Protective afforestation in agroforestry landscapes of the Middle Don basin

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Abstract. The use of forest reclamation facilities to transform the landscapes of the Middle Don basin of the European part of Russia is an important aspect in improving the natural conditions of agricultural territories. In the Central Black Earth Region, they occupy an area of about 600,000 hectares and form the ecological framework of forest agrarian landscapes. The purpose of our research is to establish the optimal conditions for the growth and reforestation efficiency of protective plantations in different conditions. Modern methods and approaches were used for forestry and land reclamation assessment of forest belts. In artificial linear plantings, the biometric indicators of growth and safety in fast-growing species are most pronounced at the initial density of creation and 3334 pcs/ha. The best companions for joint cultivation of English oak are Norway maple and yellow acacia. In the conditions of typical chernozem, the highest values for the growth of rocks are noted. In winter, protective plantations accumulate snow water reserves of 435–430 m³/ha, which makes it possible to form an additional yield of grain crops by 320–430 kg/ha in the strip zones.

1. Introduction

Protective plantations in the Central Black Earth region in the middle Don basin of the European part of Russia have formed the ecological framework of forest agrarian landscapes. With an area of about 600,000 ha, the field-protective forest cover of arable land is 1.3%. Additional arrangement of agro-territories is required [1]. Artificial plantations are formed using various silvicultural and agrotechnical methods of creation. They have a certain effect on the environmental factors of protected areas. Their effectiveness is determined by the structure of the cross-section. In Bangladesh, Brazil and European countries, artificial plantations improve the habitat, change the aesthetics of landscapes and microclimate [2-4]. Under the conditions of Canada, it has been established that the composition and structure of plantations in agroforestry plantations change due to natural and anthropogenic impact [5]. Plantation systems in agroforestry are cost-effective formations where there is a combination of production factors and biodiversity conservation. They are the most efficient in comparison with general production plantings, where the difference is 45-65% [6]. On African farmland, trees must be adapted to local conditions. This increases their environmental sustainability [7]. Our research complements the scientific concept for the formation of complete systems of protective plantations in the zonal aspect [1, 8-10].

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The purpose of our research is to identify the optimal artificial linear protective plantings based on their growth in different soil conditions and forest reclamation efficiency. This will allow transforming agro-territories, improving the ecology of landscapes, and increasing the biological productivity of agricultural crops [1, 8].

2. Methods of research
Forest reclamation plantations are objects of study in the conditions of the Central Black Earth Region (Russia). They are mostly located with geographic coordinates N-51°01.40, E-35°02.38. Investigations of the systems of protective plantings were carried out according to generally accepted methods, fully described in [8]. The soil conditions of the forest reclamation facilities were established according to the data of soil maps. For each plant species, the diameter was measured in rows at the height of the chest (1.3 m) with a measuring fork at least 200 times. Using a laser rangefinder, the height of tree species was determined in 25 plants of each species. On the trial plot, all trees were counted, followed by conversion to 1 hectare and comparison with the initial indicator of creation, which showed the safety of plant specimens. Planting density shows the initial number of studied species per hectare. The average diameter \( D_{av} \) is calculated from the average cross-sectional area of the average tree. The average height \( H_{av} \) is taken from the graph of the ratio of diameters (abscissa) and heights (ordinate). The values were taken from the ordinate axis, taking into account the average diameter. An age drill took a core from an average tree to determine the age of the plantation using annual rings. For these purposes, we also used counting on slices at the tree stump. The transverse structure of the plantation during visual assessment is given as a design, taking into account the number of gaps in the vertical profile. Forest strips of a blown-through structure have up to 15% of the number of gaps in the crowns and more than 60% of the gaps between the trunks. Openwork plantings are characterized by the presence of gaps along the entire vertical profile in the amount of 15-35%. Plantings of a dense structure are represented by objects with no gaps in the crowns and between the trunks. The ecological impact of protective plantings was established by the difference in the indicators of the near-strip zones and control plots. Snow transport in forest-agricultural landscapes was studied along the routes of snow surveys. At the meteorological stations in 6-10 times at a distance from the protective planting up to 2H (heights), the depth of the snow cover \( N_{sw} \) was measured every 5 m, then measurements were taken every 10 m (2-15H) and more than 15H (heights) after 20 m. In the near-lane zones at a distance of 2 and 5H (heights) from the windward side and 5, 15, 30 and 40H (heights) from the windward side, the snow density was determined in triplicate by a weight snow meter (VS-43) with further calculation of the snow stock water \( M, m^3/ha \). For this, the density of snow \( P, g/cm^3 \) was multiplied by the height of the snow cover \( h, cm \), taking into account the conversion factor \( K = 100 \). The winter wheat yield was studied by laying out counting plots with a size of 1.0x1.0 m in ten replicates at meteorological stations, where the microclimate was studied. The size of the biological yield was determined initially at the survey site and converted to 1 ha. The yield increase was calculated as the difference in the indicators of the near-lane zones and control plots. Materials for the analysis of biometric indicators of plantations were obtained in the period 1990-2020, snow surveys in 2010-2017, crop yields in 2013-2020.

