Introduced poplar varieties and new hybrids for protective afforestation

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Abstract. The volume of actual protective forest stands in the Central Chernozem Region is presented, and the need for their additional creation is shown. It is noted that in recent years, side by side with the main forest tree species competitive cultivars of euramerican poplars varieties and some new hybrids obtained by domestic breeding have been introduced in the forest shelter belts and protective stands, which in the reclamation fund of the Voronezh region reached a height of 15 m at 20 years, 25 m at 30 years and 30 m at 42 years. After many years of testing in various soil and climatic environments of the region the selection of promising poplars varieties, hybrids and clones for protective afforestation was carried out. The following euramerican cultivars have been recommended: ‘Vernirubens’, ‘Robusta’, ‘Regenerata’, ‘Sacrau-59’ etc. From domestic hybrids ‘Pioneer’ and ‘E.s.-38’ (Elite seedling No. 38) can be recommended, which grow well in the floodplain conditions in dry steppe zone in Volgograd region. At 30 years, they reached a height of 24-25 m; and diameter – 28-31 cm. For comparison, similar growth indices (height about 20 m, diameter – 28-30 cm) oak shelter forest plantations in Kamennaya Steppe reached only by the age of 75 years.

1. Introduction

Western researchers (J Isebrands, J Kort, W Schroeder et al [1, 2] attribute the origins of the use of poplars for the purpose of protecting human habitat to the end of the third Millennium BC in the Sumero-Akkadian Kingdom of southern Mesopotamia. By the beginning of AD in North America, poplars were used to stabilize riverbanks, and in the early Chinese dynasties – to create favorable conditions for urban residents. Also, early urban settlers in Europe and North America began using poplars along with other species to create shelterbelts to protect crops and aesthetic purposes.

In the XX⁰ century, the main direction of poplar plantations was the production of wood and fiber for the needs of the pulp and paper industry. In the late twentieth and early twenty first centuries, the goals of poplar planting shifted towards environmental use, including watershed and nutrient management, CO₂ deposition, waste management, biodiversity, animal habitat, and so on. To date, these and similar public goods are vital for human health and life [1]. The history of creating shelterbelts goes back to early agricultural settlements. Equally early is the use of poplars and willows as part of these shelterbelts. American researchers date the beginning of the first systematic planting of
shelterbelts to protect agricultural fields in 1789, conducted by German immigrants in the Russian steppes. The term ‘shelterbelt’ confidently entered the lexicon of agronomists in 1833, and since then thousands of kilometers of shelterbelts have been planted around the world. Currently, poplars and willows are widely used in shelterbelts in steppe and forest-steppe regions, states and provinces of Canada, the United States, Northern China and throughout the world’s temperate regions [1, 2].

J Kort and W Schroeder note that tall, widely spaced-poplars lead to the formation of porous windbreaks with a large distance even of wind protection across the field. As deciduous trees, poplars have greater porosity in winter than in summer, with more than 70% of the wind reduction being achieved by foliated poplar windbreak compared to 25% in leafless condition [2].

The Central Chernozem Region is insufficient of moisture, strongly divided by ravines and gullies, and characterized by a high level of intensive use. Arable lands in the region occupy 80-85%. The steppe and forest-steppe regions of the Central Black Earth region have generous Chernozem soils. However droughts, hot winds, and water erosion cause great damage to nature and agriculture. Over the past 100 years, the humus content in Chernozem soils has decreased by 30-40%. The region is highly eroded. Only in the Voronezh region there are more than 4 thousand ravines [3]. In addition, fires, industrial emissions, vehicle exhaust gases, open methods of mining iron ore, radiation pollution after accidents at nuclear power plants, and other negative phenomena cause huge damage to nature.

Protective forest stands play a great role in clearing the air from increasing anthropogenic influence factors. Kh Dzhuvelikyan notes that 1 ha of green forest stands can absorb 400 kg of SO₂, 40 kg of Fe, 180 kg of NO₂, 100 kg of Cl and other harmful substances during the growing season. Shelter belts created along highways serve as a barrier against exhaust gases. Even a 2-row shelter belt with shrubs 1.5 m high can reduce the lead concentration by 65% [4].

Russia is the birthplace of protective afforestation with more than 150 years of history [5]. Protective forest stands have a multi-functional impact on the environment. They normalize and stabilize the ecological situation, form stable, revived or fundamentally new agro-forest landscapes with a high degree of self-regulation. At the same time, the positive impact of planted forest systems increases as the area occupied by them increases. And in severe conditions of insufficient moisture forest reclamation becomes the basis for creating sustainable agricultural landscapes [6].

Based on this, protective afforestation should be considered as an important socio-economic task, as an element of the Federal governance strategy for preserving the environment, rational use and enhancement of the country’s natural resource potential, solving problems of its environmental and food security [7].

In the last century, a sharp increase in anthropogenic impact on the biosphere has led to warming, aridization of the climate and desertification of territories, degradation and destruction of soils, violation of the diversity of functional relationships in nature, reducing the ability of agro-sphere ecosystems to self-regulation and natural recovery.

In the conditions of global climate change, the most important factor in regulating the gas content of the atmosphere and the formation of carbon balance in the biosphere is its deposition in the vegetation cover and in the soil. The amount of carbon directly recorded by trees in various agricultural systems varies between 3-25 t/ha, but in some cases reaches 60 t/ha [7]. The most carbon-intensive are young, intensively growing plantings. Transformation of landscapes on the territory of Russia occurred as a result of plowing of virgin and fallow lands. The area from forest-steppe to dry steppes is currently occupied by agricultural landscapes, where the Chernozems are plowed by 75-90%. In this situation, global climate change contributes to the further degradation of ecosystems and the reduction of their diversity. The increasing aridity of the climate and weather anomalies of recent years makes it difficult to achieve high and stable crop yields. In agricultural landscapes, the main role of effective resistance to many adverse climatic conditions is assigned to protective forest shelter belts.

As noted in numerous studies conducted in extremely arid conditions of the South-East of the European part of Russia, K Kulik, A Barabanov, A Manaenkov, A Rulev, and other forest reclamation scientists of the leading in the country All-Russian Research Institute of Agro-Forest Reclamations,
currently 65% of arable land, 28% grassland and 50% pastures of Russia exposed to the damaging effects of erosion, deflation, periodic droughts, hot winds and dust storms [5-9].

Over the period from 1990 to the present, the area of farmland in the Russian Federation that is subject to erosion and deflation has increased by 2.2 million hectares to 126 million hectares. Due to water erosion, 10% of arable land lost 30-60% of its fertility and 25% of its area – from 10 to 30%. The annual loss of humus on arable land on average is 0.62 t/ha. Its content in the soil has decreased by 30-40% over 100 years.

