Influence of various tree species on the properties of soils in the “Kamennaya Steppe”

T N Kramareva¹, E N Tikhonova¹ A I Gromovik²,*, N S Gorbunova² and V A Korolev²

¹Faculty of Forestry, Voronezh State University of Forestry and Technologies named by G. F. Morozov, 8 Timiryazeva street, Voronezh, 394087, Russian Federation
²Department of Soil Science and Land Management, Voronezh State University, 1 University Square, Voronezh, 394018, Russian Federation

*E-mail: ecology@vgltu.vrn.ru

Abstract. The influence of various tree species of forest plantations on the soil properties of the "Kamennno-Stepnoye Experimental Forestry" (Talovsky District, Voronezh Region, Russia) is considered. The aim of the study is to reveal the degree of transformation of the properties of chernozems under various perennial plantations, since forest reclamation is the most important measure to optimize the agroecological state of soils. The researchers note that different tree species have different effects on soil properties. However, this issue is still insufficiently studied and relevant. The research results showed the positive role of tree species on the structural and aggregate state of soils and their water-physical properties. It was found that tree species contribute to the optimization of soil density, humus and moisture reserves. It was revealed that the influence of different tree species on the agroecological state of chernozems is not the same. Thus, under larch (Larix siberica Ldb.) and maple (Acer platanoides L.), the maximum increase in the level of soil humus was observed, as well as a significant improvement in the physical and water-physical properties of soils. What makes this breed the most promising for use in soil protection of the steppe zone.

1. Introduction
The creation of field-protective forest belts is one of the most important soil-protective measures in the conditions of the Central Black Earth Region, as well as in other regions. Wood species in the composition of field-protective forest belts play an important role in regulating the water regime of soils, they retain the necessary reserves of productive moisture for agricultural crops and thereby ensure the reproduction of sustainable crops [1]. In the works of many researchers show the leading role of field forest plantations in increasing biodiversity [2], protecting agricultural landscapes from erosion and drought [3], improving the aesthetics of agricultural landscapes [4, 5], as well as rational forest management [6]. The influence of forest shelter belts on soils is primarily manifested in the transformation of their agroecological state. In this case, there are positive changes in the chemical and physicochemical properties, and in the physical state of soils [7].

Currently, there are a large number of publications on the problem of research, but they concern only general issues of the influence of forest plantations on the transformation of the composition and properties of soils. When implementing agroforestry activities, the question of choosing tree species often arises. This is complicated not only by the structures of field-protective forest plantations, but by
the biological characteristics of the tree species used for these purposes, as well as by their ability to adapt to specific soil-bioclimatic conditions. All this dictates the need for deeper studies of various tree species on the agroecological state of soils [8, 9]. In this regard, the purpose of this work was to identify the degree of influence of various tree species on the properties of soils of the "Kamennaya Steppe". Such studies provide an opportunity for a more accurate and optimal selection of specific tree species for the construction of soil-protective forest plantations.

2. Materials and methods
The studies were carried out on the land-use territory of the "Kamenno-Stepnoye Opytnoe Lesnichestvo" (Talovsky District, Voronezh Region, Russia). The agroecological state of chernozems under such tree species as Siberian larch (Larix siberica Ldb.), Norway maple (Acer platanoides L.), Scots pine (Pinus sylvestris L.) and warty birch (Betula verrucosa Ehrh) was studied in forest belt No. 211, laid in 1959, the forest belt was created by a diagonal-group method, its length and a width of 850 and 22 m, respectively. In addition, in order to more adequately assess the forest belts for the Kamennaya sepiya chernozems, a perennial fallow of 62 years old and adjacent to the forest belt No. 211 arable land 69 years old [10].

At each site (sections of the forest belt, fallow and arable land), there were established soil pits (7 pcs.), from which soil samples were taken for subsequent analyzes. Figure 1 shows the location of research objects in detail, as well as their geographic coordinates.

