Agri-environmental role of protective forest plantations

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Abstract. Forest improvement systems in agricultural territories of the central forest-steppe of Russia are designed to ensure a stable ecological state of landscapes, reduce the risks of adverse natural phenomena and anthropogenic load. The area of preserved protective plantings is about 600 thousand hectares in the conditions of the Central Chernozem region. The effectiveness of such biological objects depends, first of all, on the structure of the transverse plantation profile. Linear plantations change the ecological conditions of plantation, the productivity of artificial phytocenoses during the growing season. Under the influence of forest belts, an increase in the moisture content of the surface air layer (by 1.8–6.9%), biological activity of the soil (by 3.6–5.3%), a decrease in the temperature regime of the surface layer of the soil (by 1.0–1.9 °C) and air (0.4-1.5 °C) takes place. Such changes contribute to an increase in the yield of winter wheat by 3.3-5.5 c/ha. The best in influencing the ecological indicators of the landscape are protective stands of the blown, open-blown and open structures, where the range of influence extends to 15-30 planting heights. The formation of protective plantings of optimal structures provide the most complete protection of agrolandscapes from negative natural phenomena, increase the ecological capacity and contributes to obtaining stable and maximum yields of agricultural crops.

1. Introduction
Linear plantations in the European part of Russia form an ecological framework in agrolandscapes. In the conditions of the Central Chernozem region protective plantings occupy an area of about 600 thousand hectares. They are peculiar frontiers for the demarcation of the vegetation ranges. Such plantations are presented by pure and mixed composition. Certain types of tree species and shrubs with various agrotechnical and silvicultural methods of cultivation can be seen there [1]. A specific design or structure of transverse plantations profile is formed. The effectiveness of such protective plantings and the environmental impact is different [1-3]. Protective plantings also play a crucial role in improving the microclimate parameters in land use territories in Bulgaria, Hungary, India, Canada, and the United States [4-6].

The goal of our research is to identify the most effective protective plantations on the basis of their silvicultural and ameliorative peculiarities, agro-ecological influence on the landscape, and to scientifically substantiate the structural parameters of the formation of forest-reclamation systems. This will make it possible to have biological objects in landscapes on arable lands with elevated ecological and land reclamation functions, which is very significant for practice and world science in the period of global climate change.
2. Materials and methods
The objects of the research (to study the reclamation and agroecological features) were protective plantations in the agroforestry landscapes of the Central Chernozem Region of Russia. The main model stands are located with coordinates N-51°.01’.40”, E-35°.02’.38”. Studies of forest reclamation facilities have been carried out according to generally accepted methods, fully described in [7-9]. The age of the plantation was determined by annual rings on stump sections or selection of core-age drill, followed by counting. The diameter was measured with a measuring stick at breast height (1.3 m) in each tree species. The height was determined using a laser ranger. The species safety was calculated on the basis of a comparison of the initial number of plants per 1 ha and the remaining specimens, expressed as a percentage. The average diameter (D) was calculated through the sum of the cross-sectional areas of trees and their number. The average height (H) was determined according to the heights schedule. The plantation design was determined by eye according to the number of gaps in the vertical plantation profile. For forest lanes of a blown structure, the area of the gaps between the trunks is more than 60% of their absence in the crowns. Open-blown plantations have more than 60% of the gaps between the trunks and 15-35% in crowns. Forest belts are characterized by a clearance area between the trunks and in crowns of 15-35%. Plantings density does not have openings in the structures along the entire vertical profile. The relative moisture content and temperature of the surface air layer were determined by an Assman aspiration psychrometer in the daytime every 2 hours during the growing season from 8 to 18 hours. The temperature of the soil to a depth of 5 cm was studied using Savvinov’s thermometers with an interval of 2 hours in the daytime from 8 to 18 hours. The relative air humidity was calculated from the readings of dry and wetted thermometers according to psychrometric charts. Meteorological stations for observation were installed on the windward side of the forest belts at a distance of 5 and 2 heights of planting (H). On the leeward side, the meteorological stations were at a distance of 2, 5, 10, 15, 25, 30 and 35 planting heights (H). For the analysis, the average data of near-belt zones 5Hn-0-30Hz and at a distance of 35-40 planting heights (H) were taken.