The area of active ravines in Russia exceeds 900 thousand hectares, and their density on the Central Russian upland is 1-3 ravines per 100 hectares. The area of the land encroached by ravines has reached about 8 million hectares. The rate of ravine formation varies from 10 to 15 thousand ha/year, and the average annual growth of eroded land reaches 0.4-0.5 million ha. Due to soil deflation, the annual removal of dust to the atmosphere is 0.37 t/ha [5-9].

According to K Kulik, A Barabanov, S Kryuchkov, G Mattis, V Turusov, A Lepekhin et al. in the entire history of protective afforestation in Russia 5.2 million hectares of protective forest stands were planted on agricultural lands [5, 9-12]. But to date, this area has decreased to 2.74 million ha, or 1.3% of the agricultural territory of the Russian Federation (204.5 million ha), which is at least 3-6 times less than the scientifically based afforestation standards. For the full restoration of disturbed agricultural systems in the country, it will be necessary to create an additional twelve million hectares of protective stands and shelterbelts [5, 11-14].

Protective afforestation in the Central Chernozem region has 120 years of experience in which the works by V Dokuchaev expedition in the Kamennaya Steppe played a big role [12]. The expedition investigated the causes of drought and developed a set of measures to combat it. The highest priority for combating adverse environmental conditions was the creation of forest protective stands.

According to V Mikhin, A Chekanyskhin, A Lepokhin 500 thousand ha of forest protective stands were created in the Central Black Earth Region [15-17]. These plantations are able to provide the woodiness of arable land by 1.5-2%. The forest shelter belts system created in the region has shown that it is possible to overcome wind and water erosion of soils and minimize the drought effects. Protective afforestation is an acceptable and long-term mean of nature-protective and environment-forming significance. In order to create a sustainable agro-ecological system, it is necessary to increase the forest cover of the arable land in the Central Chernozem region to 3.0-4.5%. To optimize the agricultural landscapes of the region according to V Turusov, A Lepokhin and A Chekanyskhin it is necessary to create 220 thousand hectares in addition to the existing ones, including 118 thousand hectares of shelter belts, 49 thousand hectares of protective forest stands from ravines and gullies and 53 thousand hectares of water preservation, greenery landscaping forest plantings, and sand protective forest stands [18].

It is believed that the main tree species for protective plantings in the region should be oak with the addition of linden, common hazel, field and Tatar maples, pear trees and apple trees. In the protective forest stands of the Voronezh region until 1917, Common oak occupied 40.8%, birch tree – 20.5%, Common pine – 15.8% of the area. During following years (1930-1941), in the newly created protective forest stands the share of Common pine had been increased and the share of Common oak had been decreased. The third part of the total area of protective forest plantings was occupied by maple, green ash and elm [3, 19].

In the 70s of the last century, in the forest shelter belts and other protective plantings the share of fast-growing species, especially poplars, increased significantly. In the period from 1976 to 1980, the share of poplar in the forest shelter plantings of Voronezh region reached 32% [20]. Poplars began to be introduced into forest protective plantations in the Kamennaya Steppe in 1884. To now date, only one poplar site has been preserved, which is 108 years old. At this age, average height of poplars was 28.5-37.0 m, and average diameter – 46-97 cm [20]. Balsamic poplars were the most widely used in the shelter belts previously created in the Central Chernozem region due to theirs more winter-hardiness and the fastest growing in the first years after planting.
The purpose of this work is variety testing and selection of the most productive varieties, clones and hybrids of the introduced euramerican black poplars and new black, white and intersectional hybrids for introduction them into protective forest stands in the research region.

2. Methods and materials

The research was carried out in two directions: first – the variety testing of introduced black euramerican cultivars, and other one – the variety testing of new poplar hybrids bred in the Central Research Institute of Forest Genetics and Breeding. Variety testing of introduced poplars was carried out at three variety testing sites: Khokhol and Zemlyansk in the Voronezh region and Kumylga in the Volgograd region.

Khokhol testing site was laid on the Washed away Chernozem soil in the hydro-reclamation fund near of the big ravines and gullies in 1997 on an area of 2 hectares with the placement of 3×3 m. Coordinates: latitude 51°35'12" North, longitude 38°45'07" East.

Zemlyansk testing site was created at the bottom of the gully on well-drained and moisture-rich Alluvial soil in 1974 on an area of 0.8 ha with the placement of 3.5×3.5 m. Coordinates: latitude 51°53'59" North, longitude 38°43'19" East.

The Kumylga testing site was planted in floodplain conditions of the Kumylga River on intrazonal floodplain Chernozem-Meadow layered-grained heavy loam soil in 1989 with placement of 4×2 m. Coordinates: latitude 49°50'40" North, longitude 42°32'39" East.

Planting on all sites was carried out by 1-year-old rooted seedlings. The 18 different cultivars and clones of poplars obtained by domestic and foreign breeding were introduced into the tests.

Variety testing of new poplar hybrids bred in the Central Research Institute of the Forest Genetics and Breeding in 1975-1982 was carried out at three sites: two of them are laid in the Khokhol district of the Voronezh region and the third one – in the Shekhman' district of the Tambov region.

Khokhol variety testing site No. 1 (shelterbelt on the border with the Nizhnedevitsk district of Voronezh region) was created in 1985 on the Ordinary Chernozem loamy soil on an area of 0.5 ha with a placement of 2.0×2.75 m. Coordinates: latitude 51°37'40" North, longitude 38°43'19" East.

Khokhol variety testing site No. 2 was planted in 1997 on the Washed away Chernozem soil in the hydro-reclamation fund near of the big ravines and gullies on an area of 2 ha with a placement of 3×3 m. Coordinates: latitude 51°35'12" North, longitude 38°45'07" East.

Shekhman’ variety testing site was laid in 1986 on the Ordinary Chernozem loamy soil on an area of 1 ha with a placement of 4×4 m. Coordinates: latitude 52°30'20" North, longitude 40°25'50" East.

Planting of all sites was carried out by 1-year-old rooted seedlings. Among of the tested new hybrids, 3 hybrids of white poplars: ‘Belar’, ‘Bolide’ and ‘Veduga’ (all obtained from crosses of P. alba L. and P. bolleana L.); two hybrids of black poplars: ‘Vertical’ (P. deltoides Marsh. × P. ‘Pyramidal'no-Osokorevsky Kamyshinsky’ Alb. (‘POK’)) and ‘Breeze’ (half-sib from P. ‘Pioneer’ Yabl.); and intersectional hybrids: ‘Versiya’, ‘Pere’del’ (P. ‘Pioneer’ × P. balsamifera L.) and ‘Stroyn’, obtained from the family P. balsamifera L. × P. ‘Pyramidal'no-Osokorevsky Kamyshinsky’ Alb. (‘POK’) were included in the group of promising ones.

During variety testing in the first years of study (up to 10 years of age), annual accounts of plant survival and complete measurements of heights and circumferences of trunks were carried out. Measurements of heights were carried out using a measuring pole. In subsequent years, heights were determined by the German altimeter Blume Leiss. The circumferences of the trunks were measured using a centimeter tape throughout the study period.

