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CULTIVATION OF HIGH-QUALITY PLANTING MATERIAL OF *POPULUS* TREES FOR DECARBONIZATION OF TERRITORIES OF THE FOREST-STEPPE REGION OF THE EUROPEAN PART OF RUSSIA

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Abstract

Fast-growing forest plantations is a profitable and economically rational method of mitigating the effects of atmospheric pollution. Soft–wooded broad-leaved species, which are the most typical for the local forests absorb the largest amount of carbon stock per year - 4930.2 thousand tons/year. The leading trees are old-growth trees and *Populus* trees (they absorb up to 3.6 tons of CO_2 per year in terms of 1 ha). Experiments on the *Populus* tree cultivation *(Populus nigra* L. × *Populus nigra* var. *italica* Du Roi, *Populus simonii f. fastigiata Schneid* and *Populus koreana* Rehder*)* determined that the best rooting of cuttings occurred in a sandy substrate, which is quite natural and meets the physiological characteristics of poplars growing in natural floodplain forests. During the experiment in a sandy substrate, the survival rate of cuttings of *Populus nigra* L. × *Populus nigra* var. *italica* Du Roi when treated with heteroauxin was 95.8% and 115%, respectively, compared to the control. At the end of the growing season (September), the conservation index of all poplar types grown in a sandy substrate and on the open ground, and treated with heteroauxin, exceeded the control by 15-44%. Heteroauxin increased the chlorophyll content in the leaves of shoots and hastened the root elongation. Thus, poplar roots were longer than the control and reached 19.98 cm. Even if the lamina of the shoots of *Populus* L. × *Populus nigra* var. *italica* Du Roi was smaller, the number of leaves growing during the maximum growth was bigger (24 ± 0.84 pcs.) compared to *Populus simonii f. fastigiata* Schneid. (16.3± 0.59 pcs.) and *Populus koreana* Rehder (14.5± 0.65 pcs.). A well-developed rooting system of these trees determines their survival rate and adaptation to different environments. Since *Populus* trees absorb carbon very well, root by stem cuttings, and grow fast, they can be considered as fast-growing plantation of woody plants to decarbonize territories.

Key words: Carbon sequestration, Heteroauxin, Survival rate, Chlorophyll, Adventitious roots.

Introduction

Raihan & Said (2022) consider greenhouse gas emissions with a predominance of carbon dioxide CO_2 is a serious problem for natural ecosystems leading to negative consequences like global climate change, increase greenhouse effect.

One of the topical issues of natural resource use in the field of forestry is the management of carbon streams to reduce emissions, increase sequestration, and redistribute these components within the available time and space (Akimbekov *et al.,* 2023; Mack *et al.,* 2021).

According to Dumitrașcu *et al*., (2020), Zhu *et al*., (2020), forests, which actively absorb CO_2 from the atmosphere and retain it in the aboveground biomass, play an important role in mitigating the negative effects of carbon dioxide emissions. Besar *et al*., (2020) consider carbon sequestration by trees as one of the main functions of forest ecosystems.

The formation of forest plantations is a more profitable and economically rational method of mitigating the effects of climate change in many countries, compared to increasing energy efficiency and switching to other fuels, renewable energy production and other approaches to CO_2 sequestration and emission storage (Raihan *et al*., 2019, Raihan *et al*., 2021, Raihan & Said, 2022).

Sustainable forestry management, forest protection, afforestation, reforestation, and the creation of plantations of fast-growing trees are of key importance in decarbonization of territories and maintenance of the normal CO_2 level (Raihan *et al.,* 2018).

In the conditions of growing demand for wood, breeding of fast-growing stress-resistant genotypes of trees as a means of increasing productivity and sustainability of forests is becoming more relevant (Gömöry *et al.*, 2021). Abiotic stress adaptation is crucial for the woody plants survival. Poplar is a buffer tree crop, which increases the absorption of atmospheric pollutants, contributes to the decomposition of organic compounds, reduces the risk of soil erosion and leaching (Minogue *et al.,* 2012).

