Study of forest strip systems agrolandscapes structure

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Abstract. The aim of the scientific work is to investigate the forest bands system structure of agrolandscapes with the aim of establishing the duration of periods of its development for determining the main forest species. Research Methodology: complete counting of trees on temporary test plots laid in typical forest belts, analysis of main tree trunks and obtaining equations of relationships between heights and ages; modeling the development of the structure of forest belts using these equations and formulas for determining the distance between forest belts. It was found out that forest lane systems in their development consistently go through certain periods: unsteady, stationary, post-stationary and decaying functioning. The main criterion for choosing the main species when creating forest belt systems is the longest duration of the stationary and post-stationary functioning of the system. For forest strips created from Quercus robur, this duration is 81 years, Fraxinus lanceolata - 63 years; Robinia pseudoacacia - 55 years. According to this criterion, it is not advisable to create forest strips from such main species as Populus nigra and Ulmus pumila on southern chernozems.

1. Introduction

Modern researchers note the leading role of forests in maintaining water purity, maintaining wildlife, reducing global warming, absorbing toxic gases and noise, reducing environmental pollution, conserving soils, and mitigating natural disasters [1]. At the same time, the need for a steady state of forests is emphasized [2], especially in the arid biomes of the Earth (1327 million hectares), whose tree cover has pronounced protective properties and occupies (in 2015) more than 10% of the area [3].

In the USA, the protective properties of forests are considered agroforestry [4]. In Russia, such properties are studied by agroforestry (forest reclamation of agrarian landscapes), the subject of which is the system of forest strips (5-8), which is reflected in the modern concept of protective afforestation [5]. The main purpose of forest land reclamation of field agrolandscapes is to ensure the functioning of forest belt systems [6]. The structure of such systems is formed by forest belts (constituent elements) and system-forming relationships between constituent elements (zones of reclamation influence of forest belts).

Any ecosystem (including the system of forest belts) undergoes certain periods of development of its structure: origin and formation, relative stability or maturity, and gradual death [7, 8]. With nucleation and formation, the system gradually acquires integral connections between the constituent elements. In the period of maturity, the system completely forms its structure, achieving maximum productivity and stability. When dying, the system gradually loses its functions. Therefore, to develop
the theory and practice of forest reclamation of agrolandscapes, it is necessary to study the development of the forest reclamation system structure.

2. Methods and Materials
Our research was based on data from a complete list of trees, on temporary sample plots (200 trees of the predominant species on each site) planted in typical forest strips of the Dono-Donetsk Forest Reclamation Area (agricultural land area 4464055 ha, including arable land 2962287 ha, forest plantations on agricultural land - 152954.3 hectares) of the Rostov region. On test plots, model trees were selected for each main species and their trunks were analyzed according to the method adopted in forest taxation. The analysis data was used to model the development of the structure of the forest strip system (graphic experiment). For this purpose, we used the equations we obtained earlier [9] to determine the distance between forest belts, based on the prevention of wind erosion in the zone of reclamation influence of forest belts ($L_1$, m) and the prevention of water erosion of soils in the slope areas between forest belts ($L_2$, m).

Studies of the structure of forest belt systems were carried out in the Krasnosulinsky and Ust-Donetsk districts of the Rostov Region (more than 60 trial plots in the southern black soil were laid). L V Vlasova took part in the studies.

3. Results and Discussion
In the selected forestry and amelioration region, the shelter-protection and stock-regulating forest belts are mainly 9-12 m wide, and the forest logging strips are 30-45 m wide.

The characteristics of the samples laid in such forest belts with the main species typical for the forestry and amelioration region (Robinia pseudoacacia, Populus nigra, Ulmus pumila, Fraxinus lanceolata, Quercus robur) are given in Table 1.

Robinia pseudoacacia L., in forest strips is mixed with mulberry, white apricot and other breeds. There are also pure plantations of robinia. In all cases, it is characterized by good growth in height and diameter, reaching a height of 11 m by 28 years and a diameter of 10 cm.