Subsequently, the diameters were calculated, the height graphs were plotted, and the volumes of the trunk were determined using the volume tables of the Yugoslav poplar breeders K Hadži-Georgiev and M Goguševiski [21]. Wood stocks were calculated using the formula (1):

\[ W = \frac{V \cdot N \cdot S}{100}, \]  

where: \( V \) – the average volume of the trunk, m³; \( N \) – the planting density (trees/ha); \( S \) – survival (%).
3. Results and discussion

Long-term variety tests of different introduced poplar cultivars, conducted in the lands of forestry enterprises in the Voronezh [22, 23], Volgograd [24] and Tambov [25] regions, showed that high survival and productivity were observed in black euramerican spontaneous hybrids and in some domestic *eupopulus* hybrids [26-28]. The results of the use of poplar in protective afforestation for the previous period up to 2018 were published earlier [29, 30].

In this issue the results of tests during the period from 2017 to 2019 are presented. The table 1 provides a brief description of the growth and productivity of some foreign and domestic poplar hybrids that are selected in the perspective assortments for protective plantations in the Central Black Earth region and South-Eastern European part of the country.

**Table 1.** The description of the growth and productivity of selected introduced and domestic poplar hybrids.

| The name of the poplar hybrids | The inventory No. | Survival, % | Height, m | Diameter, cm | Volume of the trunk, m³ | Wood stock, m³/ha | Average increment, m³/ha/year |
|--------------------------------|------------------|-------------|-----------|--------------|------------------------|--------------------|-----------------------------|
| 'Sacrau-59'                    | 50               | 68          | 17.4±0.68 | 24.8±0.96    | 0.40                   | 326                | 16.3                        |
| 'E.t.-120'                     | 28               | 63          | 13.8±0.90 | 18.7±1.28    | 0.20                   | 139                | 7.0                         |
| 'E.s.-38'                      | 94               | 78          | 18.0±1.31 | 26.3±0.87    | 0.42                   | 360                | 13.3                        |
| 'Sacrau-59'                    | 50               | 68          | 24.9±0.63 | 30.6±1.65    | 0.69                   | 604                | 20.8                        |
| 'E.t.-120'                     | 28               | 87          | 24.1±0.42 | 27.7±1.12    | 0.54                   | 587                | 20.2                        |
| 'E.s.-38'                      | 94               | 89          | 24.5±0.36 | 28.1±1.04    | 0.55                   | 612                | 21.1                        |
| Local black poplar (Control)   | 70               | 20.2±0.46   | 21.2±0.91 | 0.29         | 254                    | 8.8                |
| 'Pioneer'                      | 42               | 70          | 24.9±0.63 | 30.6±1.65    | 0.69                   | 604                | 20.8                        |
| 'Vernirubens'                  | 54               | 80          | 24.7±0.74 | 28.8±1.97    | 0.62                   | 620                | 21.4                        |
| 'Robusta-195'                  | 33               | 73          | 24.5±0.43 | 28.5±1.10    | 0.62                   | 566                | 19.5                        |
| 'Regenerata'                   | 78               | 95          | 24.2±0.46 | 27.7±1.12    | 0.54                   | 640                | 22.1                        |
| 'Sacrau-59'                    | 50               | 70          | 25.4±0.46 | 29.7±1.39    | 0.66                   | 578                | 19.9                        |
| 'E.t.-120'                     | 28               | 87          | 24.1±0.42 | 27.7±1.09    | 0.54                   | 587                | 20.2                        |
| 'E.s.-38'                      | 94               | 89          | 24.5±0.36 | 28.1±1.04    | 0.55                   | 612                | 21.1                        |
| 'Pioneer'                      | 42               | 63          | 31.0±2.08 | 41.9±1.30    | 1.60                   | 800                | 19.0                        |
| 'Robusta-195'                  | 33               | 77          | 30.8±1.38 | 41.7±0.74    | 1.59                   | 973                | 23.2                        |
| *P. trichocarpa* L.            | 83               | 72          | 29.5±0.50 | 38.0±0.65    | 1.27                   | 733                | 17.5                        |
| 'E.s.-38'                      | 94               | 70          | 30.5±0.49 | 41.0±0.69    | 1.53                   | 857                | 20.4                        |
| *P. balsamifera* L. (control)  | –                | 21          | 30.3±1.53 | 39.8±1.39    | 1.37                   | 230                | 5.5                         |

As we can see from the table 1 at the Khokhol variety testing site No. 2 in the Voronezh region on the Washed away Chernozem soil in the hydro-reclamation fund the euramerican black poplar ‘Sacrau-59’ performed the best growth and productivity, which in 20 years had a height of 17.4 m; diameter – 24.8 cm and wood stock – 326 m³/ha. Its average increment was 16.3 m³/ha per year. In the floodplain conditions of the Kumylga River in the Volgograd region the most productive at the age of 30 years was also ‘Sacrau-59’ and other euramerican black poplars: ‘Vernirubens’, ‘Robusta’, and ‘Regenerata’. At that age they had a height about 24-25 m; a diameter – 28-31 cm and a wood stock about 600 m³/ha. The average increment varied from 19.5 to 22.1 m³/ha per year. While the control (local black poplar) in the same conditions and at the same age had a height of 20.2 m; wood stock – 254 m³/ha; average increment – 8.8 m³/ha per year. At a later age (at 42 years old) at the Zemlyansk variety testing site in the Voronezh region that laid on the bottom of the gully on the Alluvial soil the height of the poplar ‘Robusta-195’ reached 30.8 m; diameter – 42 cm; the wood stock was 973 m³/ha, the average increment was 23.2 m³/ha per year.
Good results of growth and productivity in these conditions were shown by domestic hybrids obtained by A Yablokov in All-Union Research Institute of Silviculture and Mechanization of Forestry in Pushkino of Moscow region (‘Pioneer’) and by M M Veresin in Voronezh Forest Technical Institute (‘E.s.-38’ – ‘Elite seedling No. 38’), which in floodplain conditions of the Kumylga variety testing site had a height of 24.5 and 24.9 m at 30 years; diameter – 28.1 and 30.6 cm; wood stock – 604 and 612 m$^3$/ha; average increment – 20.8-21.1 m$^3$/ha per year. At the Zemlyansk variety testing site at 42 years of age the growth of these poplars reached a height of 30.5-31.0 m, and diameter – 41-42 cm. Their wood stocks at this age were 800 and 857 m$^3$/ha, the average increments were 19.0 and 20.4 m$^3$/ha per year.