3. Results and discussion
The growth, preservation and formation of protective plantings is predetermined by agrotechnical methods of creation (table 1).

In protective plantings on chernozem leached at the age of 35 years from hanging birch \( (Bp – Bétula pénúla Roth.) \), the density of plants determines the growth. When the rock is placed 2.5x1.0 m, its diameter, height and safety indicators are higher by 6.3-11.6%. For crops with a density of 4000 pcs/ha, the windproof height is 18.0 m (plantings 8 and 18).

Changes in the width of the stands and in the number of rows in them also cause differences in growth. In poplar crops \( (Pb – Populus balzamfera L.) \) at the age of 28 years, changes in the parameters of width 5.0 m contribute to a decrease in preservation by 5.4%, growth in diameter and
height by 11.4-13.9% (plantings 28 and 34). Similar patterns are manifested on gray forest soil in common ash (Fe – *Fraxinus excelsior* L.). In crops aged 40 years with a width of plantings of 9.0 m, the preservation is 5.9 %, the biometric indicators of growth in height and diameter are by 9.9-14.9% (stands 46 and 49).

Table 1. The protective characteristics of linear spaces.

| Plantation No. | Species mixture | Location of planting points, m | Species | Density landing, pcs/ha | Survivability, % | Age, years | \( D_{av}, \) cm | \( H_{av}, \) m |
|----------------|-----------------|-------------------------------|---------|-------------------------|------------------|------------|----------------|----------------|
| 8              | Bp-Bp-Bp-Bp      | 2.5×1.0                       | Bp      | 4000                    | 59.4             | 35         | 23.3           | 18.0          |
| 18             | Bp-Bp-Bp-Bp      | 3.0×1.0                       | Bp      | 3334                    | 65.7             | 35         | 26.0           | 19.6          |
| 28             | Pb-Pb-Pb         | 2.5×1.0                       | Pb      | 4000                    | 60.3             | 28         | 22.9           | 20.2          |
| 34             | Pb-Pb-Pb-Pb-Pb-Pb| 2.5×1.0                       | Pb      | 4000                    | 54.7             | 28         | 19.7           | 17.9          |
| 46             | Fe-Fe-Fe-Fe      | 3.0×1.0                       | Fe      | 3334                    | 52.3             | 40         | 17.5           | 15.1          |
| 49             | Fe-Fe-Fe         | 3.0×1.0                       | Fe      | 3334                    | 58.2             | 40         | 20.1           | 16.6          |
| 59             | Bp-Qr-Qr-Bp-Bp   | 2.5×1.0                       | Bp      | 1600                    | 37.9             | 47         | 30.1           | 24.5          |
| 63             | Ap-Qr-Qr-Ap-Ap   | 2.5×1.0                       | Qr      | 2400                    | 19.3             | 47         | 18.9           | 16.1          |
| 67             | Ca-Qr-Qr-Ca-Ca   | 2.5×1.0                       | Qr      | 2400                    | 50.9             | 47         | 25.7           | 22.4          |

*Species*: Bp – *Betula pendula* Roht., Pb – *Populus balsamivera* L., Fe – *Fraxinus excelsior* L., Qr – *Quercus robur* L., Ap – *Acer platanoides* L., Ca – *Caragana arborescens* L., Hav and Dav – average height and diameter of tree species.

Accompanying species and shrubs in different ways serve as a fit for the pedunculate oak (Qr – *Quercus robur* L.). In cultures on typical black oak soil with the introduction of Norway maple (Ap – *Acer platanoides* L.) safety is 44.5% and in plantations with yellow acacia (Ca – *Caragana arborescens* L.) – 50.9%. The best growing conditions for the main species are in oak-maple and oak-acacia plantations. In plantings, biometric growth rates in height and diameter are higher by 6.6-28.1% (stands 59, 63 and 67).

Under certain soil conditions, tree species exhibit different patterns of growth (table 2).