Populus nigra (mixed with pendulum birch and false acinia robinia), with the availability of groundwater, has good growth (up to a certain age) in height and diameter. By 22 years, he can reach a height of 13 cm and a diameter of 17 cm.

Ulmus pumila is found both in pure stands and in mixing with oak and other species. It differs in the greatest productivity in pure plantings, reaching a height of 13 cm and a diameter of 17 cm at the age of 30 years.
Table 1. Characterization of forest belts with typical main species in Krasnosulinsky and Ust-Donetsk regions.

| № sample | The composition of the forest strip | Breed | Age | Height, m | Diameter, cm | The number of trunks, pieces / ha | Stock, m³/ha | Cross-sectional area, m²/ha |
|----------|-------------------------------------|-------|-----|-----------|--------------|----------------------------------|-------------|-----------------------------|
| 1        | 2/3 Robinia, 4/5 Mulberry, 6/7 Robinia | Robinia  | 22  | 10        | 9.4          | 1860                             | 67.3        | 12.94                       |
|          |                                    | Mulberry | 22  | 9.5       | 9.5          | 596                              | 19.2        | 4.23                        |
|          |                                    | Total    |     |           |              | 86.5                             | 17.17       |                             |
| 16       | 1/2 Robinia, 3/4 Robinia, 5/6 Robinia | Robinia  | 11  | 8.3       | 8.9          | 1400                             | 39.2        | 8.81                        |
|          |                                    | Robinia  | 28  | 10.9      | 9.9          | 2513                             | 108.0       | 1.20                        |
|          |                                    | Apricot  | 28  | 6.0       | 7.0          | 312                              | 3.9         | 0.19                        |
|          |                                    | Total    |     |           |              | 11.9                             | 1.39        |                             |
| 28       | 1/2 Robinia, 3/4 Robinia, 5/6 Robinia | Robinia  | 22  | 9.8       | 10.7         | 3238                             | 136.0       | 29.19                       |
|          |                                    | Poplar   | 22  | 13.2      | 16.8         | 705                              | 102.2       | 15.70                       |
|          |                                    | Total    |     |           |              | 238.2                            | 44.89       |                             |
| 36       | 1/2 Robinia, 3/4 Robinia, 5/6 Robinia | Robinia  | 22  | 9.6       | 10.7         | 3238                             | 136.0       | 29.19                       |
|          |                                    | Poplar   | 22  | 13.2      | 16.8         | 705                              | 102.2       | 15.70                       |
|          |                                    | Total    |     |           |              | 238.2                            | 44.89       |                             |
| 46       | 1/2 Robinia, 3/4 Robinia, 5/6 Robinia | Robinia  | 22  | 9.6       | 10.7         | 3238                             | 136.0       | 29.19                       |
|          |                                    | Poplar   | 22  | 13.2      | 16.8         | 705                              | 102.2       | 15.70                       |
|          |                                    | Total    |     |           |              | 238.2                            | 44.89       |                             |
| 24       | 1/2 Elm, 3/4 Elm, 5/6 Elm, 7/8 Elm | Elm     | 29  | 11.8      | 13.7         | 1889                             | 151.4       | 27.93                       |
|          |                                    | Elm     | 29  | 9.9       | 14.3         | 459                              | 38.2        | 7.38                        |
|          |                                    | Oak     | 29  | 7.0       | 7.3          | 316                              | 5.4         | 1.34                        |
|          |                                    | Total    |     |           |              | 43.6                             | 8.72        |                             |
| 35       | 1/2 Elm, 3/4 Elm, 5/6 Elm, 7/8 Elm | Elm     | 29  | 11.8      | 13.7         | 1889                             | 151.4       | 27.93                       |
|          |                                    | Elm     | 29  | 9.9       | 14.3         | 459                              | 38.2        | 7.38                        |
|          |                                    | Oak     | 29  | 7.0       | 7.3          | 316                              | 5.4         | 1.34                        |
|          |                                    | Total    |     |           |              | 43.6                             | 8.72        |                             |
| 45       | 1/2 Elm, 3/4 Elm, 5/6 Elm, 7/8 Elm | Elm     | 29  | 11.8      | 13.7         | 1889                             | 151.4       | 27.93                       |
|          |                                    | Elm     | 29  | 9.9       | 14.3         | 459                              | 38.2        | 7.38                        |
|          |                                    | Oak     | 29  | 7.0       | 7.3          | 316                              | 5.4         | 1.34                        |
|          |                                    | Total    |     |           |              | 43.6                             | 8.72        |                             |
| 7        | 1/2 Ash, 3/4 Ash, 5/6 Ash | Ash     | 16  | 6.4       | 6.6          | 3748                             | 44.7        | 12.74                       |
|          |                                    | Robinia | 21  | 11.0      | 10.1         | 1032                             | 44.6        | 8.30                        |
|          |                                    | Ash     | 21  | 12.0      | 12.7         | 900                              | 65.7        | 11.32                       |
|          |                                    | Total    |     |           |              | 110.2                            | 19.62       |                             |
| 12       | 1/2 Elm, 3/4 Elm, 5/6 Elm, 7/8 Elm | Ash     | 17  | 8.4       | 10.0         | 1338                             | 45.3        | 10.54                       |
|          |                                    | Oak     | 17  | 6.6       | 6.9          | 746                              | 10.9        | 2.81                        |
|          |                                    | Total    |     |           |              | 56.2                             | 13.36       |                             |
| 31       | 1/2 Oak, 3/4 Apricot | Oak     | 28  | 5.9       | 13.0         | 422                              | 20.4        | 5.61                        |
|          |                                    | Apricot | 28  | 6.0       | 16.1         | 152                              | 10.2        | 3.09                        |
|          |                                    | Total    |     |           |              | 30.6                             | 8.70        |                             |