Besides, the issues of development, cultivation and prospects of using of *Populus* for improving the environment remain relevant. Regardless of the fact that poplar has significant genetic potential of species, forms, breeding varieties and hybrids (Tsarev & Mashkin, 1985), the mechanisms for the creation of fast-growing plantations have not been fully understood (Druege *et al*., 2016; Maikanov *et al*., 2020a, 2020b). The features of reproduction of individual poplar species, including *Populus nigra* L.× *Populus nigra* var., *italica* Du Roi, *Populus simonii f. fastigiata* Schneider, *Populus koreana* Rehder in different soil conditions (sand, vermiculite, gray forest soil) have not been considered.

Populus nigra L. × *Populus nigra* var. *italica* Du Roi is one of the most beautiful and resistant to the northern climate poplars. The variety is usually called Bashkir Lombardy Poplar, since it was bred in the Republic of Bashkortostan by Berezin (1993). Breeding works were being carried out from 1934 to 1940. The crossing included 79 inter-specific combinations, involving 19 poplar species and forms. As a result, 80,650 saplings were obtained during seven years. The breeder selected more than 160 hybrid saplings from various crossing combinations as elite candidates and numbered them. In the autumn of 1940, 21 hybrids were included in the elite study population according to the results of Berezin (1993) assessment. The hybrid *Populus nigra* L. × *Populus nigra* var. *italica* Du Roi is listed in the State Register of Russia as Berezin poplar (Putenikhin, 2006). It has been actively used in urban plantings of the Southern Urals since 1970s (Blonskaya *et al.*, 2019). Its morphological features are close to *Populus nigra* L. However, *Populus nigra* L. × *Populus nigra* var. *italica* Du Roi is poorly propagated by stem cuttings (Putenikhin, 2006). In this regard, this hybrid poplar was chosen as one of the subjects of research on the rooting ability of stem cuttings.

Research purpose: The purpose of the study is to find conditions for the cultivation of high-quality planting material of Populus tree species for decarbonization of territories.

The research tasks involve the assessment of carbon deposition by the main forest-forming species growing in the forest area of the region, including Populus tree species, and the study of the rooting ability of Populus stem cuttings to accelerate the cultivation of high-quality planting material in various substrates.

Material and Methods

Methods for estimation of carbon sequestration: The object of research is fast-growing dioecious woody plants of the *Salicaceae* family of the Populus genus – *Populus nigra* L. × *Populus nigra* var. *italica* Du Roi, *Populus simonii f. fastigiata* Schneider, *Populus koreana* Rehder, growing on the territory of the Forest-steppe region of the European part of Russia, in the conditions of the industrial landscape of Ufa city with a large number of industrial enterprises, in harsh winters and hot summers. Location of the study site was on the territory of the Pilot Carboniferous Polygon (Dmitrievskoye district forestry of Ufa forestry, coordinates: 54.762°, 55.712°).

The calculation of carbon absorption was carried out using the method approved by Order of the Ministry of Natural Resources of Russia from 27.05.2022 N371 "On approval of methods for quantitative determination of greenhouse gas emissions and greenhouse gas removals" (Registered in the Ministry of Justice of Russia on 29.07.2022 N 69451). The calculation involved time intervals of age groups of plantings with reference to predominant tree species (Table 1).

Experiments using cuttings of *Populus* trees were being carried out for two years in various substrates – in sand, in vermiculite and on the open ground. Cuttings of 20 cm length and a diameter of 0.5-0.8 cm were harvested in February and March, and stored in the refrigerator before planting. Before planting, the cuttings were soaked in 0.1% (1 mg/ l) solution of heteroauxine (indole-3-acetic acid, IAC) for a day (Fig. 1).

