Monitoring and polymorphism in forest-steppe plantations

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Monitoring and polymorphism in forest-steppe plantations

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Abstract. Systems of protective forest plantations actively influence the ecology of the landscape. The growth and formation of forest belts is predetermined by forest-cultural and agrotechnical methods of creation. The data on the growth of some tree species on humus-carbonate soils and chalk exposures are presented. The results of pure cultivation of pine forest stands are shown and recommendations on the formation of pine plantations are given. Dependences are got and thinning for the formation of productive and sustainable forest plantations in the conditions of fresh subor is suggested.

1. Introduction
Forest-steppe is located in the South of the European part of Russia and it is a subject of intensive anthropogenic impact [1]. Industrial and agricultural production, which negatively affects the growth and development of wood and shrub vegetation, is highly developed in this zone. In addition, the area is subjected to frequent dry-water events and erosion processes [1]. World practice has proven reduce of such negative factors only through the creation of artificial forest plantations [2,3]. In the USA and Western European countries, environmental problems for agriculture are solved by agroforestry methods, where artificial plantings increase soil fertility, improve water quality, vegetation biodiversity, carbon sequestration [3,4]. Our studies examine in more detail the growth of individual species depending on soil and climatic conditions, agrotechnical and silvicultural methods of creation, where the ecological role, the parameters for improving the natural environment in landscapes are closely correlated with the structures of plantations. Therefore, the formation of such plantations is an important part of forest reclamation practice.

Protective planting systems are created taking into account natural areas. Therefore, it is necessary to create efficient and durable artificial linear plantations with high abiotic properties in order to replenish losses in soil fertility, to complete protection of landscapes from negative ecological processes, and to increase the phytocences’ productivity. To ensure the sustainability of ecosystems, which will increase the wooded area, improve moisture, heat, gas exchange, change landscapes into more complex, and therefore, in more stable ones, where destructive processes are less active and sustainable ecology framework is formed [1]. Plantings should fulfill ecological, recultivation mission on lands which are subjected to the influence of erosion processes, abandoned and deserted [2]. Currently, in Russia [1], Western Europe [3], and USA [4], strategically, agroforestry is considered to be a relevant area in the development of forest-reclamation systems to mitigate negative natural phenomena in landscapes and increase environmental potential.
Artificial stands are created and formed with the participation of various breeds. It is possible to identify the main forest-forming species-Scots pine (Pinus silvestris L.) considering the issues of creation and formation of plantations in the forest – steppe region of the European part of the Russian Federation [5]. Therefore, it is widely used in forest reclamation practice. It is the only one from the species which can grow in any extreme soil conditions. However, today, both in Russia and in the Republic of Belarus, the issues of initial planting density and subsequent forest activities in the created plantations are not fully resolved [6,7]. At the same time, complete stand is the ideal to which all the foresters should strive in the system of ideal forest. Thus, it is necessary to increase model completeness to increase the productivity of pine stands [8].

Growth, condition, formation of protective plantations in The Central Chernozem region of Russia, their reclamation properties are most fully manifested in their optimal placement on the arable land, right combination of species, agricultural cultivation techniques, the optimal structure for these soil and climatic conditions. Increasing forest cover and landscape design is an important issue of landscape forest reclamation [9-11].

The purpose of our research is the scientific substantiation of the use of different tree species, the algorithm for the care of artificial plantations in different soil and climatic conditions based on their silvicultural and ameliorative value. This allows you to create highly effective protective plantings in terms of productivity and environmental parameters, which is important for science and world practice.

2. Materials and methods
The objects of the study are artificial plantations created on chalk exposures, as well as field-protective plantations in the Central Chernozem region (Russia). The studies have been carried out according to the generally accepted methods fully described in [12]. A test plot was set up with a measuring fork at a height of 1.3 m in diameter, a height using a laser altimeter with a certain sampling frequency (the number of trees in the test plot). The age of plantations was determined by annual rings of tree species by sampling a saw cut or incremental auger with annual rings calculated. The initial data for the analysis were the growth and productivity of various tree species and shrubs in artificial plantations for the period of 1976-2016. The growth and productivity were taken from [1].

Pine plantations with different initial planting density grown in the conditions of fresh subor (B2) (after thinning in the range of 18% stock) have also been the objects of the study with geographic coordinates N-51°01’40”, E-39°02’38”.