*a* fshb – forest shelter belt,

*b* lf – lane forest

*c* srfb – stock-regulated forest belt

Fraxinus lanceolata as the main breed, is found mixed Robinia pseudoacacia, and as a companion breed, mixed with Quercus robur. By age 21, Fraxinus can reach a height of 12 m and a diameter of 13 cm.

Quercus robur tree, among its companions, has Fraxinus lanceolata, Prunus armeniaca, and other species. By the age of 17, an Quercus can exceed a height of 6 m and reach a diameter of 7 cm. The growth progress of model trees in height at the trial plots is shown in table 2.
Table 2. Growth progress of model trees in height on trial plots.

| Age | Height, m | Age | Height, m | Age | Height, m | Age | Height, m |
|-----|-----------|-----|-----------|-----|-----------|-----|-----------|
| 1   | 0.65      | 1   | 0.65      | 1   | 0.65      | 2   | 0.40      |
| 2   | 2.80      | 2   | 1.30      | 2   | 1.30      | 3   | 0.65      |
| 3   | 3.80      | 3   | 1.80      | 3   | 1.80      | 5   | 1.30      |
| 4   | 5.80      | 5   | 2.80      | 4   | 2.80      | 6   | 1.80      |
| 5   | 6.80      | 6   | 3.30      | 5   | 3.80      | 9   | 2.80      |
| 6   | 7.80      | 7   | 3.80      | 6   | 4.80      | 11  | 3.80      |
| 7   | 8.80      | 8   | 4.80      | 7   | 5.80      | 9   | 5.30      |
| 9   | 9.80      | 9   | 5.30      | 9   | 6.80      | 10  | 5.80      |
| 12  | 10.55     | 10  | 5.80      | 12  | 7.05      | 12  | 6.80      |
| 13  | 10.80     | 11  | 6.80      | 13  | 7.80      | 14  | 7.80      |
| 15  | 11.80     | 12  | 7.10      | 15  | 8.30      | 15  | 5.70      |
| 18  | 12.55     | 14  | 7.80      | 17  | 8.80      | 16  | 8.80      |
| 19  | 12.80     | 15  | 8.10      | 18  | 9.13      | 17  | 9.30      |
| 21  | 13.03     | 17  | 8.80      | 20  | 9.80      | 18  | 9.70      |
| 22  | 13.15     | 18  | 9.30      | 21  | 10.05     | 20  | 10.60     |
| 21  | 9.80      | 22  | 10.30     | 21  | 10.30     | 21  | 11.00     |
| 24  | 10.30     | 24  | 10.63     | 27  | 10.80     |
| 28  | 10.90     | 27  | 11.30     |
| 29  | 11.80     |