Water was used as a control variant. Experiments in sand were carried out inside greenhouses using standard vegetation vessels filled with washed river sand. Experiments in vermiculite used a mineral of the hydroslude group of a subclass of layered silicates (Mg^{+2}, Fe^{+2}, Fe^{+3}) $_3$·$(OH)_2$·$4H_2O$, and golden-yellow or brown scale aggregates, or more rarely crystals. Vermiculite has a cellular structure filled with air, is highly inactive to fungal and bacterial infections. It can retain water well without rotting of cuttings. After soaking, the cuttings were planted in a greenhouse with vermiculite according to the scheme - 24 plants of each variant of the experiment on a 0.1 x 0.1 m plot (control and heteroauxin).

Experiments on the open ground were carried out in the nursery of the Dmitrievsky forest division of the Ufa forestry, in gray forest soils and carbonate-free clays. Cuttings obtained from the mother plantation of the nursery were planted into 12 experimental sites according to the scheme 100 pcs per 0.1 × 0.1 m. In the second season, the rooted cuttings were replanted into the school nursery section according to the scheme 18-30 pieces per 1.0 ×1.0 m. The order of the 12 test sites did not change.

The length of the stem from its first joint was taken as the basis for measuring the shoot. The measurements were made using a ruler with an accuracy of 1 mm. The distance from the middle of one node to the middle of the other one was measured. Thus, the internode distance of every second plant was measured. The number of internodes of every second plant was calculated at the end of the growing season after digging. The diameter of the stem reflecting its secondary thickening was measured using a caliper with an accuracy of 0.1 mm. The measurements were made in the middle of the selected internode (Fig. 2).

Table 1. Conversion rates (according to the Ministry of Natural Resources of the Russian Federation, 2022).

Dominant species	Age group			
	Young stand	Middle-aged stand	Ripening stand	Mature and overmature stands
Pinus sylvestris	0.435	0.352	0.329	0.356
Picea abies	0.614	0.369	0.351	0.364
Abies sibirica	0.420	0.308	0.283	0.270
Larix sibirica	0.392	0.371	0.398	0.398
Pinus sibirica	0.392	0.341	0.319	0.450
Quercus robur (seemnest)	0.616	0.491	0.418	0.478
Quercus robur (from vegetative shoots)	0.796	0.541	0.563	0.637
Other hard-leaved trees	0.624	0.477	0.388	0.436
Betula pendula	0.437	0.396	0.367	0.367
Populus tremula, *Populus alba*	0.356	0.363	0.335	0.365
Other soft-leaved trees	0.381	0.336	0.334	0.337

Fig. 1. Cuttings of *Populus* trees (before planting and watering in an open ground).

Fig. 2. First-year cuttings of *Populus* trees rooted in the open ground.

To determine the chlorophyll content, a month later after planting, the leaves from poplar saplings were taken in different directions of the petioles. The optical density of the acetone extract of leaf samples measured with a volume of 0.1 g in 3 replicates from the entire crushed foliage mass was measured using the SF-26 spectrophotometer in optical units. The chlorophyll content was calculated using the formula:

$$A = (D_{665} – (D_{680} + D_{630}):2)/N \quad (1)$$

where A is the chlorophyll content in optical units; $D_{665,680,630}$ is the optical density of the acetone extract at a given wavelength; N is the weight of the sample.

At the end of September, after the plants had been digged up, the weight of the shoot was determined in the ½ part of the plants using a 500 g-M Analytical Balance. All other parts of plants were cut off with a blade, the shoots were dried in an HSPT-200 dryer at a temperature of 105°C. The mass of the root system was determined using an electric scale, after drying the roots in a drier, at a temperature of 105°C, with an accuracy of 0.1 g.

Statistical analysis: The research involved using the methods of correlation and regression analysis and software products Statistica 6, Statgraphics Plus 5.0. The hypothesis of the equality of averages with unknown variances was considered. The comparison of the difference significance of the averages was carried out using the Student's criterion.

