nutrients of eight balsamic (as the most winter-hardy) poplar clones (P. balsamifera L., P. trichocarpa Hook.) and hybrid poplar (P. trichocarpa Hook. × P. deltoides Bartr.) of North American origin. The obtained results were the basis for the selection of clones for multi-purpose poplar plantations grown in cool-temperate, high-latitude climatic conditions characteristic of a large part of Sweden [13]. Currently, in various countries, due to climate changes, great importance is attached to the local latitudinal and altitudinal adaptation of various poplar clones, especially the northern P. trichocarpa [14,15]. In this regard, the main direction of research is the study of the genetics of adaptation to new conditions in ecologically and industrially important tree species, among which the poplars occupy the most important place as the fastest-growing species. In particular, the study of the genomic basis of local adaptation is necessary to assess the conditions under which trees will successfully adapt locally to global climate change, and in general to preserve and improve forest trees [16,17].

Recently, in addition to accelerated biomass production, much attention has been paid around the world to reducing pollution and producing clean water and clean energy, including bioenergy. The production of short-rotation woody crops (SRWCs), such as poplars and willows, is a promising component of global bioenergy and phytotechnologies portfolios, which supports many United Nations Sustainable Development Goals, including decarbonization of energy systems [18,19]. In the countries of Eastern Europe, work is underway to select the fastest-growing and resistant to changing climate clones and hybrids of poplar, modern technologies of breeding and selection processes are being developed [20,21], the content of biologically active compounds in the biomass of fast-growing tree species as a fodder in animal husbandry is being studied [22]. A number of researchers consider Populus trichocarpa is an important forest tree species for the generation of lignocellulosic ethanol. In this regard, they investigate the genomic basis of biomass production and chemical composition of wood as a fundamental basis in supporting genetic improvement programs [23].

The purpose of this publication is to analyze the winter hardiness, growth and the possibility of using the resulting biomass of the northern Black Cottonwood for the production of renewable energy and feed in animal husbandry.

2. Methodology
The studies were carried out with four clones of P. trichocarpa at a number of experimental and pilot production sites in the Voronezh Region. These 4 clones were obtained from the following institutions and regions of the former Soviet Union:

- Ukrainian Research Institute of Forestry and AgroForestReclamations – clone No. 45.
- Dvina Forest Research Station in Belarus – clone No. 83.
- All-Union Research Institute of Silviculture and Forestry Mechanization via Dvina Forest Research Station – clone No. 84.
- Forest nursery “New” in Voronezh – from the collection created by Professor of the Voronezh Forestry Engineering Institute M Veresin – clone No. 110.

The introduced clones of the northern Black Cottonwood have been tested at the following field experimental sites in the Voronezh region:

- Semiliky root-cutting plantation of the Central Research Institute of Forest Genetics and Breeding (currently All-Russian Research Institute of Forest Genetics, Breeding and Biotechnology).
- Populetum of the Semiluky experimental forest tree breeding nursery of the Central Research Institute of Forest Genetics and Breeding.
- Variety testing site in Zemlyansk Forestry Enterprise of the Voronezh Forestry Management Department.
- Variety testing site of the Ostrogozhsk Forestry Enterprise of the Voronezh Forestry Management Department.
- Variety testing site of the Training and Experimental Forestry Enterprise of the Voronezh Forestry Engineering Institute (currently the Voronezh State Forestry Engineering University).
- Forest park area of the All-Russian Research Institute of Forest Genetics, Breeding and Biotechnology.

The most extensive and long-term studies were carried out at the Semiluky populetum. Populetum was set up with stem cuttings in 1974. And also at the Semiluky root-cutting plantation set up with stem cuttings in 1972. Both of these sites are located next to each other. Their geographical coordinates are: latitude 51°42′ North and longitude 38°57′ East. The soil is represented by a leached chernozem. The relief is a weak dividing slope to the Veduga River. The ground water level is 4-5 m. The type of growing conditions determined by the Alekseev-Pogrebnyak scale is D2. At the Semiluky root-cutting plantation 180 clones of different varieties and genotypes of poplars were planted on an area of 1.5 hectare (ha), and at the populetum 84 clones of different varieties and genotypes of poplars were planted on an area of 4.6 ha. All plants were grouped into 6 morphological and systematic groups: white poplars with a pyramidal crown, white poplars with a spreading crown, black poplars with a pyramidal crown, black poplars with a spreading crown, balsamic poplars and intersectional poplar hybrids.