In pure balsam poplar cultures (Pb) at the age of 30 years, the highest growth rates in diameter (20.8 m), height (18.4 m) were found on typical chernozem (plantation 26). With the deterioration of soil conditions, the preservation of the rock decreases (from 64.3% to 54.4%) and biometric data decrease. On leached chernozem, average diameters and heights are lower by 17.8-19.1% compared to objects on typical chernozem and higher by 5.5-6.4 % in relation to the results on gray forest soil (plantations 37 and 64). These patterns are observed in drooping birch (Bp). The best growth and preservation (59.5%) at the age of 39 years are distinguished by forest reclamation objects on typical chernozem. Growth lag in diameter and height on leached chernozem is 12.2-12.5% (stands 29 and 44). Differences in biometric parameters in pedunculate oak (Qr) at the age of 46 years on leached chernozem and gray forest soil are 10.9-16.4%, preservation 7.6% (stands 58 and 68). These differences indicate the peculiarities of soil conditions. On more fertile soils, the greatest growth of species is manifested, which is important in the formation of the wind-shelter height of forest belts.
The influence of protective plantings on the landscape is evident. Such changes depend on the nature of the wind regime, the characteristics of precipitation and mainly on the design of crops (table 3). A snow plume 292 m long (21.9 H) with a snow water reserve of 573-634 m³/ha is formed among the plantings of the blown structure. The plantings are openwork in design and form a snow trail with a length of 215 m (16.1 H) with a snow water supply of 477-591 m³/ha. Protective plantings of a dense structure mainly collect snow inside themselves. Their range of influence extends to a distance of 117 m (8.8 H), where the supply of snow water is 435-528 m³/ha. Differences in the indicators of stub and inter-stub zones are 19.8-31.4%. The best plantings for field protection are forest belts of a blown structure. They are 1.45-2.49 times more effective in terms of the reclamation effect on the landscape.

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As a result of the positive ameliorative influence of protective plantings, changes in the qualitative and quantitative indicators of the yield of agricultural crops occur (table 4).

Artificial plantations of a blown structure increase the yield of winter wheat in the 0-30Hw zone by 430 kg/ha (12.1%). At a distance of up to 25Hw from the forest belts, the highest values were revealed. Among the open-work forest belts, the yield increase is 390 kg/ha (11.0%). Artificial linear plantings of an openwork structure contribute to an increase in yield in near-strip zones (0-30Hw) by 390 kg/ha (11.0%). Their range of influence is up to 20Hw. In the system of dense forest belts in the zone 0-30Hw, the biological yield of winter wheat increases by 320 kg/ha (9.5%). The zone of active influence to the windward side is 10-15Hw. The yield increase from the impact of the plantings of the blown structure is 10.3-34.3% higher compared to the impact of crops of other structures.
Table 4. Yield of winter wheat in the system of protective plantations (2013-2020), kg/ha.

| Structure of plantation | In the zone 0-30 Hz | Control, 35-40 Hz | Difference in relation to the control, kg/ha |
|-------------------------|---------------------|------------------|----------------------------------|
| Bt                      | 3550±26             | 3120±31          | +430                             |
| O                       | 3540±33             | 3150±29          | +390                             |
| Wp                      | 3380±40             | 3060±37          | +320                             |

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

Our long-term studies on the formation of artificial plantations and their ecological and reclamation role are confirmed by the results of studies in other countries of the world [8, 12-14]. In Bulgaria and Hungary, such plantations transform landscapes and improve their productivity [12, 13]. In the conditions of the forest-steppe zone of the Middle Don basin, protective plantations have their own distinctive biometric characteristics, are unique in terms of creation time and reproduction technologies.

4. Conclusion

In the forest-agrarian landscapes of the forest-steppe zone of the Middle Don basin of the Central Black Earth region, scientific novelty and scientific originality lies in the fact that in artificial protective plantations of pedunculate oak at the age of 47 years, the influence of accompanying species and shrubs on the growth of the main species is noted. In oak-birch forest belts, the pedunculate oak has the lowest preservation (19.3%) and biometric growth rates. The optimal plants for growing together with English oak are Norway maple and yellow acacia. In such plantations, its average diameter reaches 24.0-25.7 cm, height – 20.8-22.4%. At the age of 28-40 years, plantations of balsam poplar and common ash with a width of 7.5-9.0 m have a higher preservation, height and diameter by 5.4-14.9% than crops with a width of 12.5-15.0 m At the age of 35, in the forest belts of drooping birch, with a decrease in the density of creation by 666 pcs/ha, an increase in diameter, height and preservation by 6.3-11.6% is noted.

In forest reclamation objects with changes in soil conditions, a variation in the growth rates of rocks is noted. At the age of 30-39 years in cultures of balsam poplar and drooping birch, the maximum growth of species is noted on typical chernozem, with 59.5-64.3% of plant intactness. The smallest values at the age of 30-46 years in growth in the pedunculate oak and balsam poplar appear on the gray forest soil, where the lowest preservation (53.3-54.8%).

As a result of winter reclamation influence, the greatest distance of the snow plume spreading (21.9 H) is noted among the plantations of the blown structure. The stock of snow water is 537-634 m$^3$/ha. Forest belts, dense in structure, have a range of influence less than 2.5 times and a reserve of snow water 1.6 times in relation to the impact of crops of other structures.

Protective plantations in near-strip zones increase the yield of winter wheat by 320-430 kg/ha. The influence range extends to 10-25 Hw. The highest values in the yield increase are noted among the crops of the blown structure.

To create plantations for field protection purposes with the participation of contractual, fast-growing and accompanying species up to 15.0 m wide with the placement of plants 2.5-3.0×1.0 m.

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