AF-799
[1-8]

RESEARCH ARTICLE   Indian Journal of Agricultural Research, Volume Issue : ()

Influence of Forest Strips on Changes in Soil Properties in the Agrolandscape

A.V. Koshelev[1], M.O. Shatrovskaya[1], V.M. Kretinin[1]

10.18805/IJARe.AF-799

ABSTRACT

Background: In Russia 5.2 million hectares of protective forest plantations were created on agricultural land. Forest strips optimize moisture turnover, heat and gas exchange of the territory and transform agrarian landscapes into more sustainable forest-agrarian ecosystems (agroforest landscapes). Studying the impact of shelterbelt forests on the transformation of soil properties in the context of climate change (organic carbon storage) is an important problem. The aim of our research was to study the effect of shelterbelt forests on soil indicators and to digitally map the contours of forest-meliorated soils on the test site using GIS-technology and field studies.

Methods: In the present study, the methodology of soil studies in agroforested soils (1978) and the methodology of assessing the accumulation of substances in plants and soils in agroforested landscapes were used to study forest-meliorated soils. We proceeded from the position that the reclamation effect of forest belts occurs at a distance of 30 heights. The research was conducted from 2016 to 2022.

Result: Research has established, that the soil profile under the forest belt has an organogenic horizon A_0 (forest floor); the thickness of the humus horizon (A+B_1) under the forest belt is 8-10 cm higher compared to other zones. Spatial distribution of humus content in the A+B_1 horizon from the forest belt to the centers of inter-belt squares (zone 20H) is not characterized by great variability and clear patterns and on average makes 1.15-1.2%. The increase in calcium carbonate ($CaCO_3$) content in the soil occurs in the direction from the forest belt to the 20H zone. The indicator of dense residue in terms of the content of readily soluble salts is not relevant in estimating the forest belt's influence on transformation of soil properties. A preliminary digital map of the contours of forest-reclaimed soils has been compiled. The obtained materials will serve as a basis for modeling the spatial and temporal dynamics of soils under forest belts in the zonal section and improving soil fertility in the interstrip space.

Key words: Agroforestry, Chestnut soils, Digital mapping, Protective forest plantations, Soil fertility,

INTRODUCTION

One of the important components of the agrolandscapes of southern European Russia are protective forest plantations (PFP), which have a positive impact on the agroecological situation in them and increase soil fertility (Haddaway *et al*., 2016; Kotlyarova, 2014; Kulik, 2018; Kulik and Pugacheva, 2016; Rulev and Koshelev, 2012; Sorokona and Petrova, 2014; Taryono *et al*., 2023). The practice of agroforest-meliorative soil science testifies to the fact that reclamation effect of forest plantations transforms the physical, chemical and morphological properties of soils (Kretinin, 2009; Solovyev, 1967; Smirnova *et al*., 2020; Jiang *et al*., 2022). Forest-meliorated soils, as a rule, are formed at a distance of up to 10H on the windward and windward sides of the forest belt and within its boundaries. 10H is the product where H is the height of the plantation. When studying the dynamics of changes in the indicators of forest-reclaimed soils and their mapping, the following factors should be taken into account: age of forest plantations, structure and condition of PFP, their height, position of soils in the relief and the nature of agricultural use (Kretinin, 2009).

A zone of forest belts influence increases with age and the structure of soil cover changes gradually (in the horizontal direction).

[1]Federal Scientific Centre of Agroecology, Complex Melioration and Protective Afforestation of the Russian Academy of Sciences (FSC of Agroecology RAS), Volgograd- 400062, Russia.

Corresponding Author: A.V. Koshelev, Federal Scientific Centre of Agroecology, Complex Melioration and Protective Afforestation of the Russian Academy of Sciences (FSC of Agroecology RAS), Volgograd- 400062, Russia. Email: alexkosh@mail.ru

How to cite this article: Koshelev, A.V., Shatrovskaya, M.O. and Kretinin, V.M. (2024). Influence of Forest Strips on Changes in Soil Properties in the Agrolandscape. Indian Journal of Agricultural Research. DOI: 10.18805/IJARe.AF-799.