![Figure 1. Places of selecting soil samples: 1 – Maple section (N 51.050580º, E 40.748916º); 2 – Larch section (N 51.050917º, E 40.746058º); 3 – Birch tree section (N 51.051302º, E 40.743098º); 4 – Pine section (N 51.051847º, E 40.739985º); 5 – Deposit (N 51.050574º, E 40.753180º); 6 – Arable land (black steam) (N 51.051791º, E 40.749597º); 7 – Arable land (winter rye) (N 51.052833º, E 40.740520º).](image)

The soil cover under the lands (figure 1) is represented by ordinary chernozems (WRB - Vorony-Calci, WRB: World Reference Base for Soil Resources), medium-humus, medium-thick, light clayey. The soil forming rocks for these soils were cover carbonate heavy loams and clays [11]. Samples from soil pits No. 1-7 were taken in ten-centimeter layers to the depth of the opening of the parent rocks. The weight of each soil sample was 0.5 kg. To study the structural state of the soils of
the objects of research from a depth of 0…20 and 40…50 cm, soil samples weighing 1 kg were additionally taken with the preservation of structural and aggregate units, in the soil laboratory of Voronezh State University, chemical (humus - Corg., humus reserves), physicochemical (pH of the soil solution, exchangeable cations – Ca²⁺ and Mg²⁺, hydrolytic acidity), general physical (density, porosity and structural and aggregate composition of the soil, criterion of water resistance of soil aggregates) and water-physical (plant wilting moisture, smallest soil moisture capacity and range of active soil moisture) properties of soils.

Determination of organic carbon in soil and conversion to humus (Corg.) were carried out in soil samples devoid of roots. We moistened the mineral part of the soil (fraction 0.25 mm) with 10 ml of 0.4 N chromium mixture (K₂Cr₂O₇ : H₂SO₄ (Vekton, St. Petersburg, Russia), pl. 1.84 in 1:1 ratio) and boiled for 5 min to completely oxidize organic carbon. Further, the analysis was performed titrimetrically with Mohr’s 0.2 N salt ((NH₄)₂SO₄ ∙ FeSO₄ ∙ 6H₂O) (Vekton, St. Petersburg, Russia) in the presence of a 0.2% phenylanthranilic acid (C₁₃H₁₁NO₂) (Vekton, St. Petersburg, Russia) until the color changed to emerald green. The humus content was calculated by multiplying the results of carbon determination by a factor of 1.724. The humus reserves were calculated by multiplying the humus content by the layer thickness (cm) and its density.

The pH of the aqueous suspension was determined at a weight soil with ratio “soil : water” of 1:2.5. The suspension was thoroughly mixed in a 100 ml beaker and then allowed to stand for 24 h. Then, in the supernatant liquid, the activity of hydrogen ions was determined potentiometrically using an I-160MI microprocessor ionomer (Aquilon, Moscow, Russia).

Determination of exchangeable cations of calcium (Ca²⁺) and magnesium (Mg²⁺) in soil samples weighing 5.0±0.1 g (scales EK-300i, A&D, South Korea), sifted through a sieve with a hole diameter of 1 mm. The weighed portions were placed in porcelain cups with a capacity of 100 ml, and then a 1 M solution of sodium chloride (NaCl) (Vekton, St. Petersburg, Russia) with pH = 6.5 units was poured into them, so that the solution covered the soil with a layer of 1 cm. The contents of the cup were mixed well with a glass rod. After settling the solution, it was decanted through a filter (11-13 mm diameter white tape) into a flask with a capacity of 500-700 ml. Then, a sample of soil was repeatedly poured into a cup with such an amount of 1 M NaCl so that all the remaining liquid could be drained onto the filter in one step. When the volume of the filtrate in the flask was about 300 ml, a qualitative reaction was carried out in it for the absence of Ca²⁺ ions. To do this, 1-2 ml of filtrate was collected in a clean test tube under a funnel, 1 ml of an ammonium chloride buffer solution (pH 10 units) (Vekton, St. Petersburg, Russia) was added, a few drops of hydroxyamine and sodium sulfide were added (Vekton, St. Petersburg, Russia), mixed, and the metal indicator eriochrome black was added (Vekton, St. Petersburg, Russia). The blue color indicated the absence of Ca²⁺ in the sample. To determine the amount of exchangeable cations, 50 ml of the obtained filtrate was placed in a conical flask with a capacity of 250 ml, 2-3 drops of 1% sodium sulfide solution (Na₂S) (Vekton, St. Petersburg, Russia) and 1-2 ml of 5% hydroxylamine hydrochloric acid solution were added and thoroughly mixed. The contents of the flask were diluted to 100 ml with distilled water, 10 ml of ammonium chloride buffer (pH 10 units) (Vekton, St. Petersburg, Russia) was added, mixed, 30-50 mg of eriochrome black was added and titrated with 0.025 M EDTA solution (complexone III) (Vekton, St. Petersburg, Russia) until the wine-red color changed to blue-blue.