Biometric indicators as a diameter, height of woody plants, and their stock have been studied. Silvicultural and ameliorative assessment of artificial plantings has been carried out on the scale of Academician E Pavlovsky. The density of planting and preservation of species have been determined [12]. Planting density was calculated on 1 hectare of plantations, taking into account the area of plant nutrition. The preserved specimens of plants are calculated per unit area. Ameliorative assessment was determined by the structure of stands. The stock was calculated on the basis of the obtained volume of the average model tree, taking into account the safety of rocks. The average diameter (Dav) was determined by the sum of the areas of tree sections and their number. The average height (Hav) was determined according to the heights schedule. Differences (%) in the biometric indicators of the growth of rocks of the extreme rows and averages were obtained in relative percentage units, as the difference between larger and smaller values of diameters (Dav) and heights (Hav).

3. Results and discussion
In artificial linear protective plantations, growth, conservation and condition of species depend on agrotechnical and silvicultural methods of creation. Conducted additional studies on objects over the past 10 years characterize the features of the formation of protective plantings from the creation parameters, which are presented in the form of textual analyzes. The density of seats in the cultivation of poplar is the most important indicator of which depends on the condition, durability and ameliorative properties [1]. Balsamic poplar forest belts at the age of 20 years, 9.0 m wide, but with a
Field protection belts at the age of 24 years with 3.0 m × 1.0 m planting points and planting density of 3.334 pcs/ha have been surveyed. It is established that in protective plantations with a width of 9.0 m, safety is 64.3%, which is by 4.3 and 8.3% higher than in the belts with 12.0 and 15.0 m width. At the same time, the largest average diameter of the poplar has been seen in narrower stand (21.8 cm). Differences in the given data are 1.7 and 2.0 cm and they are confirmed by statistical processing ($t_0 = 7.86; 14.6 > t_{0.05} = 3.02$). The largest average height (19.2 m) has been seen in the forest belt with 12.0 m width. With the increase in width, there is also a decrease in average increments and stock of stemwood.

Joint cultivation of balsamic poplar with English oak and ash trees at the age of 38 years shows that poplar being a fast-growing variety exceeds other species in all biometric indices in forest belts with a planting point of 1.5 m x 0.8 m. The difference in average height is 7.4 - 8.0 m; the average diameter is 10.8 - 11.0 cm, which is relative to the average increments of 0.21 - 0.25 m/year and 0.28 - 0.29 cm/year. However, poplar has the lowest capacity for survival (29.7%) and mixed composition is formed.

Introduction of rowan in field shelter belts facilitates the formation of an openwork structure due to the compaction of the lower part of the profile. However, mixed birch and rowan plantations are more stable and have higher growth rates. Pure 4-row birch field shelter belts with 3.0 x 0.8 m planting points at the age of 25 years lag in height growth by 1.2 m, in diameter - 1.1 cm from birch-ash forest belts, which is predetermined by field participation of species and, accordingly, density of planting.

Width of forest belt and the number of rows in it in pure field shelterbelts affect the growth and state of the birch. It has been revealed that even a slight decrease in the above parameters contributes to an increase in the birch growth rates. So, with the same placement (2.5 m × 0.7 m) at the age of 25-26 years, the advantage remains for a two-row belt in comparison with a three-row band. Average height is 1.3 times larger; average diameter, average increment in height and stock is 1.4; 1.2 and 1.2 times higher, respectively. Forest-reclamation estimation of two-row plantation is 5b, three-row - 4a. An openwork-blown construction is formed in the forest belts. Differences in height and diameter are reliable ones ($t_0 = 6.25 > t_{0.05} = 2.01; t_0 = 18.48 > t_{0.05} = 1.96$) [1].

The energy of poplar growth in protective belts depends on the density of planting and placement of planting points. For example, in three-row forest belts, at a placement of 3.0 m × 1.0 m, the safety is higher by 57.2% than with a placement of 2.5 m × 0.7 m. Differences in height and diameter are significant ($t_0 = 2.94 > t_{0.05} = 2.01, t_0 = 2.03 > t_{0.05} = 1.96$). An openwork construction is formed.

Ash grows in mixed and pure in composition stands. In the studied forest belts, ash has certain regularities in growth and condition, depending on the agrotechnical methods of creating and selecting species. Thus, at the age of 35 years in four-row forest belts, the best growth, condition and conservation of ash is in stands with a density of planting of 4000 pieces per hectare than in field shelter belts with a density of 4762 pieces per hectare. The difference in safety is about 3.0%, in average height, diameter, their increments and stem wood stock of 5.2…16.4%.