The equations of connection of the heights of model trees (H, m) with their age (N, years) will be presented in Table 3.

Table 3. The relationship of the heights of model trees with their age.

| Tree species          | The equations of connection | at \( r^2 \) |
|-----------------------|-----------------------------|--------------|
| Populus nigra         | \( H = 4.28 \times \ln(N) + 0.028 \) | 0.991        |
| Robinia pseudoacacia  | \( H = 0.721 \times N^{0.87} \) | 0.985        |
| Ulmus pumila          | \( H = 0.843 \times N^{0.83} \) | 0.962        |
| Fraxinus excelsior    | \( H = 0.666 \times N^{0.92} \) | 0.998        |
| Quercus robur         | \( H = 0.421 \times N - 0.689 \) | 0.995        |

An analysis of equations shows that when plantings enter the mid-age group of age, the Populus nigra is distinguished by its maximum height, and the minimum by Quercus robur. Other breeds in this case occupy an intermediate position. The fast-growing Populus nigra is characterized by a logarithmic dependence of height on age; slow-growing Quercus robur is linear, the rest of the species are represented by power functions.

To analyze the development of the structure of systems of forest bands of agrolandscapes, the obtained equations were used. With their help, heights of model trees (southern black soil) were calculated using different age indicators (Table 3). The obtained heights (H) were substituted into equation [9] and solved using fixed values \( K = 20, \ C_d = 1.5, \cos \beta = 1 \). The slope values were taken \( i = 0.0349 \) (°), as the borderline in the design of the field-protecting m stock-regulating forest bands.

The calculated values of the extent of zones of reclamation impact of forest belts (\( L_i \)) at different ages are shown in Table 4.
With such values of the reclamation influence zones, the maximum productivity of agrocenoses is ensured and there is no wind erosion in the inter-strip areas.

The condition for preventing water erosion on the slope between the forest belts was fulfilled when calculating the distances between the forest belts according to dependence [9]. In this case, the non-erosion velocity of the water flow \( V_H = 0.14 \text{ m/s} \) was taken for southern medium loamy black soil. He fixed values of the variables in the calculations were: \( K_{fs} = 1.07 \) (average value); \( C = 30 \sqrt{I} \) and \( \sigma = 0.5 \) [10]; \( m = 1.5 \) (single slopes on the slope); \( X = 0.000017 \text{ m/s} \) (rain intensity 1 mm / min); \( K_{sp} = 1 \) (straight slope). The distance between the forest strips on a slope of steepness \( 2^\circ \) is equal to:

\[
L_2 = 0.0196 \times 1.07 / 2.25 \times 5.604 \times 0.5 \times 0.00017 \times 1 = 196 \approx 200 \text{ m}.
\]

Using the data in table 3, we plotted the dependences of the extent of the reclamation zones impact of forest belts \( (L_1) \) with different main species on their age, knowing the calculated value \( L_2 = 200 \text{ m} \) (figure 1).