Results

Assessment of the main forest-forming species ability to absorb carbon: The effectiveness of forests in stabilising the environment is determined by the ability of forest ecosystems to absorb carbon (CO_2). Special attention was paid to the study of the carbon-absorbing ability of individual tree species. On average, forests of the Republic of Bashkortostan absorb 3,618.9 thousand tons of carbon to 3,902.7 thousand tons of carbon per year^{-1} (Table 1). When forest areas are reduced due to cuttings or fires, entomo- or phyto-insects, the losses of CO_2 range from -537.5 thousand tons to -755.2 thousand tons per year^{-1}. Absorption of carbon by forests exceeds its losses, which is shown by carbon budget ranging from 3,124.4 thousand tons to 3365.2 thousand tons per year^{-1}. However, since 2008, carbon absorption has been decreased due to the increase in the area of overgrown forests, more frequent forest fires, diseases and cuttings (Table 2).

Table 2. Carbon balance in the forests of the Republic of Bashkortostan.

Indicator	The value of CO_2, tons per year-1	
	2008	2018
Absorption, thousand tons of carbon per year^{-1}		
Aboveground biomass of a stand	3,032.2	2,763
Dead wood	506.8	468
Forest litter	82.5	87.9
Soil	281.3	300.2
Total absorption	3,902.7	3,618.9
Loss of carbon, thousand tons per year		
Destructive forest fires	-20.9	-18.9
Entomo- and phyto-insects	-5.1	--15,6
Cuttings	-511.5	-720.7
Total losses	-537.5	-755.2
Carbon budget, thousand tons per year		
Aboveground biomass of a stand	263.9	2,475.2
Dead wood	427.3	354
Forest litter	68.8	68.3
Soil	230.1	227
Total carbon budget	3,365.2	3,124.4

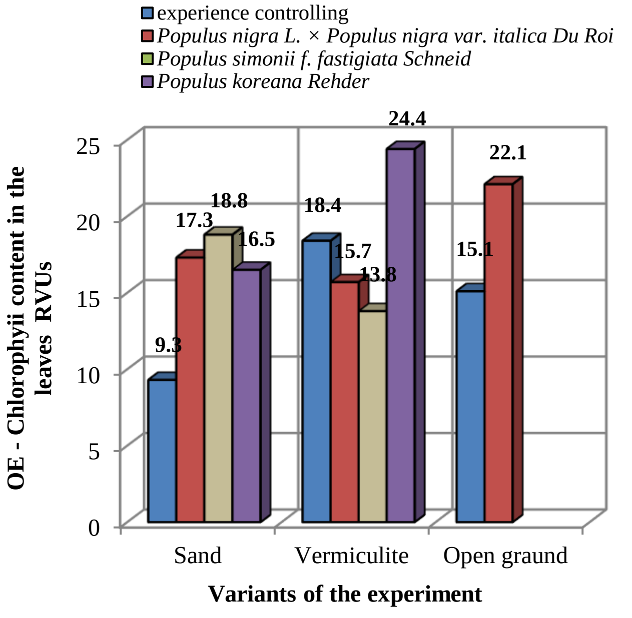

Fig. 3. Chlorophyll content in the leaves of the shoots of rooted cuttings of *Populus nigra* L. × *Populus nigra* var. *italica* Du Roi. *Populus simonii* f. *fastigiata* Schneid. *Populus koreana* Rehder.

Soft-wooded broadleaved trees prevailing in the forests of the republic absorb the largest total carbon stock – 4,930.2 thousand tons/year. However, the leaders by carbon absorption among tree species are old-growth *Populus* trees, which absorb 2.22 thousand tons/ha of carbon per year. This indicator is significantly lower for other species (Table 3).

Cultivation of planting material for carbon farms using the cuttings *Populus* trees: Strengthening and survival of plants, their adaptation to different environments are important, and depend on how good is their rooting system. In this regard, the survival and preservation of *Populus* species in various substrates was considered. In the sand, the survival rate of cuttings of *Populus nigra* L. × *Populus nigra* var. *italica* Du Roi , during treatment with heteroauxin (HA) was 95.8% or 115%, relative to the control (C). The preservation index at the end of the growing season (September) of all poplar species planted in a sandy substrate and on the open ground, when treated with heteroauxin, exceeds the control by 15-44% (Tables 4).