In proposed publication the results of long-term studies of the efficiency of propagation by stem cuttings, phenological development, growth, productivity and feed quality of *P. trichocarpa* woody greens are presented. Rootability and survival were calculated as a percentage in relation to the planted cuttings. The growth of young plants was characterized by their height. The volume of the trunk of adult plants was determined by the formula (1):

\[
V = \pi D^2 H f \left(4 \cdot 10^4\right)^{-1}
\]

where, \(\pi = 3.14\); \(D\) – diameter at a basic area (height of 1.3 m), cm; \(H\) – height of the tree, m; \(f\) – species number which for poplars = 0.39 [24].

The wood stock was determined by summing of the actual volumes of survived clones at each plot and each repetition, and transferring the resulting stock value to the area of all plots, and then to the area of 1 ha by the formula (2):

\[
W = W' \cdot 10^4 \cdot S^{-1}
\]

where, \(W\) – estimated stock of stem wood, m³/ha; \(W'\) – the actual stock of stem wood in all plots, obtained as the total amount of stocks in each plot, m³; \(S\) – total area of all plots, m²; 10 000 – the area of one hectare, m².

The feed quality analyses of *P. trichocarpa* were carried out in the feed laboratory of the Voronezh Regional Agricultural Chemization Station. Standard mathematical methods were used for data processing [25,26], as well as the Excel computer program.
3. Results
It was found that the rootability of standard quality cuttings of *P. trichocarpa* at the root-cutting plantation was 98%, and at the populetum it was 100%. During the first 3-5 years the survival of plants at the root-cutting plantation ranged from 75 to 100% in different clones of this species. The period of vegetation and the yield of standard stem cuttings suitable for successful reproduction obtained during the period of greatest productivity (at the age of 6 years) at the Semiluky root-cutting plantation are presented in table 1.

| Inventory No. of clones | The period of vegetation in different years, the number of days | Yield of stem cuttings at the 6-year-old root-cutting plantation, thousand pieces/ha |
|-------------------------|---------------------------------------------------------------|----------------------------------------------------------------------------------|
|                         | 1974 | 1977                          |                                                                                   |
| 45                      | 146  | 141                     | 592                                                                               |
| 83                      | 135  | 141                     | 1 380                                                                              |
| 84                      | 146  | 141                     | 676                                                                               |
| 110                     | 135  | 141                     | 712                                                                               |
| Average of *P. trichocarpa* | 140.5 | 141.0                  | 840                                                                               |
| Average for 6 other clones of balsamic poplars | 134.0 | 140.4                  | 630                                                                               |

From the data in table 1 it can be seen that the growing season of annual shoots at the root-cutting plantation for different clones of the North Black Cottonwoods on three-year-old roots in 1974 and on six-year-old roots in 1977 averaged 141 days with small deviations for individual taxa. This indicator for the other 6 clones in 1974 was slightly lower (by 4.9%), and in 1977 – almost identical.

The yield of standard stem cuttings for different clones of *P. trichocarpa* at the 6-year-old Semiluky root-cutting plantation ranged from 592 000 to 1 380 000 pieces per 1 ha. The average value of this indicator for *P. trichocarpa* exceeded the average value for other clones of the balsam poplar section by 33.3%. The survival, growth at a young age and wood stocks at the age of economic exploitability (~25 years) for different clones of *P. trichocarpa* are presented in table 2.

| Inventory No. of clones | Survival, % at the age of 4 years | Height at the age of 4 years, m | Average wood stocks at the age of 25 years, m³/ha | Average increments at the age of 25 years, m³/ha per year |
|-------------------------|-----------------------------------|---------------------------------|---------------------------------------------------|--------------------------------------------------------|
|                         | 4 years              | 25 years                          |                                                  |                                                       |
| 45                      | 100                  | 96                                | 6.7                                               | 355                                                   | 14.2                                                  |
| 83                      | 96                   | 96                                | 7.1                                               | 400                                                   | 16.0                                                  |
| 84                      | 92                   | 92                                | 7.0                                               | 331                                                   | 13.2                                                  |
| 110                     | 96                   | 92                                | 6.6                                               | 281                                                   | 11.2                                                  |
| Average for *P. trichocarpa* | 96.0                  | 94.0                                | 6.9                                               | 342                                                   | 13.7                                                  |
| Average for 4 other clones of balsamic poplars | 89.0                  | 84.6                                | 5.8                                               | 310                                                   | 12.4                                                  |
| *P. balsamifera ‘X6’*    | 70.8                  | 63.0                                | 5.4                                               | 220                                                   | 8.8                                                   |