To determine the hydrolytic acidity, soil samples weighing 40±0.1 g (electronic chemical scales EK-300i, A&D, South Korea) were taken and placed in flasks with a capacity of 250 ml. Weighed portions were added with 100 ml of 1.0 N acetate solution sodium (CH₃COONa) (Vekton, St. Petersburg, Russia) and the contents were shaken for 1 hour. After that, the resulting suspension was filtered through a dry folded filter. The analysis was completed titrimetrically. To do this, an aliquot (50 ml) of the filtrate in the presence of phenolphthalein indicator (Vekton, St. Petersburg, Russia) was titrated with 0.1 N sodium hydroxide (NaOH) (Vekton, St. Petersburg, Russia) solution to a slightly pink color.

The density was determined in undisturbed soil samples by means of metal cylinders with a cutting edge of 50 cm² (Litvinov’s laboratory, St. Petersburg, Russia). The cylinders cut into the desired soil
layer to obtain 50 cm³ soil monoliths. Then the samples were dried at 105°C (Olab DOF-FV300SPWF, Moscow, Russia) to constant weight prior to calculating the soil density.

To calculate the total soil porosity, the solid phase density index was used. To determine it, special pycnometers (flasks with a precisely known volume of 100 ml) (Vekton, St. Petersburg, Russia) were used. Soil samples weighing 10±0.0001 g (scales VL-S, Gosmetr, St. Petersburg, Russia) were placed in the pycnometers and filled with deaerated distilled water by 1/3 of the volume, after which the contents of the pycnometers were boiled for exactly 30 minutes. After that, the pycnometer was topped up with distilled water, and the density of the solid phase of the soil was calculated from the amount of water displaced by the soil. Knowing the bulk density of the soil (in an undisturbed state) and the density of the solid phase, the total soil porosity was calculated.

Structural aggregate analysis of the soil was carried out in samples dispersed through a system of sieves with different diameters (10, 7, 5, 3, 2, 1, 0.5, and 0.25 mm) by set of sieves kp-131 for soils (St. Petersburg, Russia). The fractions obtained by sieving were recalculated as percentages of the total weight of the sample taken for analysis. The soil structure factor was calculated from the ratio of structural fractions 0.25-10 mm in size to fractions >10 and <0.25 mm. To determine the criterion of water resistance of soil aggregates, a similar sifting of the soil, described above, was carried out, but in stagnant water (wet sieving). Wet sieving of the soil was carried out through a sieve system with a hole diameter of 5; 3; 2; one; 0.5; 0.25 mm. Based on the results of dry and wet sifting of the soil, the criterion of water resistance of soil aggregates was calculated in terms of the sum of fractions from 1 to 0.25 mm.

The plant wilting moisture was calculated by multiplying the maximum soil hygroscopicity by a factor of 1.5. The maximum soil hygroscopicity was determined by saturating it in a desiccator with air humidity close to 100%.