Submitted: 10-07-2023 **Accepted:** 20-12-2023 **Online:** 13-01-2024

The first experience in mapping the structure of soil cover under the influence of PFP was carried out by K.I. Zaychenko. In 1986, he made a soil map of the erosion stationary experimental farm All-Russian Research Institute of Agroforest melioration, VNIALMI (now Federal Scientific Center of Agroecology of the Russian Academy of Sciences) before the creation of runoff-regulating forest strips (1950) and 30 years after their creation (1980) (Zaychenko, 1986).

Development of information technologies has made it possible to apply modern digital research methods for carrying out digital mapping of soils. However, despite the rapid development of digital soil mapping, the issue of digital mapping of forest-reclaimed soils is still poorly studied.

The aim of the study was to investigate soil indicators under the influence of shelterbelt forests and in the interstrip area, digital mapping of soil contours of chestnut soils using GIS-technologies and field standardization.

MATERIALS AND METHODS

Forest-meliorated soils in the agroforestry landscape of the Kachalino test site located in the southern part of Ilovlinsky District (Volgograd Region) were the object of our study (Fig 1). The research was conducted from 2016 to 2022 on the base test fields of FSC of Agroecology RAS.

The territory of the test site is relating to the Ilovlinsko-Volzhsky gently-undulating ravine landscape area. The soils of the test site are represented with various developed shallow chestnut varieties (Kretinin, 2009). Creation of forest strips at the test site was carried out from 1985 to 1992. The total area of the test site is 3950 ha, 91.9 ha of which are forest strips. The PFPs are placed 250-300 m and 500-550 m apart perpendicular to the main prevailing southeasterly dry winds. Auxiliary forest strips are placed in and 700-2200 m and 900-2300 m.

According to the methodology of V.M. Kretinin (Kretinin, 2009), studying the ameliorative effect of forest belts in dry steppe conditions involves analysis of a layer of 0-100 cm. Investigating the changes in soil parameters required establishing a key site and drilling 7. Wells were drilled at 5H, 10H and 20H upwind and downwind, as well as directly in the forest belt (Fig 2).

Soil samples were taken every 20 cm. According to the methodology, a threefold replication was performed. Soil samples were taken to determine the studied parameters in laboratory conditions according to the generally accepted methods of agrochemistry, soil science and agroforest melioration (Kretinin, 2009; Methodological Methodological Guidelines on Complex Monitoring of Agricultural Soil Fertility 2003; Mineev, 2004; Pansu and Gautheyrou, 2014).

We have studied the change in such indicators as depth of the humus horizon (A+B), color of the horizons, particle size distribution, humus content, carbonates ($CaCO_3$), content of readily soluble salts (dense residue).

The test site consists of a 2-row strip. The species composition of the forest belt is represented by Siberian elm (*Ulmus pumila*) planted openly. The length of the forest belt is 2080 m with a width of 12 m. The average height of the tree is 7.5 m with an average trunk diameter of 14.9 cm. The age of the forest belt is estimated at 23 years, which corresponds to the 2nd class quality of the site (bonitet). Preservation of the forest belt reaches 90%. With a density of 830 trees/ha, the total stock of stem wood is equal to 35.7 m^3 ha^{-1}. The belt is in a satisfactory condition: 10% of trees are dry-top. The belt's inside is thickened with golden currants and in some areas with deranged rows, a live above-ground cover is developed.

As of the time of investigation, the inter-belt areas leeward and windward represent uncultivated fields covered by weeds and fallen rye. The distance between the forest belts at the key site is 250 m. The plantings were created under the conditions of overlapping the zones of ameliorative influence in the inter-belt squares.

In the key site area, chestnut soil varieties of heavy loamy and medium loamy granulometric composition are widespread.