In addition to introduced cultivars and previously bred varieties in recent decades the new poplar hybrids bred in the All-Russian Research Institute of Forest Genetics, Breeding and Biotechnology have been testing in the protective plantations of the Central Black Earth region. After many-years variety testing three new hybrids of white poplars (‘Bolide’, ‘Belar’ and ‘Veduga’), two new hybrids of black poplars (‘Vertical’ and ‘Breeze’) and three new intersectional poplar hybrids (‘Versiya’, ‘Peredel’ and ‘Stroyn’) have been recommended in the protective and greenery landscaping plantings in the region. Four of them (‘Belar’, ‘Bolide’, ‘Veduga’ and ‘Breeze’) have been granted by the status of varieties by the Federal Commission on Variety Testing of the Russian Federation with the issuance of patents and copyright certificates. Table 2 provides a brief description of the growth and productivity of these poplars growing at three variety testing sites located in the Voronezh and Tambov regions.

| No. in order | The name of the hybrid | Inventor No. | Height, m | Diameter, cm | Volume of the trunk, m$^3$ | Proposals of using in plantations |
|-------------|------------------------|-------------|-----------|-------------|---------------------------|----------------------------------|
|             |                        |             |           |             |                           | protective greener landscaping    |
| 1           | ‘Bolide’               | 27-10       | 13.6±0.69 | 17.5±1.34   | 0.14                      | +                                |
| 2           | ‘Belar’                | 26-09       | 13.5±1.84 | 17.6±3.14   | 0.15                      | +                                |
| 3           | ‘Veduga’               | 26-07       | 13.1±0.51 | 16.6±0.83   | 0.12                      | +                                |
| 4           | ‘Versiya’              | 22-08       | 12.8±0.35 | 15.7±0.60   | 0.10                      | –                                |
| 5           | ‘Vertical’             | 32-03       | 13.1±1.26 | 16.6±2.21   | 0.12                      | –                                |
| 6           | ‘Breeze’               | 04-06       | 14.3±0.46 | 18.0±0.94   | 0.17                      | +                                |
| 7           | ‘Stroyn’               | 11-05       | 12.7±1.09 | 16.4±1.94   | 0.13                      | +                                |
| Aggregate average (Control) | | | 13.4±0.29 | 17.3±0.52   | 0.14 | + | + |

Khokhol of Voronezh region variety testing site No. 1 (the age of 34 years)

| No. in order | The name of the hybrid | Inventor No. | Height, m | Diameter, cm | Volume of the trunk, m$^3$ | Proposals of using in plantations |
|-------------|------------------------|-------------|-----------|-------------|---------------------------|----------------------------------|
|             |                        |             |           |             |                           | protective greener landscaping    |
| 1           | ‘Veduga’               | 26-07       | 21.3±0.14 | 31.2±0.18   | 0.83                      | +                                |
| 2           | ‘Versiya’              | 22-08       | 20.9±0.16 | 28.6±0.80   | 0.67                      | +                                |
| 3           | ‘Vertical’             | 32-03       | 21.8±0.10 | 33.3±0.67   | 0.74                      | +                                |
| Aggregate average (Control) | | | 20.7±0.08 | 28.1±0.41   | 0.64 | + | + |

Table 2. The description of the growth of some selected new poplar hybrids bred in the All-Russian Research Institute of Forest Genetics, Breeding and Biotechnology and recommended for protective and greenery landscaping plantings in the Central Black Earth region.
As can be seen from the data of the table 2 the height of hybrids at the Khokhol variety testing site No. 2 in the hydro-reclamation fund near of the big ravines and gullies in 20 years varied from 12.7 to 14.3 m, the diameter – from 16 to 18 cm. At the Shekhman’ variety testing site on the Ordinary Chernozem loamy soil in 25 years the average height ranged from 19.9 to 21.9 m, the diameter – from 27 to 31 cm, the trunk volume – from 0.45 to 0.65 m³. At the age of 34, with placement 2.0×2.75 m, the height of new poplar hybrids in the shelter belt on Ordinary Chernozem loamy soil in 25 years the average height ranged from 19.9 to 21.9 m, the diameter – from 27 to 31 cm, the trunk volume – from 0.67 to 0.83 m³. Male hybrids of black poplars (‘Breeze’, ‘Stroyn’ and ‘Pereidel’), as well as white pyramidal highly decorative poplars (‘Belar’, ‘Veduga’ and ‘Bolide’) can be also recommended for greener landscaping plantations. Thus, as it above mentioned, among the introduced poplars the euramerican poplar hybrids were the best in growth and productivity. Among the previously selected domestic hybrids ‘Pioneer’ and ‘E.s.-38’ were the best. Among the new poplar hybrids bred in the All-Russian Research Institute of Forest Genetics, Breeding and Biotechnology the hybrids ‘Bolide’, ‘Belar’, ‘Veduga’, ‘Vertical’, ‘Stroyn’, ‘Breeze’, ‘Pereidel’, ‘Versiya’ showed good results at all three experimental sites created in different soil and environmental conditions. These varieties and clones can be able to perform their reclamation functions at an early age starting from 3-5 years old and by 20-30 years they reached a height of 13-22 m, a diameter of 16-33 cm.

According to A Maksimenko et al [31] as a result of the 40-year testing of poplar hybrids belonging to the subgenus *Eupopulus* in the Eastern Azov region in humus shell-soil, underlain by slightly brackish groundwater on the depths available for roots (to 150 cm), the most highly productive and sustainable were the clones of euroamerican poplars: ‘Brabantica-175’, ‘Sakrau-59’, ‘Robusta-236’, ‘Robusta-195’, ‘Bachelieri’, ‘Vernirubenes’, and ‘Caroline-162’, and also hybrids of domestic breeding ‘E.s.-38’ and the hybrid ‘No. 60001/1’ from the L'vov region of Ukraine. In terms of growth, they surpass the local Canadian and other varieties of poplars. Their resistance to climatic and biological factors of the environment is also significantly higher than that of low-productive varieties. In the Eastern Cost of the Azov Sea poplar cultures are used for recultivation of waste lands, as well as the main breed for protective afforestation.

In the Steppe zone of the Kamyshinsky district of the Volgograd region, as a result of research of a collection of 80 cultivars of 35-year-old poplars, created in 1980 by the ‘Low Volga Research Station on breeding of tree species of the All-Russian Research Institute of Agro-Forest Reclamations’, E Morozova and A Iozus identified varieties of poplars of intensive type with low environmental stability: ‘Brabantica-175’ and ‘Sakrau-79’. According to their data, varieties with high ecological stability that show good growth in a wide range of environmental conditions include: ‘E.s.-53’, ‘Udivitel'nuy’, ‘Regenerata’ and ‘Leningradsky’ [32].