**Table 4.** The height of the model trees \( (H, \text{ m}) \) and the extent of the reclamation impact zone \( (L_1, \text{ m}) \) of forest belts, m.

| Breed            | Index  | Age of model trees |
|------------------|--------|--------------------|
|                  |        | 3  | 5  | 7  | 9  | 15 | 20 | 25 |        |
| Populus nigra    |        |    |    |    |    |    |    |    |        |
| \( H \)          | 4.70   | 6.92 | 8.36 | 9.43 | 11.62 | 12.85 |    |    |        |
| \( L_1 \)        | 83.0   | 122.3 | 147.7 | 166.6 | 205.3 | 227.0 |    |    |        |
| Robinia pseudoacacia |    |    |    |    |    |    |    |    |        |
| \( H \)          | 1.87   | 2.92 | 3.92 | 4.88 | 7.61 | 9.77 | 11.86 |    |        |
| \( L_1 \)        | 33.0   | 51.6 | 69.2 | 86.2 | 134.4 | 172.6 | 209.5 |    |        |
| Ulmus pumila     |        |    |    |    |    |    |    |    |        |
| \( H \)          | 2.10   | 3.20 | 4.24 | 5.22 | 7.98 | 10.13 | 12.19 |    |        |
| \( L_1 \)        | 37.1   | 56.5 | 74.9 | 92.2 | 141.0 | 179.0 | 215.4 |    |        |
| Fraxinus lanceolata |    |    |    |    |    |    |    |    |        |
| \( H \)          | 1.85   | 2.98 | 4.08 | 5.16 | 8.31 | 10.86 | 13.38 |    |        |
| \( L_1 \)        | 34.8   | 52.6 | 72.1 | 91.2 | 146.8 | 191.9 | 236.4 |    |        |
| Quercus robur    |        |    |    |    |    |    |    |    |        |
| \( H \)          | 0.57   | 1.42 | 2.26 | 3.10 | 5.63 | 7.73 | 9.84 |    |        |
| \( L_1 \)        | 10.1   | 25.1 | 39.9 | 54.8 | 99.5 | 136.6 | 173.8 |    |        |

As follows from the data in figure 1, for the Populus nigra, the line of the graph of the length dependence of the reclamation influence zones on age crosses the horizontal line of 200 m (estimated interband distance \( L_2 = 200 \text{ m} \)) at the age of 14 years. For a Robinia pseudoacacia, this intersection point is 25 years old; for Ulmus pumila - 24 years; for Fraxinus lanceolata - 22 years; for Quercus robur - 29 years.

Having omitted the perpendiculars from these points to the abscissa axis, we determine the ages of the periods end of unsteady functioning and the beginning of periods of stationary functioning of systems whose forest bands are represented by the corresponding main species.

The early ages of the onset of stationary functioning of forest belt systems explain the reasons for the preference for using such main species as Populus nigra, Robinia pseudoacacia and Ulmus pumila in practice when creating forest belts. However, the main reason for the preference of a particular breed should be considered the maximum duration of the periods of stationary functioning systems, when in the inter-strip fields both the absence of water and wind erosion and the maximum productivity of agrocenoses are ensured.
The duration of stationary functioning (STF) is determined by the difference between the age of the renewal ripeness (VVS) of the main tree species of forest strips and the length of the period of unsteady functioning (NUF) of the system. After the end of the stationary period of the system’s development, some of the main species of forest stripes, sharply reducing their growth in height, continue to exist for some time without obvious signs of degradation (dryness, partial drying of crowns, etc.). The time of this existence determines the period of post-stationary functioning (PSTF) of the system.

According to our observations in the Donets-Donetsk forestry and amelioration region, the duration of this time of the systems existence is: for forest belts with the main species, Robinia pseudoacacia - 10 years; Fraxinus lanceolata - 15 years; Quercus robur - 20 years.

**Figure 1.** Relations of the lengths of zones of reclamation impact of forest belts with their age: row 1 - the main breed of Populus; row 2 - Robinia; row 3 - Ulmus; row 4 - Fraxinus; row 5 - Quercus.

*Populus nigra* and *Ulmus pumila* in forest strips begin to dry at the end of the STF system.