The environmental impact of protective plantings was established by the difference in the indicators of the near-strip zones and control plots. The biological activity of the soil was determined by the application method fourfold in the vegetation period by laying cotton fabric area of 0.25 m² in the upper soil layer to a depth of 0.3 m at a distance from protective plantations - 5 heights (H), 25 heights (H) and 35 heights (H). The percentage of decomposed tissue from its original area (0.25 m²) was determined after 30 days. The average values of replications used for the analysis. The winter wheat crop was studied by laying out accounting sites of size 1.0×1.0 m in tenfold repetition at meteorological points where the microclimate was studied. The size of the biological crop was determined initially on the accounting platform and transferred to 1 hectare. The yield increase was calculated as the difference in the indicators of the near-strip zones and control plots. Materials for the analysis of biometric indicators of protective plantings, relative humidity and temperature of the surface air layer, temperature of the soil surface were obtained in the period of 1990-2017, crop yields - of 2013-2017.

3. Results and discussion
Forest belts have different biometric indicators in their development and form a transverse profile in different ways (table 1).

With ordinary mixing of English oak (EO) (Quercus róbur L.) and birch (Be) (Bétula péndula Roth.) at the age of 50 years and espacement of planting points of 2.5×1.0 m, birch has higher rates than pure forest belts from birch. Survivability is 6.7% higher, the average height is 0.3 m, and the diameter is 1.2 cm or 4.3% higher. The silvicultural and ameliorative assessment of the mixed plantation is high and an open structure is formed. Pure plantation has a blown structure.

Poplar survivability is 6.5% higher in the first case when balsamic poplar Bp (Populus balsamífera L.) grows with pea tree (Pt) and European birch at the age of 40 years and espacement of planting
points of 3.0×1.0 m, but it is inferior in height and diameter, and at the same time an open structure is formed in the forest belts.

Table 1. Biometric indicators of protective plantations.

| Plantation No. | Scheme of species mixture | Espacement of planting points, m | Age, years | Species | Survivability, % | H, m | Structure of plantation |
|----------------|---------------------------|---------------------------------|------------|---------|------------------|------|-----------------------|
| 31             | Be-Be-Be-Be-Be           | 2.5 x1.0                        | 50         | Be      | 30.0             | 22.5 | B                     |
| 43             | Be-Wp-Wp-Wp-Wp-Be        | 3.0 x1.0                        | 40         | Be      | 33.1             | 23.6 | B                     |
| 47             | Pt-Wp-Wp-Wp-Pt           | 3.0 x1.0                        | 40         | Wp      | 34.5             | 22.8 | O                     |
| 53             | Eo-Be-Eo-Be-Eo-Pt        | 2.5 x1.0                        | 50         | Be      | 36.7             | 22.8 | O                     |
| 57             | Be-Be-Be                | 2.5 x1.0                        | 18         | Be      | 75.8             | 13.4 | OB                    |
| 69             | Pt-Wp-Wp-Pt-Pt-Pt       | 2.5 x1.0                        | 25         | Wp      | 51.9             | 16.9 | Wp                    |

Note: B - blown structure; OB - open-blown structure; O - open structure; Wp - windproof (dense) structure.

Forest belts consisting of three rows of European birch, when espacement of planting points is 2.5×1.0 m at the age of 18, have a safety of 75.8%. The average height of a birch tree is 13.4 m; the open-blown structure is formed.

In protective plantations consisting of balsam poplar, European birch and pea tree when espacement of planting points is 2.5×1.0 m at the age of 25 years, a dense structure is formed. Poplar reaches a height of 16.9 m, birch - 15.2 m; the preservation is 51.9 and 64.5% respectively.

Protective plantings affect the relative humidity of the surface air layer, which depends on their design and time of day (Table 2). The studies were conducted on the same objects, where structural and biometric indicators of forest belts were studied during dry hot weather during the vegetation period. In the daytime, forest belts of the blown structure increase the relative humidity of air in the 5Hn-0-H-30Hz zone by an average of 6.9%.

Table 2. Relative air humidity in the system of protective plantations (1990-2017), %.

| Structure of plantation | Period of the day | In plantation | In the zone 5Hn-0-30Hz | Control, 35-40Hz | Difference with respect to control, % |
|------------------------|------------------|---------------|------------------------|-----------------|--------------------------------------|
| B                      | Daytime          | 50.3          | 53.9                   | 47.0            | +6.9                                 |
| OB                     | Daytime          | 47.9          | 50.3                   | 46.6            | +3.7                                 |
| O                      | Daytime          | 57.5          | 59.3                   | 55.7            | +3.6                                 |
| Wp                     | Daytime          | 49.8          | 55.4                   | 53.6            | +1.8                                 |

Open-blown protective plantations only contribute to an increase in the relative humidity of air in the inter-strip field by 3.7% or by an average of 1.9 times less than the previous ones.

According to our research, the forest belts having open structure in the interband zone (5H-0-30H) also increase the relative air humidity by 3.6% on average. In this case, the maximum is observed at a distance of 5H on the windward side of the forest belts.