To create protective plantings on irrigated lands, they recommended cultivars: ‘Robusta-173’, ‘E.s.-38’, ‘Regenerata’, ‘Leningradsky’, ‘E.s.-53’ and ‘Udivitel'nuy’. For creation of protective plantations in rainfed conditions, according to them, the most promising will be cultivars: ‘Bachelieri’, ‘E.s.-53’, ‘E.s.-38’, ‘Kazakhstansky’ and ‘Vernirubens’. With the aim of obtaining the greatest biomass on the irrigated plantations fit “Brabantica-175”, ‘Sakrau-79’ and ‘Robusta-173’. From poplars bred by A Al'bensky, according to their data, the most promising should be considered the ‘Moscow seedling’ No. 1 344, ‘Krasnonervny’×‘Berlinsky’ No. 1-15, ‘Moskovsky’×‘Krasnonervny’ No. 1 384, 1 381, 1 179 [32].

Outside the Russian Federation, poplars are widely used to create protective forest stands of various target orientation. For example, in Northern Italy, new methods are being developed for creating poplar plantations in the Po River floodplain using *Populus alba* L. for adaptation in adverse conditions of flooding and soil erosion. The main goals are to regulate water runoff, reduce soil erosion, restore rivers, improve the landscape, and expand biodiversity [33].

In southern Germany, on land unsuitable for food production, hybrid poplars are used to create Short-Rotation Coppices (SRC) to produce bioenergy raw materials and pulp for the paper industry. Important side-effects of public environmental benefits over the entire life of the SRC (21 years) are: a significant reduction in greenhouse gas emissions (CO₂, CH₄ and N₂O) and an increase in organic
carbon in the soil [34]. In New Zealand, the creation of soil-protecting and shore-strengthening stands of poplars in the coastal areas of Hawke's Bay has been widely developed, which on average reduce soil slipping by 78%, and in the 10-meter zone of trees – almost to zero [35]. In Canada, in the North-East of the province of Alberta, oil sands are being reclaimed at the Syncrude mine site using selected most salt-resistant clones of local balsam poplar [36].

In north Patagonia (Argentina), the possibility of reuse of treated urban wastewater for forest irrigation is being tested. To this end, in Rincon de los Sauces, Neuquén, hybrids of *Populus × Canescens* are tested, which at the age of 1 showed a safety of 85% and a height of 2.8 m. Such high safety and productivity at an early age will allow creating short-rotation forestry (SRF) irrigated with urban wastewater to prevent spills to rivers and lakes. Thus, environmental and economic effects will be realized and combined [37].

In the USA short rotation woody crops (SRWCs) including *Populus* species and their hybrids are considered as an ideal for incorporating biomass production with phytotechnologies such as phytoremediation in the Midwest (Illinois, Iowa, Wisconsin) and Southeast (Alabama, Florida, North Carolina). This also allows them to simultaneously solve the environmental problems of reclamation of disturbed land and commercial use of wood and pulp grown in the shortest possible time. Phytoremediation success can be increased with the identification and deployment of genotypes tailored to grow well and tolerate a broad diversity of various contaminants (generalists) [38].

According to S Rood, S Patino, K Coombs and M Tyree, despite the attractiveness of using poplars in shelterbelts due to rapid growth, their high demands on moisture, soil fertility, rapid spread of the surface root system over long distances and negative impact on nearby crops encourage agricultural landowners and tenants to prefer other longer-lived and less competitive species, especially in areas with limited moisture [39].

Despite some negative impact of poplars on nearby crops, D Pandey believes that in the state of Haryana in India, shelterbelts created from *P. deltoides* have less negative impact on crops than shelterbelts created from *eucalyptus*. Thus, land managers must optimize rapid growth, protective effect, and potential economic value in each case [40].

In cases where the soil and climate are suitable for growing poplars, they may be preferred over other species or used in combination with other species, especially if they have economic, aesthetic or other advantages in addition to their wind protection function. This allows maximizing the value of the land used [41].

In various countries and regions of the world with a wide variety of climatic, economic, social or cultural conditions or traditions, the use of poplars in protective stands has led to a wide variety of practices for cultivating them for these purposes. For example, creating poplar farmyards in the North American Great Plains, poplar shelterbelts in the steppe and forest-steppe regions of Russia, or planting poplars along the borders of agricultural fields in Punjab and Haryana states of India. In India, poplars are also planted along the banks of rivers originating in the Himalayas to capture soil and debris during periods of flooding [42].

J Kort and W Schroeder based on the results of studying the use of poplars in shelterbelts concluded that if shelterbelt includes not only fast-growing poplars, but also other slow-growing, but longer-lived species, then over time, slow-growing ones increase the density of shelterbelt and its life span, thereby complementing the rapid growth of poplar. They also note that in the United Kingdom, France and Denmark, some researchers consider poplars to be more preferable windproof species compared to others. But they also consider the need to co-grow fast-growing but short-lived poplars with other longer-lived species [2].

In South America, in Chile and Argentina, 1,500 km of poplars windbreaks have been created in areas of southern Patagonia, which provide protection for important irrigated crops [43].

J Carle and Q Ma reviewed the implementation of the large-scale ‘Great Green Wall’ program in the three Northern provinces of China, adopted in 1978. This program provided for the creation of ‘Three North Shelterbelts’ from poplars to protect crops or animals, as well as for the production of wood. The total protected area is 4 million km², including more than 20 million hectares under the
The protection of hybrid poplars [44]. In total, according to Z Fan et al, there are about 2.2 million ha of poplar shelterbelts in China [45].

In the USA poplars widely used to create forested riparian buffer in lower Mississippi Alluvial Valley and in the Pacific Northwest. At the same time, the widely developed root system of poplars ensures the splitting of pesticides and the absorption of nitrates from ground water. The rapid growth of poplars, the height of trees and the dense canopy contribute to the shading of streams, which reduces their warming, and as the trees mature and overturn, they bring large wood fragments into the streams, creating a number of reefs and pools necessary for fish habitat [46, 47].

In the Central Chernozem region of Russia no other forest tree species can approach the poplars speed of growth and productivity, especially those that are selected as a result of long-term variety testing. For comparison, according to V Turusov, A Lepekhin and A Chekanyshkin, birch stands in the Kamennaya Steppe in the reclamation fund in 20 years had a height of 8.2 m, a diameter of 8.0 cm, and a wood stock of 70 m³/ha. Larch stands at the same age had a height of 7.2 cm, a diameter of 10.2 cm, a wood stock of only 46 m³/ha. By 42 years its indicators increased to 12-18 m, 15-18 cm and 89-220 m³/ha respectively. At the age of 21 years, the pine stands had a height of 7-9 m, a diameter of 11-13 cm, and a wood stock of 64-75 m³/ha. At the age of 42 years, theirs height increased to 16-21 m, a diameter – to 22-28 cm, and a wood stock – to 219-391 m³/ha [17, 18].