The final September accounting showed that the preservation of *Populus nigra* L. plants × *Populus nigra* var. *italica* Du Roi trees treated with heteroauxin was 95.8% (120% against the control). The survival rate and preservation of the cuttings of *Populus koreana* Rehder trees treated with heteroauxin a month after planting, by the end of June, was the highest - all the cuttings produced roots, which were 20% more than in the control. The treatment with heteroauxin increased the preservation of *Populus koreana* Rehder trees by the end of the growing season, by 22% compared to the control. The rooting of cuttings contributes to the cultivation of a sound planting material (saplings). At the same time, the harmonious development of the entire plant is essential. The indicators of the aboveground part of the rooted cuttings of different experimental variants do not change significantly.

The average number of shoots ranged from 1.09 to 1.37. There was no significant difference in the variants of the experiment. The shoots' length reached a maximum by the end of the growing season and did not significantly differ in the variants of the experiment. The plants treated with heteroauxin had the best size indicators. The average diameter of plants treated with heteroauxin was slightly higher than the control. The ability to produce adventitious roots is an important factor in clonal propagation. From the ecological point of view, it provides a selective advantage for woody plants with this type of reproduction (Table 5).

The number of second-order roots and the length of the main roots in all variants did not exceed the control. The length of the main roots in all variants of the experiment was approximately the same. However, when plants treated with heteroauxin, the length of the main roots was slightly higher than in the control (19.98 cm).

The number of leaves and their morphometric indicators did not differ much according to the variants of the experiment. However, they differed significantly depending on the poplar type (Table 6).

While the leaves of the shoots of *Populus nigra* L. × *Populus nigra* var. *italica* Du Roi had the smallest blades, there were more leaves growing on them during the period of the maximum growth (24± 0.84 pcs.) compared to *Populus simonii* f. *fastigiata* Schneid. (16.3±0.59 pcs.) and *Populus koreana* Rehder (14.5±0.65 pcs.). Assessment of chlorophyll content in leaves using a spectrophotometric method is a reliable way to determine the impact of environmental factors on a plant. The chlorophyll content of leaves of the shoots of rooted poplar cuttings varies depending on the variant of the experiment (Fig. 3). In the experiment with sand, when treating the cuttings of *Populus nigra* L. × *Populus nigra* var. *italica* Du Roi with heteroauxin, the content of chlorophyll in leaves is 17.3 RVUs (185.9% against the control).

The chlorophyll content in the leaves of *Populus koreana* Rehder treated with heteroauxin is 16.48 RVUs (133.9% against the control). During the experiment with vermiculite, there was an increase in chlorophyll content in the leaves of *Populus koreana* Rehder compared to the control and other poplar species. On the open ground, the content of chlorophyll in the leaves of *Populus nigra* L. × *Populus nigra* var. *italica* Du Roi when using hegeroauxin is higher by 7 RVUs than in the control.

When using heteroauxin in experiments, the quantitative and qualitative parameters of the above ground part of plants, the weight of the root system, the number of the main roots and the roots of the second order slightly differed from the indicators of the control variant of the experiment. The height and the thickness of the rooted shoots of the plants treated with heteroauxin decrease. However, preliminary soaking of the cuttings in heteroauxin increased their survival and preservation. Besides, the content of chlorophyll in the leaves of the shoots of the rooted cuttings of *Populus nigra* L. × *Populus nigra* var. *italica* Du Roi, *Populus simonii* f. *fastigiata* Schneid and *Populus koreana* Rehder also increased.

Table 3. Absorption of CO_2 by forest stands of the Republic of Bashkortostan according to age groups and tree species, t per 1 ha per year.

