Growth and ameliorative role of protective plantation in conditions of forest-steppe zone

V I Mikhin1,*, V V Taniykevich2 and E A Mikhina1

1Faculty of Forestry, Voronezh State University of Forestry and Technologies named after G. F. Morozov, 8 Timiryazeva street, 394087, Voronezh, Russian Federation
2Faculty of Forestry, Novocherkassk Engineering and Land Reclamation Institute named after A. K. Kortunov, 111 Pushkinskaya street, 346428, Novocherkassk, Russian Federation

*E-mail: lf_mikhinvi@vgltu.ru

Abstract. The systems of protective plantations transform agro-territories of the forest-steppe of the European part of Russia. With an area of artificial linear plantings in the Central Black soil region of 600000 ha, negative natural phenomena and erosion processes in landscapes were significantly reduced. In windbreaks with fast-growing tree species, the highest growth rates are observed with a row spacing of 3.0 m and a tree spacing of 1.0 m. A convex transverse profile is formed in middle-aged stands, where the height of the middle rows is higher by 12.1 - 17.2% than in the extreme. The average tree growth continues up to 30 years. The growth rate is 0.73 - 0.83 m/year with the decrease from the age of 15-24 years. In the system of forest belts during the growing season, there is an increase in relative humidity of 1.8 - 9.8%, which altogether leads to an increase in the yield of grain crops by 330 - 550 kg/ha. The formation of plantings on the arable land of optimal parameters and structures will make it possible to have biological structures of long-term use with an increasing reclamation effect.

1. Introduction

The forest-agrarian landscapes of the Central Russian Upland of the European part of Russia are subject to adverse natural phenomena and erosion processes [1]. Artificial linear plantings are formed according to the principles of the noosphere type model, taking into account ecological landscape farming. In the conditions of the Central Black soil region, the area of preserved forest reclamation plantations is about 600000 ha. In such plantations there are differences in the growth and preservation of trees, depending on the initial density of the creation, the type of soil. A special transverse profile is formed in them, where trees grow in different ways in the marginal and central rows. They play a huge reclamation role. Such plantings in Brazil, Bangladesh and European countries also change the ecological conditions and aesthetics of the landscape [2-4].

This objects change the ecological conditions and aesthetics of landscape in Bangladesh and European countries [2-4]. Our research in Russia has a zonal in-depth aspect, where protective plantings grow in various soil and hydrological conditions, created at a certain time using a diverse assortment of trees and reproduction technology [1, 5-7]. The artificial linear planting systems are used for fixing the boundaries of agricultural crop rotation, where covering agricultural territories with woody vegetation allows transforming landscapes and increasing their bioproductivity.
The productivity of agricultural land depends on the creation of a special microclimate in the fields, which is formed under the influence of linear plantings of various structures [1, 5].

The aim of the study is to scientifically substantiate forest reclamation parameters (structure, width, and placement of plants) in the formation of complete systems of protective plantations with the participation of fast-growing species, taking into account their growth, state and reclamation functions (influence on the microclimate and biological productivity of agricultural territories). This will make it possible to have highly effective plantations on arable land in terms of forestry, land reclamation and ecology, which is important for science and practice in the conditions of global changes in climatic factors of agricultural territories.

2. Methods of research

The systems of protective stands are the objects of our research. These stands are presented in the form of linear forest belts consisting of trees and shrubs. The protective stands in the forest-agrarian landscapes of Central Chernozem region of Russia are characterized by a large number of species. The main objects of modeling are located with geographical coordinates N-51°01.40, E-35°02.38. Investigation of forest reclamation facilities was carried out according to the generally accepted methods [8]. In protective plantations, a continuous enumeration of woody plants was carried out with the measurement of diameters at the height of the chest (1.3 m) using a measuring fork, determining the height using a laser range finder. To determine the average diameter, at least 200 trees were taken for each species and 25 measurements of their heights were performed for each experimental plot under study (trial plot). The number of plantings, the mixing scheme and the placement of species were taken from the primary materials of agroforestry facilities of agricultural enterprises. The number of preserved specimens was expressed as a percentage of the initial indicator, planted plants per 1 ha of area. The initial planting density of plants was calculated through the nutritional area of one plant, taking into account the parameters of the placement of specimens in a row and row spacing, followed by transfer to a hectare of area. The age of the plantings was determined by the reporting materials or by counting the annual rings on the cuts at the stump and core of wood. The average diameter of tree species (Dav, cm) was obtained from the table of ratios of diameters to sections, taking into account the conversion of the average cross-sectional area of an average tree into diameter.