Growth indices of the main forest tree species in the Central Chernozem region – the Common oak (Quercus robur L.) were as follows: at the age of 21 years old, pure oak stands in the slope conditions had a height of 6.9 m, a diameter of 7-9 cm, and a wood stock of 37-54 m³/ha. In 42 years, theirs height increased to 14-18 m, a diameter – up to 15-19 cm, and a wood stock – up to 146-175 m³/ha. In mixed forest stands with the presence of oak up to 50 % in interfluvies and division of the waters areas in upland environment in 54 years, the height was 14.5-18.0 m, the diameter-15-19 cm, the wood stock – 149-186 m³/ha. And only by the age of 75 years old its height became equal to 20 m, the diameter-29-30 cm, and the wood stock – 250-338 m³/ha [17, 18]. I. e. only at this age the growth rates of oak almost equaled the growth rates of bred and selected 25-30-year-old poplars.

According to Lepyokhin and Chekanyshkin [48], in 5-row shelterbelt No. 240 (the edges rows of European birch in mixture with Norway maple, and the 3 central rows were occupied by Common oak), established in 1969 in Kamennaya Steppe (Talovsky district of Voronezh region) with a width of 12.5 m with a plant density of 4,800 pcs/ha (including oak – 3,200 pcs/ha) and with placement of seedlings 0.7-1.0 × 2.5 m at the age of 17 years (1986) the average height of the oak, depending on the scheme of mixing tree species was 5.9-8.2 m and an average diameter – 5.4-8.1 cm. Until 1986 regular improvement thinning was carried out. 31 years after thinning, i.e. in 2017 at the age of 48, the average height of the oak was 15.1-16.4 m, and the average diameter was 17.4 – 22.4 cm.

Due to our data (as shown above), under similar conditions poplar hybrids in the shelterbelt reached an average height of 12.7-18.0 m and an average diameter of 15.7-26.3 cm at the age of 20.

M Sautkina, N Kuznetsova and V Tunyakin noted that in the 67-year-old shelterbelt No. 133, created in the Kamennaya Steppe under the leadership of E Pavlovsky, the average height of selected model oak trees on the flatland was 21.4 m, the average diameter – 50.3 cm and on the slope average height was 17.6 m, the average diameter – 29.8 cm [49].

By the data of V Mikhin and E Mikhina, in protective forest stands of the Central Chernozem region of Russia, with placement 5.0×3.0 m, depending on the type of soil (Gray Forest Soil, Leached Chernozem and Typical Chernozem), the average height of the Common oak at the age of 33 was 8.0-12.2 m with an average diameter of 10.4-15.4 cm, and with placement 1.5×0.7 m at 40 years of age in similar soil conditions, the average height of the oak was 10.2-14.5 m, the average diameter – 10.5-16.5 cm [50].

O Grybacheva in the Steppe zone of the Lugansk region of Ukraine identified the diameter of the Common oak in the shelterbelt in 60 years was 19.2-22.0 cm [51].

A Chernodubov, S Kryukova and V K Shirnin based on research results in the Central Forest-Steppe zone showed that the average height of the seed offspring of Common oak plus-trees at the age
of 23 years in $D_2$ environment conditions with the placement of $2.5 \times 1.0\ m$ was 10.2 m, the average diameter – 11.5 cm [52].

In 2014-2017, researchers of the All-Russian Research Institute of Forest Genetics, Breeding and Biotechnology under supervision of V Shirnin and V Kostrikin had been conducting an inventory of selected Common oak breeding seed production objects in 5 regions of the Central Chernozem zone, including oak plus trees [53]. Initially, it was recommended to include individuals that exceed the average tree in the plantation by more than 10% in height and by more than 30% in diameter. However, due to different ages and erosion of the oak gene pool, these criteria were lowered to 8% and 20% respectively.

Based on inventory results in the Voronezh region, height of Common oak plus trees at the age of 78 years was 28-30 m with a diameter of 30-32 cm; at the age of 110 years height was 30-33 m, diameter – 42-59 cm; at the age of 125 years height – 33-36 m, diameter – 55-76 cm; at the age of 135 years, height – 31 to 37 m with a diameter of 46-73 cm; at the age of 190 years, height – 32 to 37 m, diameter – 58-100 cm [53].

So, as we can see, the most fast and productivity poplar hybrids grow minimum three times faster than the best oak plus trees. But oak is more and more durable and longer-lived than poplar. And as a compromise in shelterbelts Common oak can be cultivated in corridors of fast-growing species (hybrid poplars) with a row spacing of 2.5-3.0 m, separating the rows of the main species from the fast-growing rows of accompanying species (Norway maple, Small-leaved linden) [50].

Conclusions
Thus, many years variety testing of introduced poplar cultivars and new hybrids bred in the All-Russian Research Institute of Forest Genetics, Breeding and Biotechnology allowed drawing the following conclusions.

In recent years, long-term variety testing and study of domestic poplar hybrids and euramerican poplar cultivars have been conducted in the Central Black Earth region, new poplar hybrids and varieties have been bred, genotypes promising for protective afforestation have been selected.

The most promising and competitive among them there are the following euramerican poplar spontaneous hybrids: ‘Vernirubens’, ‘Regenerata’, ‘Robusta’, ‘Sacrau-59’ and others. From the old domestic hybrids poplars ‘Pioneer’ and ‘E.s.-38’ have been recommended for using in protective afforestation. The recommended poplars reached a height of 24-25 m and a diameter of 28-31 cm at the age of 30 years. Their average increment was 20-22 m$^3$/ha per year.

From the new poplar hybrids obtained in the All-Russian Research Institute of Forest Genetics, Breeding and Biotechnology, the hybrids ‘Belar’, ‘Bolide’, ‘Veduga’, ‘Vertical’, ‘Versiya’, ‘Peredel’, ‘Stroyn’ and ‘Breeze’ have been recommended to introduce in the protective forest stands of the region. These hybrids at the age of 25-30 years (at the age of the economic exploitability) had a height of 20-22 m, a diameter of 27-31 cm, a trunk volume of 0.45-0.65 m$^3$.

In General, the widespread use of introduced, as well as the new varieties and hybrids of poplar will allow enriching the species range of created protective forest plantations, to increase their stability, to accelerate the reclamation effect and to improve the environmental situation of the region.