Full protection stands of dense structure during the day only slightly increase the relative air humidity (1.8%). The greatest change is noted on the leeward side at a distance of 5-15 heights (H).
The relative humidity of the air is 1.8–5.6% less in the plantations (daytime) than in the inter-belt space. Thus, according to the influence on the relative humidity, open-blown structures should be considered the best belts in agroforestry landscapes. However, they have a distinctive zonal character, where the range of the total effect of plantations of various structures is established.

**Table 3.** The temperature of the surface air layer in the system of protective plantings (1990-2017), °C.

| Structure of plantation | Period of the day | In plantation | In the zone 5Hn-0-30Hz | Control, 35-40Hz | Difference with respect to control, % |
|------------------------|------------------|---------------|------------------------|------------------|---------------------------------------|
| B                      | Daytime          | 28.3          | 28.9                   | 30.4             | -1.5                                  |
| OB                     | Daytime          | 29.4          | 30.1                   | 30.6             | -0.5                                  |
| O                      | Daytime          | 27.0          | 28.3                   | 28.7             | -0.4                                  |
| Wp                     | Daytime          | 27.7          | 27.9                   | 27.8             | +0.1                                  |

The forest strips of the blown structure on the average between lanes (5Hn-0-30Hz) reduce the temperature of the surface air layer by 1.0-2.0°C (3.4 - 7.2%) during the daytime which is very important for crop growth during the period of hot dry weather. Protective plantings of the open-blown structure reduce the air temperature by 0.4 - 0.7°C (1.3 - 2.3%) in the daytime. On average, the air temperature is lower by 0.8-0.9 °C (2.9 - 3.2%) in the open forest belts in the influence zone in the first half of the day and noon time then in the second half of the day there is an increase by 0.1°C Dense forest belts (in the inter-belt field in the first half of the day) lower the temperature of the surface air layer in comparison with the control one by 0.1 °C and increase in the afternoon.

In general, protective plantations reduce the temperature of the surface air layer by 0.4-1.5 °C in the daytime in hot dry weather in the 5Hn-0-30Hz zone except for densely wooded forest areas (table 3). Here the temperature increases by 0.1°C. The temperature is 0.6–1.3°C (1.3–4.8%) lower than in the impact zones of the belts.

Conducting research in the summer period (June, July) in the fields occupied by winter wheat at an approach angle of 70–80 ° wind flow showed that the forest belts of the blown, open-blown and open structure contribute to a decrease in the temperature of the surface soil layer (0–5 cm) in near-belt.

**Table 4.** Soil temperature in the system of protective plantations (1990-2017), °C.

| Structure of plantation | Period of the day | In plantation | In the zone 5Hn-0-30Hz | Control, 35-40Hz | Difference with respect to control, % |
|------------------------|------------------|---------------|------------------------|------------------|---------------------------------------|
| B                      | Daytime          | 18.3          | 30.4                   | 32.3             | -1.9                                  |
| OB                     | Daytime          | 17.3          | 29.8                   | 31.3             | -1.5                                  |
| O                      | Daytime          | 19.7          | 29.9                   | 30.9             | -1.0                                  |
| Wp                     | Daytime          | 23.6          | 29.9                   | 29.9             | 0.0                                   |

A decrease in temperature by 1.2 - 2.4 °C is noted in the 5Hn-0-30 Hz of blown forest belts during the daytime on the soil surface (0 - 5 cm) (table 4). The zone of effective influence extends up to 25 heights (H) to the leeward side. Open-blown forest strips also lower the soil temperature in the 0–5 cm layer from 1.0 to 1.7 °C in the first, second half of the day and midday hours.

Protective plantings of the open structure lower the soil temperature in the 0–5 cm layer by 1.1–2.0 °C in the first half of the day and midday hours, and the soil temperature practically does not increase in the second half of the day. Forest belts of dense structure reduce the temperature in the surface layer of the soil (0 - 5 cm) to 1.4 °C in the first half of the day, the temperature increases by 0.5 - 0.9 °C in the afternoon and afternoon. Protective plantings actively influence the distance up to 2-5 degrees (H) on the leeward side.
In the shelter stands themselves, the temperature of the soil to a depth of 0–5 cm during the day is 6.3–12.5°C lower than in the near-belt zones.

The temperature of the surface air layer in forest-agrarian landscapes correlates with the temperature of the surface soil layer. In this case, the determining factor on which the temperature of the soil depends is the design of protective plantations.

The soil cover in its aggregate structure is enriched with cellulose-spreading microorganisms. At the same time, the soil is a natural environment, where its biological activity is a special component [8]. Protective linear plantations affect the indicators of the biological state of the soil (table 5).