The average diameter of tree species (Dav, cm) was obtained from the table of ratios of diameters to sections, taking into account the conversion of the average cross-sectional area of an average tree into diameter. The cross-sectional area of an average tree is obtained as the sum of the cross-sectional areas of all measurements of trees by the result of dividing their number. The cross-sectional area of each tree at chest height (1.3 m) is derived from the measured cross-section diameter. The average height of tree species (Hav, m) was determined by the graphical-analytical method from the graph of the ratio of heights and diameters. A graph is built in a rectangular coordinate system, in which the diameter indicators are plotted along the abscissa axis, and heights are plotted along the ordinate axis. The values are aligned, the average diameter is plotted, and the value is interpolated onto the ordinate axis with heights. The average height is then taken.

Differences in the growth rates of stands by the diameter and height of the extreme and middle rows (∆H, ∆D) were obtained in relative percentage units (%), as the difference between the larger and smaller diameters (Dav, cm) and height (Hav, m).

The design (structure) of stands was determined by the number of gaps in the vertical profile of forest strips. The plantings of a ventilated structure in a vertical profile in the crowns should be at least 15%, between the trunks more than 60%.

Openwork plantings are characterized by a degree of openwork throughout the profile from 25% to 75%. Dense plantings visually have practically no gaps.

For model trees cut into segments after 2 m annual rings were counted, followed by a graph-analytical method for constructing tables of the course of growth of tree species aged 4 to 30 years.

In the inter-strip fields during the daytime in dry hot weather, the relative humidity was determined using an Assman aspiration psychrometer every 2 h during the growing season of plants from 8 to 18 h. It was calculated according to the readings of dry and wet thermometers according to
psychrometric graphs. Meteorological stations for observation were installed on the windward side of
the forest strips at a distance of 5 and 2 planting heights (Hn). On the windward side, the observation
stations were at a distance of 5, 10, 15, 25, and 30 planting heights (Hz). For the analysis, the average
data of the stripping zones 5Hn-0-30Hz at a distance of 35-40 planting heights (Hz) were taken.

Harvest of winter wheat was studied by laying bookmarks at 1.0x1.0 m in ten replicates at weather
stations where the microclimate was studied. The size of the biological crop was determined initially
at the reference site and transferred to 1 ha. The yield increase was calculated as the difference in the
indicators of the strip zones and control plots. The materials for the analysis of biometric indicators of
plantations, relative humidity were obtained in the period 1990-2019, crop yields 2015-2019.

3. Results and discussion
In forest belts, tree species have different indicators in growth, condition, and preservation, depending
on the agrotechnical, forest-cultural, and reclamation methods of creation (table 1). At the age of 44, in
the balsam poplar (Pb – Populus balzamifera L.) stands, with an increase in the area of plant nutrition,
the growth and preservation rates of the breed increase by 1.7-12.8%. At the age of 32, in plantations
with the participation of balsamic poplar and silver birch (Bp – Betula pendula Roth) a blown structure
is formed where poplar preservation rate is by 12.7% higher than birch trees one. Similar results also
occur with the growth of white poplar (Pa – Populus alba L.) and silver birch.

Table 1. Taxation indicators of protective stands.

| Plantation # | Species mixture | Location of planting points, m | Species | Density landing pcs/ha | Survivability, % | Age, years | Hav, m | Dav, cm |
|--------------|-----------------|--------------------------------|---------|------------------------|-----------------|-----------|-------|--------|
| 59           | Bp-Pa-Pa-Pa     | 3.0x1.0                        | Pa      | 1334                   | 43.0            | 32        | 20.6  | 26.3   |
| 68           | Pb-Pb-Pb-Pb     | 2.5x1.0                        | Pb      | 2000                   | 35.1            | 44        | 16.8  | 21.9   |
| 72           | Pb-Pb-Pb-Pb     | 3.0x1.0                        | Pb      | 4000                   | 28.3            | 36.2      |       |        |
| 53           | Bp-Bp-Pb-Pb-Bp  | 2.5x1.0                        | Bp      | 3333                   | 30.0            | 44        | 22.8  | 36.2   |

*Bp – Betula pendula Roth., Pa – Populus alba L., Pb - Populus balzamifera L., Hav and Dav – average height and diameter of tree species.

At the same time, a forest strip consisting of poplar and birch with a location of 3.0 x 1.0 m at the
age of 32 years is represented by a blown structure, where the safety of poplar is 4.9% higher
compared to a forest strip of poplar and birch, where the location is 2.5 x 1.0 m, which indicates the
need to increase the row spacing.