Age groups*	Coniferous trees Scientific names				Total
	Pinus sylvestris	*Picea abies*	*Abies sibirica*	*Larix sibirica*	
I	1.700	1.220	1.020	1.540	1.290
II	970	660	490	560	560
III	170	140	50	200	140
IV, V	950	1.190	600	520	810
Total	950	800	540	700	710
Age groups*	**Hard - wooded broadleaved trees**			**Total**	
	Quercus robur **(seemnest)**	***Quercus robur*** **(from vegetative shoots)**	***Ulmus scabra, Ácer platanoídes, Fraxinus excelsior***		
I	1.340	1.800	1.010	1.390	
II	170	1.130	270	520	
III	200	550	80	280	
IV, V	760	2.220	740	1.250	
Total	660	630	640	640	
Age groups*	**Soft – wooded broadleaved trees**			**Total**	
	Betula pendula	***Populus tremula, Populus alba***	***Alnus glutinosa, Tilia cordata, Salix***		
I	1.380	1.380	1.540	1.430	
II	1.030	1.120	1.020	1.060	
III	140	810	440	460	
IV, V	1.490	2.221	1.940	1.880	
Total	1.010	1.380	1.230	1.210	

*Note: The age groups are shown in Table 1

Table 4. Survival rate and preservation of rooted poplar cuttings according to experiment options.

Chemical	Survival rate, %		Preservation, %							
	May	% Against the control	June	% Against the control	July	% Against the control	August	% To the control	September	% Against the control
An experiment variant planted in the sand										
Populus nigra **L. ×** ***Populus nigra*** **var.** ***italica*** **Du Roi**										
H_2O(C)	83.3	100	83.3	100	83.3	100	79.2	100	79.2	100
Heteroauxin	95.8	115	95.8	115	95.8	115	83.3	105	95.8	120
Populus koreana **Rehder**										
H_2O(C)	83.3	100	83.3	100	83.3	100	79.2	100	75	100
Heteroauxin	100	120	100	120	95.8	115	91.7	116	91.7	122
Populus simonii f. fastigiata **Schneid**										
H_2O(C)	83.3	100	83.3	100	83.3	100	83.3	100	83.3	100
Heteroauxin	95.8	115	95.8	115	95.8	115	95.8	115	95.8	115
An experiment variant planted in vermiculite										
Populus nigra **L. ×** ***Populus nigra*** **var.** ***italica*** **Du Roi**										
H_2O(C)	79.2	100	75	83.3	75	100	75	100	-	-
Heteroauxin	100	126.3	87.5	116.7	75	100	75	100	-	-
Populus koreana **Rehder**										
H_2O(C)	95.8	100	95.8	100	95.8	100	95.8	100	-	-
Heteroauxin	91.7	95,7	91.7	95,7	91.7	95,7	91.7	95,7	-	-
Populus simonii **f.** ***fastigiata*** **Schneid**										
H_2O(C)	95.8	100	100	100	95.8	100	91.6	100	-	-
Heteroauxin	87.5	91.3	87.5	87.5	87.5	91.3	87.5	95.5	-	-
An experiment variant planted on the open ground										
Populus nigra **L. ×** ***Populus nigra*** **var.** ***italica*** **Du Roi (1st year/2nd year)**										
H_2O(C)	-	-	53	100	34	100	45	100	44/43	100
Heteroauxin	-	-	49	92.5	66	194	40	89	52/66	118/144

Table 5. Average growth indices of the root system of rooted poplar cuttings at the end of the growing season.