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References
[1] Isebrands J and Richardson J 2014 Introduction In ‘Poplars and Willows: Trees for Society and the Environment’ (Eds J Isebrands and J Richardson) Dedicated to the memory of Victor Steenackers Published jointly by CAB International and FAO (London: CPI Group (UK) Ltd, Croydon, CR0 4YY) chapter 1 pp 1-7
[2] Kort J and Schroeder W 2014 Windbreaks and Shelterbelts In ‘Poplars and Willows: Trees for Society and the Environment’ (Eds J Isebrands and J Richardson) Dedicated to the memory of Victor Steenackers Published jointly by CAB International and FAO (London: CPI Group (UK) Ltd, Croydon, CR0 4YY) chapter 6.2 pp 259-266

[3] Treschevsky I and Shatalov V 1982 Forest Reclamation and Zonal Systems of Antierosion Measures (Voronezh: Publishing house of the Voronezh State University) p 264 [In Russia]

[4] Dzhuvelikyan Kh 2007 Ecological State of Natural and Anthropogenic Landscapes of the Central Chernozem Region, Dr thesis, Petrozavodsk State University

[5] Kulik K, Barabanov A and Manayenkov A 2015 Forecasting the development of protective afforestation in Russia until 2020 Studies on Russian Economic Development 26 351 DOI 10.1134/S1075700715040073 [In Russia]

[6] Kulik K and Pugachyova A 2016 Forest reclamation – the basis for arrangement of sustainable agrolandscapes in conditions of insufficient moistening Forest Engineering Journal 6 29 DOI 10.12737/21677 [In Russia]

[7] Kulik K, Barabanov A, Manayenkov A and Kulik A 2017 Forecast assumption and analysis of the development of protective afforestation in the Volgograd region Studies on Russian Economic Development 28 641 DOI 10.1134/S1075700717060053 [In Russia]

[8] Barabanov A, Manayenkov A and Uzolin A 2017 Experience and strategy of protective afforestation in the right Bank of the Central Don of the Volgograd region Volga Region Farmland 4 17 [In Russia]

[9] Kulik K, Rulev A and Tkachenko N 2017 The changing climate and agroforest amelioration Proc. from Lower Volga Agro-University Complex: Science and Higher Education 2 58 [In Russia]

[10] Kryuchkov S and Mattis G 2014 Afforestation in Arid Environments (Volgograd: Publishing house of the ‘All-Russian Research Institute of Agro-Forest Reclamations’) p 301 [In Russia]

[11] Kulik K et al 2014 Strategy for the Development of Protective Afforestation in the Russian Federation for the Period up to 2025 (Volgograd: Publishing house of the Federal State Budgetary Scientific Institution ‘All-Russian Research Institute of Agro-Forest Reclamations’) p 36 [In Russia]

[12] Turusov V and Lepekhin A 2016 Protective forest cultivation in Kamennaya Steppe Achievements of Science and Technology of the Agro-Industrial Complex 30 56 [In Russia]

[13] Yuferev V et al 2006 Agro-Forest Reclamation 5th edition, revised and expanded (Volgograd: Publishing house of the All-Russian Research Institute of Agro-Forest Reclamations) p 746 [In Russia]

[14] Kulik K 2005 Proc. from the All-Russian Scientific and Practical Conf. dedicated to the 75th Anniversary of the Volga Agroforestry Research Station: ‘Protective afforestation in the Middle Volga region’ (Volgograd: Publishing house of the All-Russian Research Institute of Agro-Forest Reclamations) p 158 [In Russia]

[15] Mikhin D, Mikhin V and Kruglyak V 2012 Shelter Belt Afforestation in Voronezh region Scientific Journal of KubSAU 79 1 [In Russia]

[16] Mikhin V 2013 Forest Shelter Belt Afforestation in the Central Black Earth Region of Russia, Dr. thesis, Voronezh Forest Engineering Academy [In Russia]

[17] Chekanyshkin A and Lepyokhin A 2015 The state of the protective afforestation in the Central Chernozem zone Forest Journal 4 7 [In Russia]

[18] Turusov V, Lepyokhin A and Chekanyshkin A 2017 Experience of Forest Reclamation of Steppe Landscapes, ed by V Turusov (Voronezh: ‘Origin’ Publishing house) p 228

[19] Treschevsky I, Popov V and Kovaliev P 1973 Forest Shelter Belt Afforestation (Advanced Experience of Cultivation and Economic Efficiency of Forest Shelter Belts), ed I Treschevsky (Voronezh: Central Chernozem book publishing house) p 130 [In Russia]
[20] Tsareva R and Kovalev P 1983 Use of poplars obtained by domestic and foreign breeding in afforestation of the Voronezh region (Voronezh: Publishing house of the Central Research Institute of Forest Genetics and Breeding) 60 [In Russia]

[21] Hadži-Georgiev K and Goguševski M 1972 Dvolazne tabele mass za topola klona Populus euramericana cv. I-214 u geveliskom području J. Topola. XVI(90) (Beograd: Yugoslavenske nacionalne komisije za topolu) 25

[22] Tsarev A, Tsareva R and Tsarev V 2017 Proc. Int. Sci. and Techn. Conf. on Biotechnology, Genetics, Breeding in Forestry and Agriculture, Ecosystem Monitoring (Voronezh: Publishing house of RHYTHM) p 492 [In Russia]

[23] Tsarev A, Tsareva R and Tsarev V 2019 Poplar testing and breeding in the Central Chernozem region of Russia IOP Conf. Ser.: Earth Environ. Sci. 392 012010 DOI 10.1088/1755-1315/392/1/012010

[24] Tsareva R and Tsarev V 2018 Results of the long-term variety testing of various forms and hybrids of poplars in the Volgograd region Scientific Agronomical Journal 4 24 [In Russia]

[25] Tsarev A, Tsareva R, Tsarev V and Miligula E 2019 The new poplar hybrids’ growth in the Central Black Earth region of Russia IOP Conf. Ser.: Earth Environ. Sci. 392 012011 DOI 10.1088/1755-1315/392/1/012011

[26] Tsarev V 2019 Results of the intersectional poplar hybrids’ testing in the Central Chernozem region IOP Conf. Ser.: Earth Environ. Sci. 226 012006 DOI 10.1088/1755-1315/226/1/012006

[27] Tsarev V 2019 Long-term variety testing of the intersectional poplar hybrids in the Central Black Earth Forest-Steppe Zone Forest Engineering Journal 9 102 DOI 10.12737/article_5c92016edc4eb3.39242637

[28] Tsarev V 2019 Variety testing and selection of the intersectional poplar hybrids for industrial plantation forests in the Central Chernozem region of Russia Abstr. of the XXV IUFRO World Congress, Curitiba, PR, Brazil: (Colombo: Embrapa Florestas) p 185 [In Russia]

[29] Tsarev A, Tsareva R, Tsarev V, Lenchenkova O and Miligula E 2019 Variety testing and selection of poplar hybrids for shelter belt plantings Forest Engineering Journal 9 93 DOI 10.12737/article_5c92016e6498a5.38774878

[30] Tsareva R 2019 Poplar breeding for protective afforestation. Abstr. from the Int. Congress of the Vavilov Society of Geneticists and Breeders (St. Petersburg: Publishing house of the St Peterburg State Forest Engineering University) p 931 [In Russia]

[31] Maksimenko A, Maksimtsov D, Martynova V, Nedelyaeva K, Kholyavko O and Bondarenko P 2016 Results of forty-year variety testing of hybrid poplars on sand-shell soils of the Eastern Azov region Scientific Journal of KubSAU 124 181 DOI 10.21515/1990-4665-124-009 [In Russia]