The highest moisture capacity was determined in monoliths taken to determine soil density. The monoliths were moistened on the surface, and after the free gravitational water drained from them by drying the monoliths at 105°C (Olab DOF-FV300SPWF, Moscow, Russia) to constant weight, the moisture content was determined, which corresponded to the highest moisture capacity. The range of active moisture was calculated as the difference between the highest moisture capacity and the moisture content of breaking capillary bonds. All determinations were processed statistically using Microsoft Excel and Statistica software.

3. Results and discussion

The results of numerous studies show that in Kamennaya Steppe, as well as in other regions with similar natural conditions, under the long-term influence of forest belts on soils, significant changes have occurred in their structural and aggregate composition, indicators of the humus state and physicochemical properties, as well as general physical and water-physical properties. These veils are noted in the works of Y.I. Baeva, I.N. Kurganova, V.O. Lopes de Gerenyu and others [12] and W.B. Possu [13]. In a number of scientific works, researchers note signs of degradation of the physical properties and regimes of soils without proper forest reclamation measures. So in the works of I. Novakovska et al. [14], the degradation of the soil structure under agrotechnogenic impact is shown.

According to the humus content (from 7.3 to 7.9±0.2%) in the upper part of the humus horizon of the soils under various sections of the forest belt can be attributed to the medium humus species (figure 2). These soils are also characterized by rather high reserves of organic matter. Thus, in the first half-meter and one-meter soil strata under the forest belt, humus reserves left 281-299 and 417-436±3 t ha⁻¹, respectively (figure 3). In the fallow area, ordinary chernozem was also characterized as medium-humus. Here, in the upper part of the soil profile, the humus content was 7.8±0.2%, which did not differ significantly in comparison with the soils under tree plantations. Ordinary chernozems on arable land are distinguished by a lower humus content (6.8-7.0±0.1%) in relation to the soils occupied under the forest belt. However, the stocks of humus on arable land were higher than under the forest belt by 54-64 t ha⁻¹ in a thickness of 0-50 cm and by 63-90 t ha⁻¹ in a thickness of 0-100 cm. This is
explained by higher values of the bulk density arable soils as a result of the compacting action of agricultural machinery.

Analysis of the study of the soil-absorbing complex (SAC) of the studied soils showed some differences in the amount of exchangeable cations of calcium (Ca$^{2+}$) and magnesium (Mg$^{2+}$). The least exchangeable cations were found in soils on arable land, where this parameter varied from 41.6 to 42.2±0.4 cmol·kg$^{-1}$. At the same time, the SAC of soils under the forest belt and perennial fallow land was more saturated with exchangeable cations, where their sum was 44.2…45.0±0.3 and 46.2±0.4 cmol·kg$^{-1}$, respectively. A higher supply of SAC with exchangeable cations was found in the soil under larch. Such a distribution of exchangeable cations in the soils of the research objects is due to the different content of organic carbon (Corg.) in the soils.

In view of the different chemical composition of tree litter and the biochemical characteristics of its decomposition in soils under the forest belt, the indicator of hydrolytic acidity is higher. This parameter was determined by the tree species. So, under larch and pine, in view of the predominance of fungal decomposition of litter, the value of hydrolytic acidity was 7.5 and 6.1±0.3 cmol·kg$^{-1}$, respectively, while under maple and birch, due to the predominance of bacterial decomposition of litter, the hydrolytic acidity in the upper part of the humus horizon varied within narrower limits from 4.3 to 5.2±0.4 cmol·kg$^{-1}$. On arable lands and fallow lands, the considered indicator ranged from 2.3 to 3.5±0.3 cmol·kg$^{-1}$. Despite such significant differences in hydrolytic acidity in the upper part of the soil profiles, they gradually smoothed out with depth, and were completely absent in the carbonate horizons. The degree of saturation of the soil-absorbing complex with exchange bases is closely related to the values of hydrolytic acidity. Under the forest belt it is 86-91±2%, on fallow lands 93±3% and arable land 95±3%.

The results of determining the pH of aqueous suspensions of soils showed that forest belts contribute to weak acidification of the upper part of the soil profile. This was most clearly manifested under pine and larch, where the pH value was 5.9-6.0 units, while under maple and birch it was close to a neutral reaction (6.5-6.7 units). On arable lands and fallow lands, the actual reaction of the environment was neutral, since the pH value was 6.9-7.0 units.