Chemical	*Populus nigra* L. × *Populus nigra* var. *italica* Du Roi			*Populus koreana* Rehder			*Populus simonii* f. *fastigiata* Schneid		
	Number of roots (pcs)		Root system weight (g)	Number of roots (pcs)		Root system weight (kg)	Number of roots (pcs)		Root system weight (g)
	Main roots	Second-order roots		Main roots	Second-order roots		Main roots	Second-order roots	
Experiment in sand									
H_2O(C)	20.1 ± 0.96	17.1 ± 2.28	0.71 ± 0.06	10.8 ± 1.22	22.4 ± 3.17	0.67 ± 0.1	16.1 ± 1.39	9.0 ± 0.82	0.30 ± 0.03
Heteroauxin	19.36 + 1.0	17.5 ± 1.74	0.38 ± 0.05	11.8 ± 1.25	10.11 ± 1.39	0.23 ± 0.02	16.2 ± 1.04	22.55 ± 3.3	0,30 ± 0.04
Experiment in vermiculite									
H_2O(C)	17.6 ± 1.8	17.8 ± 1.49	0.67 ± 0.08	18.79 ± 1.6	15.83 ± 1.2	0.84 ± 0.02	19 ± 1.5	20.3 ± 2.1	0.50 ± 0.08
Heteroauxin	16.46 ± 1.8	20.4 ± 2.27	1.03 ± 0.01	17.0 ± 1.6	16.6 ± 1.2	0.65 ± 0.09	17 ± 1.9	21.9 ± 2.1	0.49 ± 0.08
Experiment on the open ground									
H_2O(C)	15.4 ± 1.8	10.1 ± 1.98	0.68 ± 0.006	-	-	-	-	-	-
Heteroauxin	15.0 ± 0.9	9.6 ± 1.65	0.64 ± 0.012	-	-	-	-	-	-

Table 6. Morphometric parameters of shoots' leaf blades.

Chemical	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)	Petiole length (cm)	Leaf weight (g)
***Populus nigra* L. × *Populus nigra* var. *italica* Du Roi**					
H_2O(C)	4.04 ± 0.12	3.54 ± 0.13	10.8 ± 0.6	2.05 ± 0.08	0.76 ± 0.09
Heteroauxin	3.99 ± 0.08	3.61 ± 0.1	8.08 ± 0.39	2.02 ± 0.06	0.53 ± 0.15
***Populus simonii* f. *fastigiata* Schneid**					
H_2O(C)	5.76 ± 0.09	3.51 ± 0.08	11.8 ± 0.4	0.49 ± 0.02	0.13 ± 0.01
Heteroauxin	6.07 ± 0.1	3.67 ± 0.07	13.13 ± 0.47	0.54 ± 0.01	0.09 ± 0.01
***Populus koreana* Rehder**					
H_2O(C)	7.87 ± 0.34	3.37 ± 0.16	19.6 ± 1.06	1.01 ± 0.06	0.48 ± 0.12
Heteroauxin	6.45 ± 0.35	2.58 ± 0.15	12.3 ± 1.1	1.28 ± 0.09	0.24 ± 0.03

Discussion

Afforestation is one of the most effective ways to slow down the effects of the climate change (Updegraff *et al*., 2004). The potential of carbon sequestration of the arable land in Europe can reach 7.29 t/ha^{-1} $year^{-1}$if forest plantations are created nearby. Maximizing the carbon potential in agricultural forestry and participating in carbon programs can reward agricultural producers with genuine carbon credits that are sold to organizations seeking to offset their emissions (Bertsch-Hoermann *et al*., 2021).

Woody plants accumulate up to 60% of the terrestrial carbon. Its content in various parts of a tree is up to 45-50% (Rizvi *et al*., 2011).

The ecological importance of *Populus* trees, their ability to absorb $CO_{2,}$ identified during this research in the forests of the Southern Urals agreed with earlier studies. Bannoud & Bellini (2021) consider *Populus* trees to be one of the most economically advantageous species worldwide.

Research on poplar trees is under way in different directions. Poplar gave a good showing during Cd phyto-extraction in moderately polluted soils. However, in heavily polluted soils, it can only be considered as a phyto-stabilizer (Redovniković *et al.,* 2017). Some studies consider the global impact of hybrid poplars on the environment, since this species is economically and environmentally attractive for the production of biomass with short rotation (Schweier *et al*., 2017). Liu *et al*., (2019) in their studies examined plant reactions to salt reagents illustrating the phenotypic adaptation of Populus trees to salt stress. There are studies on morphological and physiological parameters of saplings of aspen hybrids in vitro which showed that the productivity of saplings depended on the intensity of light treatments (Kondratovičs *et al.*, 2022).