Therefore, for an objective choice of the main tree species, it is necessary to analyze the duration of the stationary and post-stationary functioning periods of agro landscapes forest belt systems. The results of this analysis are presented in table 5.
**Table 5.** The duration of the periods of functioning of the systems of forest strips in the Donets-Dontesk forestry and amelioration region.

| The main species of forest strips | VVS, age | The duration of the periods of functioning of the system of forest strips, age |
|----------------------------------|--------|----------------------------------|
|                                 |        | NUF  | STF  | PSTF | STF+ PSTF |
| *Populus nigra*                 | 40     | 14   | 26   | 0    | 26        |
| *Robinia pseudoacacia*          | 70     | 25   | 45   | 10   | 55        |
| *Ulmus pumila*                  | 50     | 24   | 26   | 0    | 26        |
| *Fraxinus lanceolata*           | 70     | 22   | 48   | 15   | 63        |
| *Quercus robur*                 | 90     | 29   | 61   | 20   | 81        |

According to table 4, the longest periods of stationary and post-stationary functioning are systems whose forest belts were created with the participation of the following main species: *Quercus robur* (81 years), *Fraxinus lanceolata* (63 years) and *Robinia pseudoacacia* (55 years). It is not advisable to create forest strips with the main species from *Ulmus pumila* and *Populus nigra* in the Don-Dontesk forestry reclamation area. In other forest reclamation areas of the Rostov Region (Priazovsky, Nizhne-Don and Salsko-Manychsky) it is necessary to continue research on the structure of forest reclamation systems to justify the species composition of forest strips.

4. Conclusion

In southern Russia, on ordinary black soil, the following main species mainly participate in forest strips: *Populus nigra*, *Robinia pseudoacacia*, *Ulmus pumila*, *Fraxinus lanceolata*, and *Quercus robur*. The maximum height in the forest strips is distinguished by *Populus nigra*, and the minimum is *Quercus robur*. Other breeds in this age period in height occupy an intermediate position. As the main species grows in height, the structure of forest reclamation systems develops due to an increase in the range of the reclamation impact of forest belts.

An analysis of the trunks of these breeds made it possible to obtain equations for the relationship of the heights of model trees with their age. The fast-growing *Populus nigra* is characterized by a logarithmic dependence of height on age; slow-growing *Quercus robur* is linear, the rest of the species are represented by power functions.

Using the obtained communication equations, as well as the well-known formulas for determining the distances between forest belts, based on the absence of wind and water erosion of soils in the interstrip sections, we conducted a study of the structure of land reclamation systems. We found out that forest reclamation systems of agrolandscapes successively go through periods of their development: unsteady, stationary, post-stationary and decaying functioning. The duration of stationary functioning is determined by the difference between the age of the renewal ripeness of the main tree species of forest strips and the length of the period of unsteady functioning of the system. The duration of the post-stationary functioning of the systems was determined during observations on temporary trial plots. The system of forest belts, the main species of which are *Populus nigra*, is characterized by a period of unsteady functioning of 14 years and stationary functioning of 26 years. After this, a period of decaying functioning of the system of forest strips begins.

For a system of forest belts, the main species of which is the *Robinia pseudoacacia*, the duration of the period of unsteady functioning is 25 years, stationary functioning - 45 years, post-stationary functioning - 10 years. The system of forest belts, the main species of which is *Ulmus pumila*, has a period of unsteady functioning of 24 years, and stationary functioning of 26 years. The period of post-stationary functioning of such a system is absent.

The system of forest belts with the main species has *Fraxinus lanceolata*, the duration of the period of unsteady functioning is 22 years, stationary functioning - 48 years, post-stationary functioning - 15 years. If the main species is *Quercus robur*, then the period of system unsteady functioning is 29...
years, stationary functioning - 61 years, post-stationary functioning - 20 years. The main criterion for choosing the main species when creating systems of forest belts is the largest sum of stationary and post-stationary functioning durations. For forest strips created from *Quercus robur*, this amount is 81 years, *Fraxinus lanceolata* - 63 years; *Robinia pseudoacacia* - 55 years.

It is not advisable to create forest strips with the main species from *Ulmus pumila* and *Populus nigra* in the Don-Donets forestry reclamation area. In other forest reclamation areas of the Rostov region, it is necessary to continue research on the structure of forest reclamation systems to justify the species composition of forest strips.

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