Various tree species have the most favorable effect on the agrophysical properties of the studied soils. A significant increase in the structural and aggregate composition of soils in the amount of agronomically valuable structural aggregate fractions (0.25-10 mm) was noted under the field-protective forest belt. Their share in the structural and aggregate composition was 85-89±2%, while on
arable lands this indicator was at the level of 65±3%. It should also be noted that, in arable land, a large share (31±2%) in the structural and aggregate composition was accounted for by the blocky fraction, which negatively affected the physical condition of the arable land. Due to this, soils under the forest belt were distinguished by the highest structural coefficient, where this indicator was 6.7-8.1. The best soil structure was noted under the maple. On arable land, the structural coefficient was several times lower than under the forest belt and amounted to 1.8-1.9. On fallow lands, this indicator practically did not differ from soils under tree plantations and amounted to 8.1 (figure 4).

Tree plantations also help to resist soil aggregates from destruction by water. Thus, the water resistance of soil aggregates under the forest belt and fallow area was the highest and amounted to 75-80±2% and 83±2%, respectively, while, as on arable land, this indicator did not exceed 67-68±2% (figure 5). As one of the features, it can be noted that the most noticeable favorable changes in soils under the influence of tree species occur in the upper 0-20 cm layer, while in the 40-50 cm layer they are not so noticeable.

![Figure 4. Coefficient of soil structure.](image1)

![Figure 5. Criterion of water resistance of soil aggregates (%).](image2)

A very beneficial effect of the forest shelter belts was noted on the general physical properties (soil density and porosity). In the upper part of the soil profile, the density of soils under tree crops is optimal and amounted to 0.95…1.00 g·cm⁻³; down the profile, it regularly increased to 1.38…1.42±0.06 g·cm⁻³ (figure 6). The soils of arable land and fallow land in the upper part of the humus horizon had higher density values – 1.06…1.11 g·cm⁻³. Due to the optimal density values under tree crops, the highest soil porosity (59-61±0.9%) was noted, and hence their better aeration compared to arable land and fallow land (figure 7).
The most optimal water-physical properties of soils were noted under the forest belt. Here the soils are distinguished by the smallest reserves of unproductive moisture (inaccessible to plants) – 192…202±3 mm, while on arable lands, this figure is much higher – 230±2 mm (figure 8a and 8b). It should be noted that for rather high values of the reserves of inaccessible firmly bound moisture, the considered soils can potentially accumulate and retain a sufficiently large amount of productive moisture (available to plants) (figure 9a and 9b). This is evidenced by the rather high values of the indicator of the highest moisture capacity, especially in the soils under forest belts (39.3…46.2±0.4%). The highest values of the range of active moisture (23.1…27.0±0.4%) were typical for soils under tree species, especially under larch. In the soils of arable lands, this indicator was minimal and amounted to 16.8-20.6±0.3%.

Figure 6. Soil density.

Figure 7. Porosity of soils.

Figure 8. Water-physical properties of soils layer of 0…30 (a) and 0…50 (b) cm.
4. Conclusion
The use of tree species in the composition of soil-protective forest belts has a beneficial effect on the agro-ecological state of chernozems in the steppe zone of the Central Chernozem region, which is manifested in an increase in the content of organic carbon (Corg.). As well as exchangeable cations in soils. In addition, in the soils under forest belts, the proportion of agronomically valuable soil aggregates increases and the water resistance of the soil structure increases, as well as the reserves of productive moisture. The greatest differences in the main indicators of soil fertility under forest belts in comparison with arable lands are noted in the upper part of the soil profile, and with depth they become less noticeable. The results obtained agree with the literature data [12, 13]. The uniqueness and scientific novelty of our research is due to the fact that the influence of individual tree species on the composition and properties of soils was considered. While in other scientific works this is not emphasized. It was found that different tree species have different effects on the properties of chernozems. To optimize the fertility of soils under forest belts, first of all, the biological characteristics of the used tree species and agroclimatic characteristics should be taken into account. According to the results of our research, the most promising tree species from the point of view of their use for soil protection purposes in the steppe zone are larch (Larix siberica Ldb.) and maple (Acer platanoides L.).