In protective stands, tree species grow differently depending on its location in the transverse profile
(table 2). The wood species in middle-aged stands (35-44 years old) form a convex transverse profile.
On gray forest soils and chernozems in birch and balsamic poplar forest belts, an advantage in the
height of the central rows above the marginal (ΔH) is by 7.4-12.5% and a growth lag in average
diameter (ΔD) is of 6.1- 18.2%. The most significant changes in diameter are noted in poplar stands,
significant differences in height are characteristic of birch forest belts.
Table 2. Features of the growth of tree species in protective plantations stands.

| Plantation # | Age, years | Species | Extreme rows | Middle rows | Difference in performance |
|--------------|------------|---------|--------------|-------------|--------------------------|
|              |            |         | H_{av}, m    | D_{av}, cm  | H_{av}, m    | D_{av}, cm  | ΔH, % | ΔD, % |
| 131          | 35         | Bp      | 21.4±0.21    | 25.9±0.22   | 23.1±0.18   | 24.4±0.19   | 7.4   | 6.1   |
| 156          | 40         | Pb      | 23.8±0.27    | 36.3±0.18   | 26.6±0.17   | 30.7±0.21   | 10.5  | 18.2  |
| 143          | 44         | Bp      | 22.5±0.19    | 29.8±0.19   | 25.7±0.19   | 26.4±0.20   | 12.5  | 12.9  |

aBp – Betula pendula Roht., Pb - Populus balzamivera L.

In different soil conditions, tree species have differences in biometric growth indicators (table 3). The growth of non-mixed fast-growing tree plantations has been studied under experimental conditions of chernozem soil. According to model trees, it has been found that at the age of 30 in a plantation of balsamic poplar on chernozem a average annual growth in height was 0.89 m/year, and birch trees grew up to 0.81 m/year. Under leached chernozem, growth rates are, respectively, 0.78 m/year and 0.73 m/year. The changes in growth and a decrease in growth energy are observed from the age of 15-21, for leached chernozem from the age of 18-24 years. On typical chernozem, silver birch shows a decrease in growth at the age of 18-19 years. On leached chernozem, a decrease is observed at the age of 16-20 years. Soil conditions affect the growth of tree species. At the age of 30, balsam poplar has a height of 26.8 m on more fertile soils (typical chernozem). At the same age, silver birch has a height of 24.3 m on a typical chernozem. On less fertile soils (leached chernozem), the wind protection height is 23.5 and 22.0 m (table 3). Taking into account the found patterns, the distance between protective plantings can be increased on fertile soils. This will not affect the reclamation efficiency of these plantations.

Table 3. Dynamics of growth of tree species in height in protective plantings, m.

| Age, years | Typical black earth | Leached chernozem |
|------------|---------------------|-------------------|
|            | Balsam poplar | Dwarf birch | Balsam poplar | Dwarf birch |
| 4          | 4.3      | 3.6     | 3.9      | 3.2     |
| 6          | 5.0      | 4.6     | 4.5      | 3.8     |
| 8          | 6.7      | 6.1     | 5.2      | 4.8     |
| 10         | 8.5      | 7.2     | 6.6      | 6.0     |
| 12         | 10.4     | 9.2     | 9.8      | 8.2     |
| 14         | 13.2     | 11.3    | 12.8     | 10.0    |
| 16         | 15.1     | 13.6    | 14.3     | 11.6    |
| 18         | 17.1     | 15.0    | 15.3     | 14.5    |
| 20         | 19.2     | 18.4    | 16.8     | 15.8    |
| 22         | 21.3     | 20.3    | 18.0     | 16.5    |
| 24         | 22.8     | 21.6    | 19.3     | 17.4    |
| 26         | 23.4     | 22.3    | 20.8     | 19.4    |
| 28         | 24.5     | 22.8    | 21.7     | 20.2    |
| 30         | 26.8     | 24.3    | 23.5     | 22.0    |

The protective stands in forest-agrarian landscapes influence the relative air humidity indicators of the surface air layer. Such changes have differences depending on the structure of forest reclamation objects (table 4).

In the system of protective plantations from forest strips of the blown structure during the vegetation period in hot dry weather during the daytime in the strip zones of 5 Hn-0-30Hz, an increase in relative humidity of 9.8% was revealed, which favorably affects the growth and development of artificial agricultural land (table 4). Forest strips of openwork-blown structure during the same period
contribute to the increase in air humidity by an average of 5.8%, which is also important for plant growth in the streak zones. Openwork protective structures are less effective. Among it, there is an increase in air humidity of only 3.6%. Plantations of a dense structure with an indicator of influence on air humidity of 1.8% are considered less effective. In all cases, the greatest changes were revealed on the windward side at a distance of 5-12 Hz (heights) from the stands. Thus, experimental studies have established that the best protective stands for influencing the relative humidity of the surface air layer are forest strips of the blown and openwork-blown structure. It significantly contributes to the redistribution of air masses of the lower layers of air, which is especially important for the formation of a microclimate of inter-band fields.