Field-protecting forest belts on black soils with the participation of English oak grow in pure and mixed stands. Our studies have shown that growth and condition of oak to a certain extent depends on the accompanying species and agrotechnical methods of cultivation. The introduction of ash into the rows of English oak trees shows that capacity for survival of oak is higher by 3.0%, the average diameter, height, their average increments are larger by 4.1-7.1%, the stock is 15.3% higher than in pure composition at the age of 30 years, with a square-socket arrangement of planting points of 5.0 m × 3.0 m in mixed stands. Forest belts have silvicultural and meliorative assessment of 4b.
Table 1. Characteristics of growth of tree species in different rows of forest belts in the conditions of the Central Chernozem Region of Russia.

| #  | Age, years | Specie | H_{av}, m | D_{av}, cm | H_{av}, m | D_{av}, cm | ΔH, % | ΔD, % |
|----|------------|--------|------------|------------|------------|------------|--------|--------|
| 25 | 28         | B      | 15.3±0.19  | 18.4±0.17  | 16.7±0.19  | 17.4±0.12  | 9.2    | 5.4    |
| 27 | 30         | Fre    | 12.5±0.21  | 15.8±0.20  | 15.1±0.16  | 13.6±0.17  | 17.2   | 13.9   |
| 29 | 45         | Bp     | 23.3±0.19  | 34.5±0.20  | 25.3±0.18  | 30.3±0.23  | 17.2   | 13.9   |
| 30 | 35         | Qr     | 15. 1±0.11 | 21.1±0.21  | 17.0±0.23  | 16.9±0.30  | 12.6   | 19.9   |
| 33 | 28         | Qr     | 12.5±0.13  | 17.2±0.21  | 15.3±0.13  | 14.7±0.21  | 22.4   | 14.5   |
| 36 | 35         | Fre    | 13.8±0.18  | 17.3±0.15  | 15.2±0.20  | 16.8±0.18  | 10.1   | 7.5    |

There are advantages in the growth of the height (ΔH, %) of central rows on the edges of 7.9 – 22.4 % and the gap in average diameter (ΔD, %) of 5.4 -19.9 % on black soils, dark gray and gray forest soils at the age of 28-45 years in the stands of birch (B - Bétula péndula Roth.), Balsamic poplar (BP - Balzamífera Populus L.), English oak (Qr - Quércus róbur L.), European ash (Fre - Fraxinus excelsior L.) (table 1).

In protective plantations of Balsamic poplar and White birch the highest growth rates are seen in typical black soils at 30 years of age. The decrease in energy growth has already been observed from the age of 14 – 24 years. The average annual growth is 0.63-0.79 meters per year.

Artificial linear plantings in forest landscapes change microclimatic parameters, which is important for the growth and development of agricultural censuses. Forest belts are blown, open and dense in their structure. These indicators are determined by the number of fall places in the vertical profile of plantations. Visually there are no fall places in the profile of dense plantations, for openwork plantations – 15-35%, for the plantations which are blown between the trunks - more than 60% and in crowns - less than 15%.

There is an increase in the relative and absolute humidity of the surface air layer (by 1.3 – 7.4% and 0.4 – 4.5 mm) during the daytime in the system of forest belts, a decrease in the temperature of the surface air layer by 0.5 – 1.4°C in winter and redistribution of snow cover among the plantations. Differences in snow cover height and snow water reserves of the affected zones and inter-belt areas reach 17.6-28.5 %.

Field-protective plantings, accumulating and redistributing energy, forming an ecological framework in the landscape, changing the microclimate, contribute to the growth of crop yields. Under their influence, there is an increase in the yield of winter wheat in the amount of 2.7-4.8 quintals per hectare (10.3-16.6 %) in the zone of influence.

Under the influence of field protection belts which have blown structure, biological yield of winter wheat is higher by 5.4 c/ha or 18.2% than on the control plot; length of stem, head, weight of 1000 grains, respectively, by 10.8 cm or 16.5%, 1.1 cm or 21.1%, 5.7 g or 16.8% in the 0-30Hz zone.

The maximum indicator of biological yield is recorded at a distance of 5 Hz and a zone of active influence extends to 28 Hz. The range of effective influence on the mass of 1000 grains and the length of the head and stem is limited to a distance of up to 25 Hz with the largest indices at a distance of 2 Hz.

Open work forest strips in the sub- zone have given an increase in yield of 4.2 centners per hectare or 14.7%, length of the head - 0.8 centimeters or 16.3%, stem length - 8.1 centimeters or 12.7 %, mass of 1000 grains - 4.2 g or 11.6% compared to unprotected areas of the landscape. The range of influence extends to 24 Hz.