References
[1] Jing Huang B G and Ridoutt K R 2019 Thorp Water-scarcity footprints and water productivities indicate unsustainable wheat production in China. Agr. Water Manage. 224 105744 doi: 10.1016/j.agwat.2019.105744
[2] Doddabasawa B M and Chittapur M M 2018 Murthy Traditional agroforestry systems and biodiversity conservation. Bangl. J. Bot. 47(4) 927
[3] Felix G F and Bayala J 2018 Enhancing agroecosystem productivity with woody perennials in semi-arid West Africa: a meta-analysis. Sci. Total Environ. 640-641 89 doi:10.4121/uuid:d60d11d6-cd5f-47b4-a5ad-4a4a97d41501
[4] Saint-Laurent D 2019 Habitat fragmentation and structure and composition of tree populations in an agroforestry landscape (Southern Quebec, Canada). Agroforest Syst. 92(6) 517
[5] Santos P Z F 2019 Can agroforestry systems enhance biodiversity and ecosystem service provision in agricultural landscapes? A meta-analysis for the Brazilian Atlantic. *Forest Ecol. Manag.* **433** 140

[6] Stepanova Yu N, Zinoveva I S, BezrukovaT L and Kuksova I V 2018 Rational use of Forest as a renewable natural resource. *Eur. Res. S. J.* **21(1)** 443

[7] Zarafshar M, Bordbar S K, Abbasi A, Negahdarsaber M, Bazot S, Matinizadeh M, Rousta M J, Enayati K and Kooch Y 2020 Do tree plantations or cultivated fields have the same ability to maintain soil quality as natural forests? *Appl. soil Ecol.* **151** 103536 doi:10.1016/j.apsoil.2020.103536

[8] Trap J, Blanchart E, Bonkowski M, Plassard C and Villenave C 2016 Ecological importance of soil bacteriovores for ecosystem functions. *Plant Soil* **398** (1-2) 1 doi: 10.1007/s11104-015-2671-6

[9] Du X F, Li Y B, Liu F, Su X L and Li Q 2018 Structure and ecological functions of soil micro-food. *Chinese J. Applied Ecol.* **29(2)** 403 doi: 10.13287/j.1001-9332.201802.033

[10] Korolev V A, Gromovik A I and Yonko O A 2012 Changes in the physical properties of soils of the Kamennaya Steppe under the influence of forest shelter belts. *Eurasian. Soil. Sci.* **3** 299

[11] Khitrov N B, Cheverdin Yu I and Rogovneva L V 2018 Two-dimensional distribution of the properties of a vertical solonetz with a gilgai microrelief in the Kamennaya Steppe. *Eurasian. Soil. Sci.* **11** 1285 doi: 10.1134/S0032180X18110035

[12] Baeva Y I., Kurganova I N, Lopes de Gerenyu V O, Kudeyarov V N and Pochikalov A V 2017 Changes in physical properties and carbon stocks of gray forest soils in the southern part of Moscow region during postagrogenic evolution. *Eurasian. Soil. Sci.* **50(3)** 327334DOI: 10.1134/S1064229317030024

[13] Possu WB, Estrada J F N and Jurado H O 2018 An overview: the potential role of agro forestry in enhancing carbon sequestration and reducing greenhouse gas emissions on agricultural lands. *Stud Plan & Agr Res* **8** (6) 417430

[14] Novakovska I, Bulgakov V, Rucins A and Dukulis I 2018 Analysis of soil tillage by ploughs and optimisation of their aggregation. *Proc. 17th Int. Scientific Conf. Rural Development* (Jelgava: Latvia University of Agriculture) doi: 10.22616/ERDev2018.17.N401