[32] Morozova E and Iozus A 2016 Features of variety testing promising for protective afforestation on irrigated and dry-farming land species, hybrids and forms of poplar in conditions of dry steppe in the Lower Volga region Advances in current natural sciences 11 306 [In Russia]

[33] Chiarabaglio P, Allegro G and Giorelli A 2014 Environmental sustainability of poplar stands Actas de las Jornadas de Salicaceas 2014’Cuarto Congr. Int. de Salicáceas en Argentina ‘Sauces y Alamos para el desarrollo regional’ (Ciudad de La Plata, Buenos Aires, Argentina), available at https://www/sites.google.com/site/documentossalicaceas/jornadas-de-salicaceas-2014-iv-congreso-internacional-de-salicaceas-en-la-argentina

[34] Schweier J, Molina-Herrera S, Ghirardo A, Grote R, Diaz-Pinés E, Kreuzwieser J, Haas E, Butterbach-Bahl K, Remmeneg H, Schnitzler J-P and Becker G 2017 Environment impact of bioenergy wood production from poplar short-rotation coppice grown at a marginal agricultural site in Germany GCB Bioenergy 9 1207 DOI 10.1111/gcbb.12423

[35] Schwarz M, Phillips C, Marden M, McIvor I, Douglas G and Watson A 2016 Modelling of root reinforcement and erosion control by ‘Veronese’ poplar on pastoral hill country in New Zealand New Zealand Journal of Forestry Science 46 1 DOI 10.1186/s40490-016-0060-4
[36] Thomas B and Kamelchuk D 2016 Using native balsam poplar (*Populus balsamifera*) for reclamation in the oil sands region of north-eastern Alberta, Canada. *Abstr. of Submit. Papers prep. for the 25th Session of Int. Poplar Commission Jointly Hosted by FAO and the German Federal Ministry of Food and Agriculture in Berlin, Germany*: ‘Poplars and Other Fast-Growing Trees – Renewable Resources for Future Green Economies’ (Rome: International Poplar Commission Working Paper IPC/14. Forestry Policy and Resources Division, FAO) chapter 5 p 201

[37] Tucat C, Romagnoli S, Thomas E and Cerrillo T 2016 Use of treated wastewater in forest plantations in north Patagonia, Argentina. *Abstr. of Submit. Papers prep. for the 25th Session of Int. Poplar Commission Jointly Hosted by FAO and the German Federal Ministry of Food and Agriculture in Berlin, Germany*: ‘Poplars and Other Fast-Growing Trees – Renewable Resources for Future Green Economies’ (Rome: International Poplar Commission Working Paper IPC/14. Forestry Policy and Resources Division, FAO) chapter 5 p 202

[38] Zalesny-Jr. R et al 2019 Ecosystem services of poplar at long-term phytoremediation sites in the Midwest and Southeast, United States *Wiley Interdisciplinary Reviews: Energy and Environment* 8 1 DOI 10.1002/wene.349

[39] Rood S, Patino S, Coombs K and Tyree M 2000 Branch sacrifice: cavitation-associated drought adaptation of riparian cottonwoods *Trees* 14 0248 DOI 10.1007/s004680050010

[40] Pandey D 2008 Trees outside the forest (TOF) resources in India *International Forestry Review* 10 125 https://doi.org/10.1505/ifor.10.2.125

[41] Puri S and Nair P 2004 Agroforestry research for development in India: 25 years of experiences of a national program *Agroforestry Systems* 61 437 DOI 10.1023/B:AGFO.0000029014.66729.e0

[42] Dhiman R 2012 Status of poplar culture in India. *ENVIS Forestry Bulletin* 12 Proc. from 24th Session of International Poplar Commission at Forest Research Institute, Dehranum (India): ‘Poplars in India’ 15 (Dehranum: ENVIS Centre on Forestry Forest Research Institute) p 171

[43] Peri P and Bloomberg M 2002 Windbreaks in southern Patagonia, Argentina: a review of research on growth models, windspeed reduction, and effects on crops *Agroforestry Systems* 56 129 DOI 10.1023/A:1021314927209

[44] Carle J and Ma Q 2005 Challenges of transplanting science into practice: poplars and other species in the Three North Region of China *Unasylva* 221 31 http://www.fao.org/3/a0026e/a0026e09.pdf

[45] Fan Z, Gao J, Zeng D, Zhou X and Sun X 2010 Three-dimensional (3D) structure model and its parameters for poplar shelterbelts *Science China Earth Sciences* 53 1513 DOI 10.1007/s11430-010-3033-0

[46] Gardiner E and Stanturf J 2014 Use of poplar and willow to create forested riparian buffer in Lower Mississippi Alluvial Valley *Poplars and Willows: Trees for Society and the Environment* eds J G Isebrands and J Richardson (London: CPI Group (UK) Ltd, Croydon, CR0 4Y) chapter 6.3.2 pp 266-270

[47] Johnson J 2014 Streamside restoration and stabilization with riparian buffers in the Pacific Northwest, USA. In *‘Poplars and Willows: Trees for Society and the Environment’* eds J G Isebrands and J Richardson (London: CPI Group (UK) Ltd, Croydon, CR0 4Y) chapter 6.3.3 pp 270-271

[48] Lepyokhin A and Chekanyshkin A 2018 Growth and vitality of English Oak in plantations after improvement thinning *Forestry Journal* 6 70 DOI 10.17238/issn0536-1036.2018.6.70

[49] Sautkina M, Kuznetsova N and Tunyakin V 2018 Current state of protective shelterbelts with the predominance of the Common oak (*Quercus robur* L.) in the Kamennaya Steppe *Forestry information* 1 78 http://dx.doi.org/10.24419/LHI.2304-3083.2018.1.07

[50] Mikhin V and Mukhina E 2018 Formation of English oak protective plants in the Central Chernozem region of Russia *Forest Engineering Journal* 8 109 DOI 10.12737/article_5c1a321965cf38.69751554 [In Russia]
[51] Gribacheva O 2019 The Current state of the shelterbelt featuring English Oak (*Quercus robur* L.) and Norway Maple (*Acer platanoides* L.) *Forestry Journal* **4** 34 DOI 10.17238/issn0536-1036.2019.4.34 [In Russia]

[52] Chernodubov A, Kryukova S and Shirnin V 2019 State of the 23-year-old Common oak progeny test in the Central Forest-Steppe. *Proc. 6th Int. Conf.: ‘Conservation of forest genetic resources’* 253 (Kokshetau, Kazakhstan: Publishing house ‘The world of printing’) p 282 [In Russia]

[53] Shirnin V, Kostrikin V, Shirnina L, Blagodarova T, Kryukova S and Tselikov M 2018 *Objects of Selected Oak Seed Production in the Central Chernozem Region* (Voronezh: Publishing house ‘Chernozem region’) p 196 [In Russia]