Under the influence of plantations of dense construction in the 0-30Hz zone, the biological yield has increased by 3.2 centners per hectare or 11.4 %, the length of the ear was 0.7 centimeters or 14.2
%, the stem 5.5 centimeters or 9.1 per cent, the mass of 1000 grains is 2.8 g or 7.9%. The zone of active influence on the windward side has been 19 Hz.

Forest strips occupy a certain area on arable land, forming afforestation and protection of lands. The data have been grouped and aligned by the method of least squares in terms of field protection of forest cover (0.75 - 3.50%) at intervals of 0.25% and soil quality of 80 points to reveal the connection between the afforestation of arable land and the productivity of agricultural crops.

It has been established that with an increase in the percentage of sheltered forest cover of arable land, the yield of various crops is increasing. So, with a soil quality of 80 points, the yield of oats varies from 18.5 centners per hectare to 33.9 centners per hectare with a forest cover from 1.25% to 3.50%. For the bioproductivity of the crop with a difference in forest cover of 1.5%, the difference in productivity is 29.8%.

The increase in yield by an average of 0.5% of the field sheltered forest cover from 0.75 to 3.50% has the following values for crops with a soil quality of 80 points: oats – 3.1centner/ha. A significant difference in the increase in yields for oats is no longer observed with indices ranging from 2.85 to 3.25% of the arable lands. Therefore, 3.1% of afforestation can be considered the optimal value. This indicator should guide the calculation of volumes for protective afforestation.

Formation of the agro forestry complexes should be implemented taking into account ecological and landscape arrangement of a territory where it should be taken into account silvicultural and ameliorative features of plantations and the rate of afforested farmland.

The problem in the forest-steppe is afforestation of chalk exposures and humus-carbonate soils, the area of which is more than 1.5 million hectares and it is constantly increasing [5].

The conducted research has allowed revealing the characteristic features of the growth of Scots and Black Austrian pine on humus-carbonate soils with different depths of the plate chalk. Assessing the state of the stand for capacity for survival it can be said that it differs depending on the depth of occurrence of the plate chalk, the original density of the creation of plantations and steepness of the slope.

When the steepness of the slope is 5-6° platy chalk lies at a depth of 40-50 cm. Further increase of the slope steepness leads to the formation of humus-calcareous soils with a depth of platy chalk of 15-20 cm or less. Examined cultures of Scots pine have showed a relatively stable relationship of capacity for survival on the steepness of the slope. At a depth of 40-50 cm, capacity for survival of stands at the age of 26 was 64% with an initial planting density of 5.5 thousand pieces per hectare. The sample size is 175 plants (table 2).

| Pine             | Age, years | Survival, % | Sample trees, pieces | H, m | D, cm |
|------------------|------------|-------------|----------------------|------|-------|
| Black Austrian pine | 32         | 68.1        | 213                  | 6.3  | 7.2   |
| Black Crimean pine     | 26         | 64.0        | 175                  | 5.5  | 5.5   |
| Scots chalk pine      | 33         | 58.2        | 217                  | 6.5  | 4.8   |
| Scots sand pine       | 33         | 52.1        | 205                  | 5.0  | 5.2   |
| Scots sand pine       | 26         | 39.6        | 186                  | 4.7  | 4.6   |

With the increase of slope steepness the power of humus-carbonate layer decreases to 30-40 cm, which leads to a decrease in the survival of forest stands to 35 %. In pine stands created on the slope of 30-35° at a depth of plate chalk of 15-20 cm survival at 36 years of age was 41 %. In the cultures of Black Austrian pine at the age of 44 years, growing in similar conditions, the safety is higher. It is 48.5 %, which allows us to conclude about some advantages of Black Austrian pine.

The study of the growth and productivity of some types of pine: Black Austrian, Black Crimean and soil types of ordinary pine – sand and chalk at the age of 26-33 has showed the advantage of chalk pine, the second place is taken by Black Austrian pine.
Artificial plantations of birch, oak, and mixed pine-birch stands successfully grow in the upper part of the slopes on humus-carbonate soils, where their capacity is 50 cm and more. The planting of birch is laid on a relatively flat surface with a slope not exceeding 3-4°. The depth of occurrence of the plate chalk is 40-50 cm.

Birch stands at the age of 30 reach an average height of 10.4 m and breast height diameter of 8.8 cm. It grows in the II site class. The survival rate is 26%. The total stock per hectare is 94 m³. This indicates that the planting of birch in these conditions of growth at the age of 30 years has good growth energy in productivity.