The trees of this species are used as a source of wood raw materials and fiber, and in plantings that perform environmental and protective functions. Thomas *et al*., (2021) evaluated the productivity of the plantations of fast-growing *Populus nigra* × *P. deltoides* and *Alnus glutinosa* trees as a way to meet the growing demand for wood biomass necessary for renewable energy sources in Europe. Tullus *et al*., (2012) emphasized that the hybrid aspen (*Populus tremula* L. x *Populus tremuloides* Michx.) was one of the fastest growing broadleaved species with a large woody biomass. It has become an economically valuable broadleaved wood in Northern Europe. Kim *et al*., (2021) revealed in their studies on the prediction of the growth and productivity of *Populus alba* x *Populus glandulosa* "Clivus" and *Populus euramericana* in the environment with an increased content of CO_2 that the content of carbohydrates, including starch and total soluble sugar in *poplar* trees, significantly increased with an increase of CO_2.

Wang *et al*., (2020) suggested that in future climatic scenarios, the center of species diversity of *Populus* tended to expand to the northeast and northwest. The high environmental adaptability and strong cold resistance of Populus simonii x P. nigra is important for the geographical distribution and survival of these trees in extreme seasonal climate conditions (Zhou *et al.*, 2019). In China, cloned poplars are used for large-scale cheap production of wood on plantations with a short turnover. This is facilitated by the high growth rates of Populus hybrids (Yu *et al.*, 2022). Particular attention is paid to the plantation growth of poplar hybrids, and to the study of the root systems (Zhu *et al.*, 2018; Bannoud & Bellini, 2021). Since poplar stem cuttings can form adventitious roots, which is very important for the rooting and survival of these trees, their ability to propagate clonally is widely used in forestry practice. Adventitious rooting in various *Populus* species has been the main feature of their use in breeding programs for many years. Thus, many factors affecting the poplar trees growth have been identified.

Adventitious roots play an important ecological role. They contribute to the survival of plants exposed to biotic and abiotic stresses (Steffens & Rasmussen, 2016), the dynamics of plant populations (Kinsman, 1990), increase the efficiency of phytoextraction of contaminated soils (Low *et al.*, 2011). Moreover, a strong root system is necessary to ensure the wind resistance of plantings (Ronald *et al*., 2009).

Polish scientist Stobrawa (2014), in his work, gives results in improving cultivation methods, introducing many new hybrids with desired characteristics.

It was found that various *Populus* species differed significantly in their ability to take roots (Bannoud & Bellini, 2021). *Populus nigra* L. × *Populus nigra* var. *italica* Du Roi, *Populus simonii* f. *fastigiata* Schneider, *Populus koreana* Rehder belong to plants, which take roots hard. The experiments on the vegetative propagation of these species described in this paper prove the differences between them, too.

Conclusions

The formation of fast-growing forest plantations is a profitable and economically rational method of mitigating the effects of man-made atmospheric pollution. Poplar trees have an absolute priority in the creation of these specialized plantations among woody plants. They are characterized by a high ability to absorb carbon. The rapid growth of poplars and their large biomass make it possible to create plantations and forest crops with short rotation especially in unused agricultural forest landscapes with rich soils that allow intensive deposition of atmospheric carbon in the aboveground and underground biomass of woody plants (Singh & Gill, 2014).

Best rooting of cuttings occurs in a sandy substrate, which is quite natural and meets the physiological characteristics of poplars growing in natural floodplain forests. Heteroauxin increased the chlorophyll content in the leaves of shoots and hastened the root elongation. A well-developed rooting system of these trees determines their survival rate and adaptation to different environments.

In addition, preservation of poplar trees, their survival rate and growth improved when processing the tree cuttings with heteroauxin. Since *Populus* trees absorb carbon very well, root by stem cuttings, and grow fast, they can be considered as woody plants used for the creation of fast-growing plantations to decarbonize territories.

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