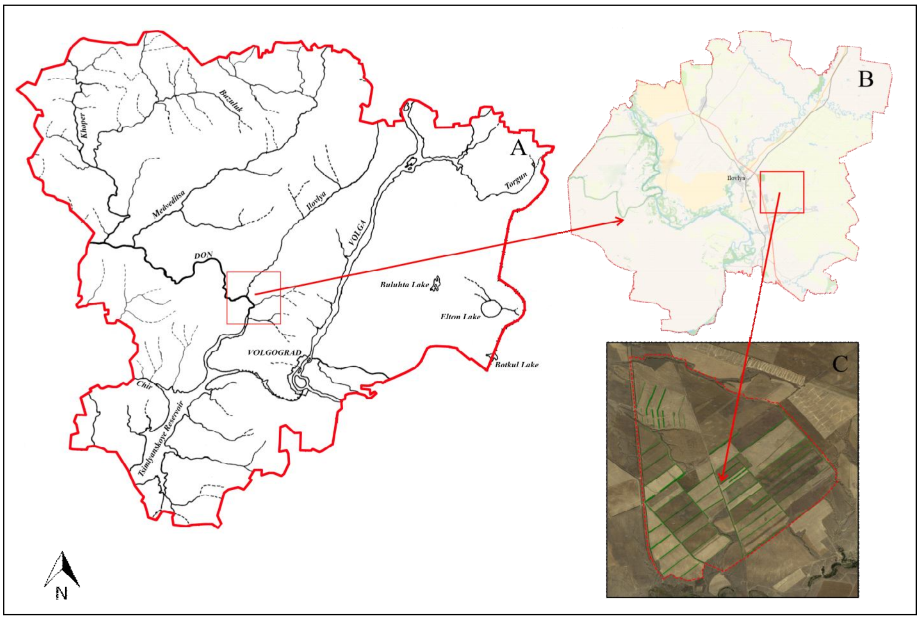

Fig 1: Location map of the research object: A- Volgograd region; B- Ilovlya district; C- Kachalino test site.

The process of digital mapping of agroforest-meliorated soils is a sequence of certain steps (Koshelev, 2018). At the first stage, preliminary laboratory interpretation is carried out, which includes collection and analysis of data on the structure of the soil cover in the sample areas. At the second stage, it is important to perform field standardization of space images directly on the test site. This implies thorough field studies of forest belts and the soils on which they grow. The next stage includes laboratory analysis of all obtained data. At this stage, mathematical and statistical processing of the results is performed. The final stage is the mapping itself, which includes making digital maps (soil contours and isolinear thematic maps).

The collection of information on soil cover and spatial distribution of protective forest plantations is the stage of preliminary laboratory interpretation of the structure of agricultural landscapes. This stage is based on the preliminary interpretation of satellite images. Modern satellite images and GIS technologies allow obtaining the necessary amount of quantitative information for reliable recognition of soil contours (Koshelev, 2018; Yuferev *et al*., 2010). Places of test plots establishment and soil sections for field standardization are determined using global positioning systems.

At the stage of field standardization of satellite images, the in-situ characteristics of soil cover are compared with decoding features of soil contours. A compulsory condition is the laying of soil sections on the test plot. Their number is determined by the scale of mapping and the category of complexity.

Digital mapping of the contours of reforested soils at the study site was performed only after laboratory processing of all field materials. Digital soil mapping was based on the data from the field materials processed in the laboratory, as well as a digital elevation model (DEM). Specialized software packages were used in digital mapping, including MapInfo, Global Mapper and Surfer, *etc*. (Koshelev, 2018; McBratney *et al*., 2003; Savin *et al*., 2000; Yuferev *et al*., 2010).

RESULTS AND DISCUSSION

Analysis of the morphological structure of soil profiles by the thickness of horizons shows (Table 1), that the soil profile under the forest belt corresponds to the forest litter and has a horizon A0 with a thickness of 3 cm. Humus horizon A+B_1 has a thickness of 46 cm, which is on average 8-10 cm more indicators in the interstrip cells and in the open field (control).

Analysis of the data on particle size distribution of soil wells shows that its relief from heavy loamy to medium loamy is directed from the forest belt to the field center, both windward and leeward. All zones are characterized by the prevalence of silt fraction (<0.001 mm) and its maximum content in the 0-20 cm layer is observed in the forest belt (27.99%) and 5H zones (29.87% and 33.41%). Fractions of coarse (0.05-0.01 mm) and medium dust particles (0.01-0.005 mm) in the 0-20 cm layer have equal values (14.12% and 14.52%) under the forest belt, while in zones 5H, 10H and 20H, the content of coarse dust particles

Fig 2: Diagram of soil wells location at the key site.