Pine-birch plantations created in similar conditions with the placement of 2.0m × 0.5 m at the age of 38 at the density of 0.7 grow in the I site class.

The rapid growth of birch is due to greater activity, expressed in the increased intensity of the main physiological processes at a young age. Capacity for survival in the plantation is high and is 69.4%, including birch-50% and pine-19.4%. The stock of birch and pine wood is 64 and 141 cubic meters per hectare, respectively.

Plantations of English oak, created on humus-carbonate soils, with a depth of chalk 40-50 cm are now 40 years of age. They have an average height and diameter 12.3 m and 10.0 cm, respectively, and grow at the III site class. Cultures are very sparse, have the fullness of 0.3. Safety is 19.6%. Stock is 88 cubic meters per hectare. It characterizes the planting like successfully growing in these conditions.

Considering the processes of reforestation, it can be noted that the primary issue is to determine the optimal density of standing trees per unit area, which in the process of reforestation depends on the conduct of forest management. The change of the area of supply of the trees with age must be reasonable and timely thinning enhances the productivity and sustainability of plantations in general.

The actual density of pure pine stands varies within 1090-1600 pieces per 1 hectare, respectively, and the area of food varies from 6.25 to 9.2 m². The average diameter varies from 19.8 to 22.0 cm (within 10%), and the average height - from 19.2 to 20.5 m (within 6.3%). Site class (II-I) changes in accordance with the average height. Stock of stem wood is within 379-447 m³ per 1 ha (in the range of 15.2%). Scots pine, Austrian pine, English oak and pine-birch plantations have been studied on sample plots with the number of the main species of at least 200 plants, where the diameter of the trunks of each plant was determined using calipers (at the height of 1.3 m) and altimeters (height of 25 trees). The density of plants per 1 hectare was determined through the feeding area, safety - through comparison of initial indicator and number of surviving plants in the studied age. The stock of stem wood per 1 ha was determined as the product of the remaining number of plants and average size of the model tree.

When describing the state and development of stands, the number of parameters increases: age of the plant, average height of trees, average breast height diameter, number of trunks in the plant, the sum of the cross-section areas, stock of stem wood, site class, completeness of plantings, average and current growth of the plantings. The modes of forest thinning are designed on the basis of measurements of these parameters.

The algorithm of formation of mathematical models of the stands growth includes [6]:

1. Input of initial data - the tables of growth rates of forest stands approved in practice.
2. Mathematical calculation of the absolute errors obtained by the deviation of the empirical dependence on the experimental data.
3. Selection of the model type that corresponds to the minimum absolute error.
4. Calculation of the coefficients of the empirical model.
5. Visual evaluation of the relative position on the graph of the simulation results in the form of empirical dependence and experimental values. If the model does not meet the requirements of accuracy, the transition to the third point of the algorithm is done, where the choice of another type of model is made.
6. Checking the adequacy of the obtained model using Student-Fischer test. If the calculated model does not meet the requirements of adequacy after verification again, then the third point is also passed.
7. The model is accepted after all calculations and checks. The type and coefficients of the new model are transferred to other sub-programs and used in the further work of the control system.

The studies are confirmed by the obtained laws of the researchers from other countries of the world [3,4,7,8], where our results are unique for the conditions of the Central forest-steppe of Russia.

4. Conclusion

For the conditions of the forest-steppe of the Central Chernozem region, scientific novelty and scientific originality lies in the fact that differences in the growth rates of artificial plantation species have been found, where modal chernozem soils has the highest values in comparison with other soils. In forest belts, tree species in the marginal and central rows differ in growth by 5.4-22.4%, in connection with the ecological and physiological processes of plant growth. Under the influence of protective plantings in landscapes, the ecological conditions for the growth of artificial phytocenoses change, which contributes to their growth by 10.3 - 16.6%.

On humus-carbonate soils of forest belts for the first time, the possibility of the formation of both pure and mixed cultures of Scots pine and pedunculate oak has been established. Seedlings of chalk and Black Austrian pine successfully grow on chalk exposures.

The initial density of planting and timely thinning of a certain intensity and frequency should be taken into account. Creation of optimal feeding area and even placement of trees in the area should be made in the process of felling. Formation of plantings is differentiated by optimal modes, taking into account the characteristics of the stand, the type of forest growing conditions. The intensity of thinning is set by the percentage of felled stock, which is less varied less than the density within the types of forest conditions.

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