It should be noted that by this age among the balsamic poplars all four clones of *P. trichocarpa* were survived. From the other six balsamic poplars planted in populetum only 4 have been survived to
some extent (P. simonii inv. No. 133, P. suaveolens inv. No. 99, P. maximovichii inv. No. 86, and local P. balsamifera inv. No. ‘Xe’). The last poplar was planted in populetum as a control. As can be seen from the data in table 2 the survival of P. trichocarpa clones at the age of 4 years exceeded the average survival of other balsamic poplars by 12.9%, and exceeded the control clone of the local balsamic poplar ‘Xe’ – by 35.2%. The study of growth showed that the average height of P. trichocarpa clones at the age of 4 years was higher than other balsamic poplars by 18.9%. By the age of economic exploitability the survival of P. trichocarpa clones ranged from 92 to 96%. The average survival of other balsamic poplars was slightly lower by 5.6%, while the survival of the control clone of P. balsamifera ‘Xe’ was lower by 49.2%.

Table 2 also shows that the average wood stock and average increment for P. trichocarpa clones at the age of economic exploitability was higher than remaining four clones of other balsamic poplars. At the same time, it significantly exceeded these indicators for the control local balsamic poplar ‘Xe’. From the components of woody greenery (leaves, stems and shoots), the leaves are the most valuable forage, and according to some publications they accumulate up to 80% of nutrients and minerals [27]. To study the feed value of the leaves, three clones of P. trichocarpa, which were quite productive at a young age, were taken (No. 45, No. 83, and No. 110). The material was picking up at the experimental facilities located in the forest-steppe zone of the Voronezh Region. As a control, the green mass of grass from floodplain meadows and alfalfa was used. The results of the analyses are shown in table 3. As can be seen from the data in table 3 the feed value of the leaves of P. trichocarpa clones varied significantly in some indicators, while the variation was small in others. Their comparison with the grass from floodplain meadows and alfalfa (Lucerne) showed their close values.

4. Discussion
We investigated the duration of the growing season of P. trichocarpa was about 141 days. According to our early observations and literature sources, it was shorter than in all the other five morphological and systematic groups of poplars by 20-30 days.

Table 3. The leaves fodder value of P. trichocarpa and some grasses.

| Components                   | Clones of P. trichocarpa | The grass from floodplain meadows | Alfalfa (Lucerne) |
|------------------------------|--------------------------|----------------------------------|------------------|
|                              | No. 45                   | No. 83                           | No. 110          |                  |
| Feed units, kg               | 0.26                     | 0.24                             | 0.22-0.28        | 0.21-0.26        | 0.17-0.22 |
| Digestible protein, g        | 29.6a                    | 29.6a                            | 16-17            | 12-26            | 38-40    |
| Calcium, g                   | 5.83                     | 8.33                             | 9-24             | 2.8-32           | 4.5      |
| Phosphorus, g                | 0.88                     | 0.92                             | 0.92-1.18        | 1.3-0.67         | 0.7      |
| Carotene, mg                 | 98±5.5                   | 56±2.3                           | 28-50            | 32-66            | 29-96    |

Chemical composition of the feed, %

| Components                  | Clones of P. trichocarpa | The grass from floodplain meadows | Alfalfa (Lucerne) |
|-----------------------------|--------------------------|----------------------------------|------------------|
| Water                       | no data                  | no data                          | 53-58            | 71.15            | no data  |
| Crude protein               | 29.6a                    | 29.6a                            | 3.7-4.1          | 2.1-3.9          | 5.00-5.39 |
| Crude fat                   | 4.9a                     | 4.4a                             | 1.70-1.87        | 1.00-1.06        | 0.70-0.88 |
| Crude fiber                 | 14.5a                    | 17.6a                            | 7.22-9.44        | 8.6-9.47         | 5.98-6.80 |
| Nitrogen-free extractive substances | 53.3a                    | 54.9a                            | 7.22-9.44        | 13.21-15.0       | 9.48-10.0 |
| Ash                         | 9.4a                     | 11.0a                            | 5.2-7.0          | 2.12             | no data  |

*Content in 1 kg at completely dry state.