Table 1: Morphological parameters of the forest-reclaimed chestnut soil of the key site.

Morphologica lparameters, cm		Forest belt	Inter-belt square						Open field
			Windward side			Leeward side			
			5H	10H	20H	5H	10H	20H	
Horizon depth:									
	A_0	3	-	-	-	-	-	-	-
	A	22	16	15	15	15	14	15	15
	B_1	15	10	12	11	12	13	11	13
	B_2	11	10	11	12	11	11	12	12
	B_C	50	60	62	62	62	62	62	58
	A+B	46	36	38	38	38	38	38	40

exceeds the content of medium dust particles by 3.5-5 times. Based on the prevailing fractions, the soil should be called coarse-dust-silty heavy loamy and medium loamy soil.

The analysis of color change of soil samples under the forest belt (Fig 3) showed a gradual color change with depth. Thus, from dark brown in the 0-20 cm layer, the color changed to brown around 20-40 cm and then from 40 cm a transition to light brown was found, changing to beige from 60 cm. The character of the color transition is fundamentally different in zones 5H, 10H and 20H, where the color change from dark brown to light brown and beige is sharper and characterized by a transition from one horizon to another.

Soils of $A+B_1$ horizon are shallow and according to the analysis are low humified. On average, the thickness of this horizon varies in the range from 26 cm to 28 cm, the only exception is the forest belt, where the thickness of the horizon reaches 37 cm. The spatial distribution of humus content in the $A+B_1$ horizon from the forest belt to the centers of inter-belt squares (zone 20H) is not characterized by variability and makes 1.12-1.36%. Moreover, there is no clear pattern in its distribution: under the forest belt, it makes 1.15%; in the 5H zones- 1.36% and 1.17% windward and leeward; in the 10H zones - 1.12% and 1,15%; and in the 20H zones - 1.22% and 1.21%, respectively.

The high agricultural use of land has resulted in low humus content in the 5H, 10H and 20H interstrip zones. In the forest zone, however, this may be due to the wide row spacing of 7 m and the short period of exposure to deforestation. In all zones down the soil profile there is a decrease in humus content with depth. This indicator decreases to a depth of 60 cm by 1.5-1.7 times. Below this layer the changes are already insignificant (Fig 4).

In the lower part of the soil profile there is a compacted screen caused by the coarse structure and high content of carbonate salts. In the lower part of the soil profile, a compacted screen caused by the coarse structure and high content of carbonates is noted. On the windward side of zone 5 H, an increase in the content of calcium carbonates ($CaCO_3$) with depth can be noted. In the 10H zone, a sharp increase in carbonate content is noted from a depth of 20 cm and in the 20H zone, even from the A horizon. A similar distribution of calcium carbonates in the forest belt, where their content is 2.6% at the surface of the soil profile and increases significantly with depth. In the layer 40-60 cm, this figure increases already 7 times. It is noteworthy that

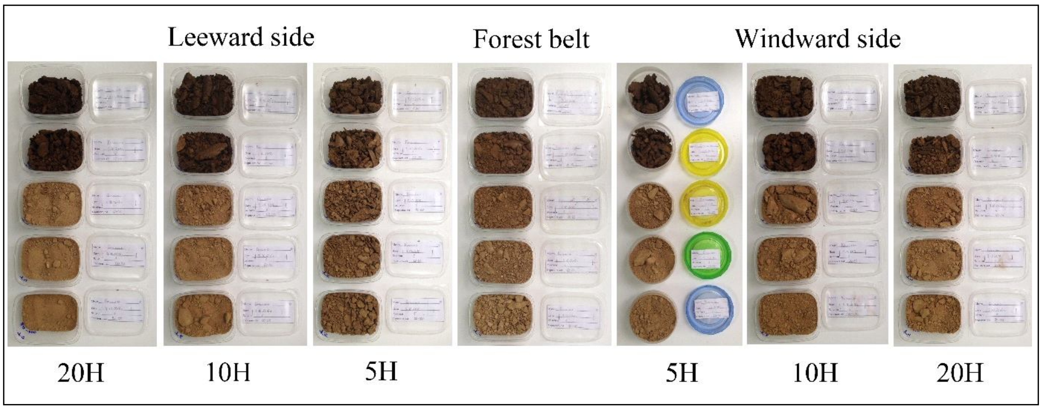

Fig 3: Horizontal and vertical color change of soil wells.