Table 4. Relative humidity in forest reclamation systems (1990-2019), %.

| Structure of plantation | Period of the day | In plantation | In the zone 5Hn-0-30Hz | Control, 35-40Hz | Difference with respect to control, % |
|------------------------|------------------|---------------|-----------------------|-----------------|------------------------------------|
| B                      | Day time         | 48.3          | 50.4                  | 40.6            | +9.8                               |
| OB                     | Day time         | 53.4          | 52.4                  | 46.7            | +5.7                               |
| O                      | Day time         | 60.1          | 56.7                  | 53.1            | +3.6                               |
| Wp                     | Day time         | 58.8          | 54.2                  | 52.4            | +1.8                               |

*B, OB, O, Wp – blown, openwork blown, openwork, windproof (dense) structures (structure) of protective plantings; Hn – windproof height for the windward side; Hz – windproof height for the windward side, m.

As a result of the positive impact of protective plantings on the microclimate of agricultural territories, crop yields change (table 5). The protective plantations in the stripe zones (0-30 Hz) change the quantitative and qualitative composition of winter wheat. The biological yield in the protective areas of the fields among the forest strips of the blown structure is 550 kg/ha or 18.2% higher than in unprotected landscapes. In agricultural territories, among the openwork plantations, the wheat yield is higher by 410 kg/ha or 15.8% compared with the control plots of the fields (35-40 Hz). Dense plantings of dense structure are less effective. The yield increase under its influence is 330 kg/ha or 10.6%. As a result of the reclamation effect, the active zone for plantings of the blown structure extends to 26-30 Hz, openwork -18-23Hz and dense -14-17Hz. The significance of differences in the indicators is significant.

Table 5. Productivity of winter wheat in the system of protective plantings (2015-2019), kg/ha.

| Structure of plantation | In the 0-30Hz zone | Control, 35-40Hz | Difference in relation to control, kg/ha |
|------------------------|-------------------|-----------------|----------------------------------------|
| B                      | 3620±27           | 3020±31         | +550                                   |
| O                      | 3140±33           | 2690±42         | +410                                   |
| Wp                     | 3410±38           | 3120±43         | +330                                   |

*B, O, Wp – blown, openwork, and windproof (dense) structures (structure) of protective plantings.

Harvest is the final indicator in identifying the optimal planting structures for forest reclamation arrangement of agricultural territories. In other countries, there have been numerous studies of agro-forestry systems. The biodiversity of these systems was investigated. Growth, condition, improvement of microclimate and habitat, reduction of erosion processes were also investigated [5, 9-11]. These works confirm the results of our studies, which are unique for the conditions of the Russian Central forest-steppe zone. Protective plantings have an optimum density of 1000-2000 trees per hectare in Valonia, Greece. In Germany (in the Sprellwald floodplain), the placement of these plantations every 50 meters creates a highly eco-friendly environment. When creating protective plantations, it is necessary to establish patterns in forest-agricultural landscapes.
4. Conclusion

For the conditions of the forest-steppe of the Central Black Earth Region of Russia, the obtained scientific novelty and scientific originality consists in the fact that the best conservation indicators, biometric data of fast-growing species (poplar balsamic and silver birch) are revealed in artificial stands with less planting density. In middle-aged stands (32-44 years) with the placement of seats 2.5-3.0x1.0 m, the safety of rocks reaches 25.4-43.0%. In poplar and birch plantations on chernozems and gray forest soils at the age of 35-44 years, the fringe rows have a larger diameter by 6.1-18.2% than the average ones. Moreover, the average height of central rows is 7.4-12.5% higher than the extreme ones. By the age of 30 years, balsamic poplar and birch on chernozems reach a wind-shelter height of 22.0-26.8 m. Their average growth is 0.73-0.89 m/year, the growth energy tends to decrease from the age of 15-24 years. The best indicators are noted on chernozem typical in comparison with other soil conditions.

Among the plantations in the protected areas of the fields during the growing season, there is an increase in the relative humidity of the air of the surface air layer by 1.8 - 9.8%. The greatest influence is noted among the forest strips of the blown and openwork-blown structure. Reclamation impact of plantings is accumulated in an increase in the yield of winter wheat in protected fields in the amount of 330-550 kg/ha. This planting structure should be considered more actively.

When forming forest reclamation systems from fast-growing species (poplar, birch), the width of the plantings should be up to 15 m, row spacing 2.5x3.0 m, where the optimal structure of the transverse profile will be created and the largest crop yield will be formed.

The scientific novelty of the work lies in the establishment of the regularity of the growth of tree species and the formation of the profile of plantations, depending on silvicultural and agrotechnical methods, soil conditions, where, with a decrease in planting density, the safety and biometric growth indicators increase. A special eco-friendly environment is formed in the near-strip zones of plantations, which contributes to an increase in the yield of agricultural crops by 9.3-19.8%. The obtained patterns and parameters can be used in agroforestry in the near and far abroad when creating or assessing forest reclamation systems.

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