Swedish scientists in their phenological studies of P. trichocarpa believe that this indicates increased winter hardiness of this poplar, and accordingly, it can be used in plantings of northern latitudes [8,9,28]. The high survival of P. trichocarpa clones by the age of economic exploitability showed that this
introduced species has significant winter hardiness in the studied region. Such results were obtained also in Sweden [9,29] and in controlled growth chamber test [30]. As for the wood stocks of the compared poplars by the age of economic exploitability, it should be noted that the average stock of all clones of *P. trichocarpa* differed from the average stock of other poplars by a small amount (10.5%). At the same time, it significantly (by more than 55%) exceeded the stock of local balsamic poplar, which was planted at the populetum as a control.

In general, the study of *P. trichocarpa*, especially the clone inv. No 83, showed that it is a promising species for use in the bioenergy plantations. Thus, clone No. 83 showed an average increment in the age of economic exploitability exceeded the average increments of other balsamic poplars by 29%, and exceeded the control clone ‘Xc’ by 81.8%. The importance of poplars for bioenergy production has been repeatedly noted in various international publications [9,31,32]. The plantations with a short cutting cycle in short rotation coppices are of particular interest [33,34]. And the programs for obtaining wood biomass of poplars at a young age, as it practiced in Germany and other countries, had an advantage [35-37]. A detailed review of the achievements in the genetics and breeding of poplars in Germany in 2016-2019 presented by Mirko Liesebach [38] shows that the creation of new genotypes and the identification of the most promising among them is an important area of research.

In our work the importance of these areas was confirmed, which made it possible to select the most winter-hardy poplars for the studied region. In this regard the study of *P. trichocarpa* in the harsh conditions of Russia is practically an important and promising area of work. In addition, studies conducted in the Central Chernozem region of the forage value of tree greens show the possibility of having a certain reserve of feed in dry climatic periods. The woody greens of poplars are often used as animal feed not only in our country, but also abroad. For example we can mark the use of poplar greens for sheep and cattle feed in New Zealand, Turkey, and other countries [39,40].

Comparison of the data in table 3 and data obtained in other studies showed that the feed value of fresh leaves of *P. trichocarpa* clones is comparable to the feed value of grass from flood meadows, as well as to the feed value of alfalfa. For example, the content of feed units in 1 kg of leaves at natural moisture ranged from 0.22 to 0.28 feed units (f.u.), and in 1 kg of grass from flood meadows 0.21-0.26 f.u., and in 1 kg of alfalfa 0.17-0.22 f.u. Similar results were observed for the other ingredients of nutritional value. Given in attention the high winter hardness of the black cottonwood, it can be used in interspecific hybridization with less winter-hardy euramerican hybrids and some introduced black poplars. The positive experience of such hybridization was first demonstrated by A Henry in 1912 in the UK, when he managed to synthesize × *P. generosa* Henry (*P. trichocarpa* Hooker × *P. angulata* Ait.) [10]. Subsequently, this possibility was noted by Dickmann D [41] and Stanton B [42]. This gives confidence in the need to continue such experiments.

5. Conclusion

Studies of *P. trichocarpa* poplars allow to make the following conclusion:

1) In the Central forest-steppe this poplar was distinguished by its growth energy, especially at a young age as evidenced by the increased yield of standard cuttings.

2) By the age of economic exploitability the following clones of *P. trichocarpa* showed the best results in growth and productivity: No. 45, No. 83, No. 84 and No. 110. Their wood stock by the age of economic exploitability was 280-400 m³/ha, and the average increment was 11.2-16.0 m³/ha per year.

3) The feed value of the leaves of *P. trichocarpa* is comparable to the feed value of alfalfa and grass from flood meadows. Therefore they can be used as animal feed.

4) Given in attention that at young age *P. trichocarpa* has rapid growth and high winter hardness, it has great opportunities for short-rotation cultivation, when in a short time per unit area you can get significant reserves of both woody biomasses for energy and forage greens.

5) Clones of *P. trichocarpa* can be used in hybridization with black poplars to increase their winter hardiness, especially with euramerican cultivars both in Russia and abroad.
6) The obtained results could be the basis for the selection of both winter-hardy and fast-growing clones for multi-purpose poplar plantations grown in cool-temperate, high-latitude climatic conditions characteristic of a large part of Northern Europe and America as well as in the highlands of Asia.

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