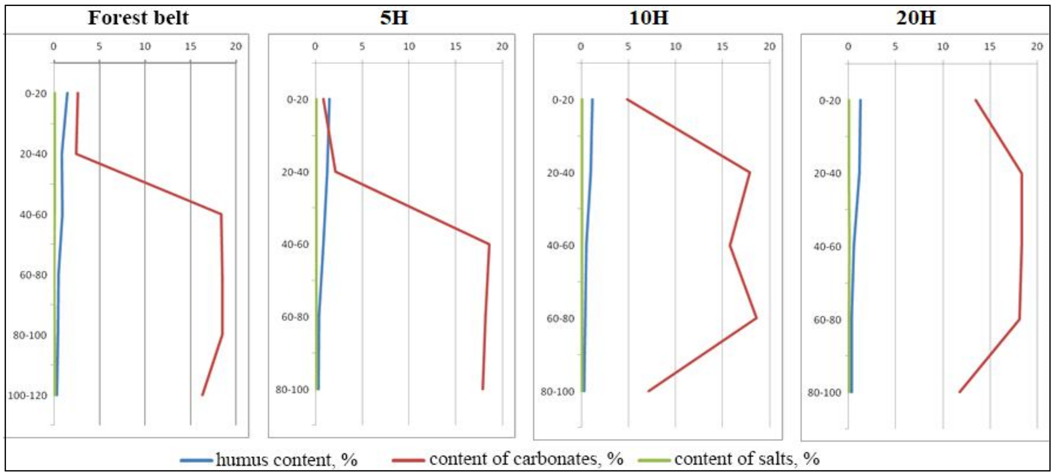

Fig 4: Dynamics of soil indicators by depth and distance from the forest belt.

when moving from the forest belt from the leeward side to zone 5 H the content of calcium carbonates in the soil sharply increases from the horizon A. It is worth noting that in zones 10 H and 20 H the growth of carbonates begins only from layer 40-60 cm, before this layer 0-20 was noted their decrease. The windward side is characterized by a completely different character of the distribution of calcium carbonates. Thus, when moving from the forest belt on the windward side to the 20H zone, an increase in carbo nativity is noted (Fig 4).

The performed analysis of the aqueous extract of all zones showed that in the meter soil profile there is an insignificant amount of solid residue (up to 0.096%). This indicates that easily soluble salts are washed out of the soil horizon. Total alkalinity ranges from 0.025% to 0.042%. The low index of solid residue corresponds to non-saline soils. The low content of magnesium cations is noted throughout the profile of all zones, which is almost 2 times less than the content of calcium cations.

In this case, when assessing the impact of the forest belt on changes in soil properties, the indicator of the dense residue of readily soluble salts is not decisive.

Based on the results obtained, a map of forest-meliorated soils contours was made (Fig 5). Visually, it can be estimated that this ecological group of soils is marked within the forest belt and at a distance of up to 10 H from it (depending on the prevailing soil subtype).

The contours of forest-meliorated soils for the entire Kachalino test site were plotted along the entire perimeter at an equal distance of 10H from the forest belts on the leeward and windward sides. As mentioned above, forest belts improve the morphological and physicochemical parameters of soils. In this connection, we propose to name these soils forest-reclaimed chestnut post-agrogenic. Their area at the test site makes 1264.6 hectares.

The first information about the effect of forest belts on soils was published by Tumin (1930). The authors' opinions on the contribution of forest belts to the process of soil formation in more recent studies vary considerably (Kogut *et al.*, 2009; Kaganov, 2012; Prikhodko *et al.*, 2013).