**Table 5. Microbiological activity of the soil in the system of protective plantation, %.

| Structure of plantation | Distance from plantings | 2015  | 2016  | 2017  | Average for 3 years | Difference in relation to control, % |
|-------------------------|-------------------------|-------|-------|-------|--------------------|-------------------------------------|
| B                       | 5 H                     | 40.6  | 36.0  | 42.6  | 39.7               | +5.3                                |
|                         | 25 H                    | 36.4  | 32.9  | 40.0  | 36.4               | +2.0                                |
|                         | 35-40 H(control)        | 32.8  | 31.6  | 38.7  | 34.4               | -                                   |
|                         | 5 H                     | 37.3  | 31.9  | 37.7  | 35.6               | +3.6                                |
| O                       | 25 H                    | 34.5  | 30.0  | 36.5  | 33.7               | +1.7                                |
|                         | 35-40 H(control)        | 31.7  | 28.5  | 35.7  | 32.0               | -                                   |
|                         | 5 H                     | 33.6  | 29.8  | 35.2  | 32.9               | +2.7                                |
| Wp                      | 25 H                    | 31.0  | 27.4  | 34.5  | 31.0               | +0.8                                |
|                         | 35-40 H(control)        | 29.9  | 26.9  | 33.9  | 30.2               | -                                   |

Cellulose-depleting activity of the surface layer of the soil is 39.7% in the landscape at a distance of 5 heights (H) from the plantings having blown structure. It is 36.4% with a distance of 25 heights (H). The indicator is 34.4% in areas without protection.

Microbiological activity is 35.6 and 33.7%, respectively, among plantations of openwork structure at a distance of 5 heights (H) and 25 heights (H). The difference with respect to the control plots is 1.6 - 3.6%.

Dense on the structure of plantations affect the indicator of microbiological activity of the soil less actively. The differences in the areas of the near-belt zones (5H, 25H) and unprotected landscapes reach only 0.8 - 2.7%. Thus, according to the degree of impact, the stands of the blown and open structure are the best one (3.6–5.3% higher).

It was established that the most effective impact on the formation of the winter wheat crop was made by protective plantings of the blown structure (table 6). The index of biological yield in the zone 0 - 30H is higher by 5.5 c/ha or 1.19 times as compared with the control one. Under the influence of forest strips of the open structure, the yield increase in the zone of influence is 4.1 c/ha or 15.6%.

**Table 6. The yield of winter wheat in the system of protective plantation (2013 -2017), c/ha.

| Structure of plantation | In the 0- 30H zone | Control, 35-40H | Difference in relation to control, c/ha |
|-------------------------|--------------------|------------------|----------------------------------------|
| B                       | 35.1±0.29          | 29.6±0.38        | +5.5                                   |
| O                       | 30.3±0.36          | 26.2±0.40        | +4.1                                   |
| Wp                      | 35.0±0.41          | 31.7±0.49        | +3.3                                   |

Dense forest belts have a less effective impact on the yield and structure of grain crops. In the zone of 0–30 heights (H), the yield increase of winter wheat is only 3.3 c/ha or 10.4% of the open field. The active zone of impact of forest belts according to the above parameters for a blown structure is up to 25-30 heights (H), openwork – 20-25H and dense - 15-20 heights (H).

Our research on the agri-environmental role of protective plantings in forest-agrarian landscapes is confirmed by various studies in other countries of the world [4,5,6,10,11,12], but they have a zonal character and are unique only for the forest-steppe of the European part of Russia.
4. Conclusion
For the conditions of the central forest-steppe of Russia, scientific originality and scientific novelty of the paper consists in the fact that blown and open-blown structures are formed in defensive stands consisting of 3-5 rows at the age of up to 50 years with the participation of fast-growing species. The introduction of shrubs into the marginal rows thickens the lower profile, which contributes to the formation of an open and dense structure.

Protective stands in the near-band zones increase the relative humidity of the surface air layer by 1.8–6.9%, reduce the air temperature by 0.4–1.5°C, and the temperature of the surface soil layer by 1.0–1.9°C in the daytime during the growing season. The best influence on the environmental performance of the microclimate is exerted by the stands of the blown and open-blown structure. The maximum impact extends to 15 heights (H) plantations.

Microbiological activity of the surface layer has the highest values at a distance of 5 heights (H) from plantations (32.9-39.7%). More significant indicators (an increase of 3.6-5.3%) were found in the inter-belt fields among the plantations of the blown and open structure.

A positive ameliorative effect of artificial linear plantations in agricultural landscapes occupied by winter wheat should be noted. There is an increase in the yield from 3.3 c/ha to 5.5 c/ha. The range of influence extends to a distance from 15 to 30 heights (H) of plantations.

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