Many works have been devoted to the study of soil formation factors under forest belts and their influence on soil (Verin and Medvedev, 2020; Kretinin *et al.*, 2020; Tanyukevich and Poluektov, 2011; Gromovik *et al.*, 2013; Berlin *et al.*, 2015; Ukenov and Voropaev, 2015; Verkhoshentseva *et al.*, 2015; Trots, 2016). In doing so, special attention is paid to the assessment of organic carbon stocks and balance in forest belt ecosystems (Chendev *et al.,* 2013), forest parks (Nevedrov, 2018), including in phytodetritus (Klimchenko, 2015).

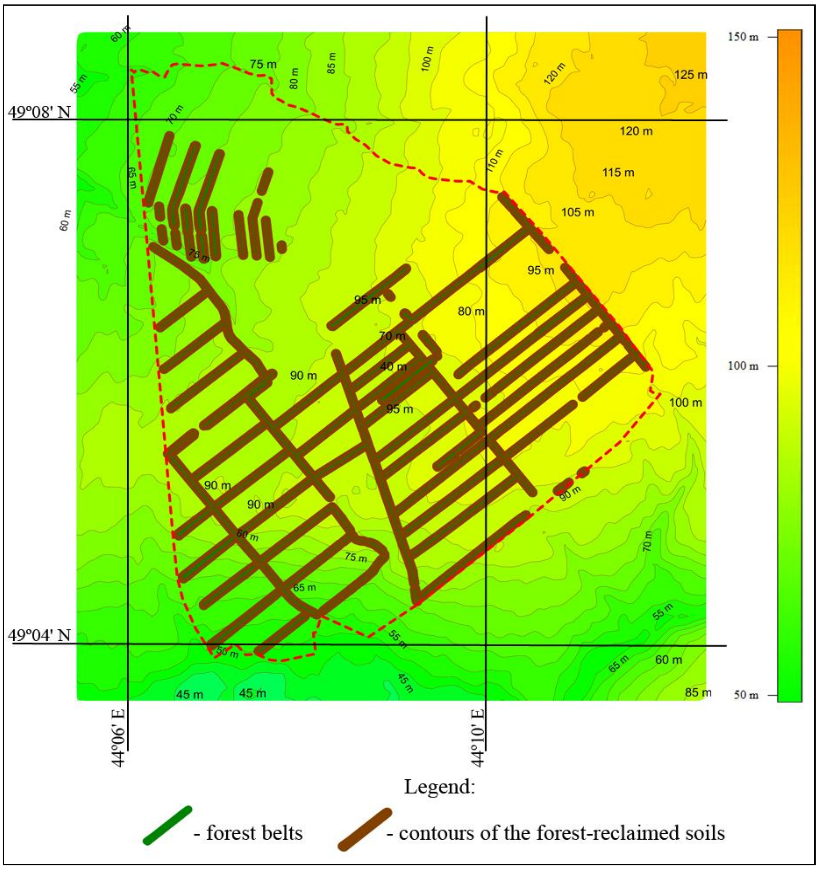

Fig 5: Digital map of contours of the forest-reclaimed soils of the Kachalino test site.

Some sides of influence of shelterbelt forests on soil properties are well enough studied (Solovyov, 1967; Lisetsky, 2008; Kort, 1988; Brandle *et al.*, 2004). However, there are also many unresolved issues, one of which is to clarify the role of forest belts in the production of soil organic matter (Kogut *et al.*, 2009; Kaganov, 2012; Prikhodko *et al.*, 2013; Sauer *et al.*, 2007, 2011).

Over the past two decades, interest in organic carbon under forest plantations has increased among foreign researchers (Mayer *et al.*, 2020; Yu *et al.*, 2020; Gao *et al.*, 2020; Zhang *et al.*, 2020). The regularity in the spatial distribution of humus reserves in the soil with the distance from the forest belt to the central part of the open field is noted (Sauer *et al.*, 2007; Hernandez-Ramirez *et al.*, 2011). The dynamics of organic matter reserves in soils of forest origin is justified by the age of these plantations (Sauer *et al.*, 2012).

In our studies, we tried to consider the morphological and physicochemical properties of chestnut soils under the forest belt and their spatial change. The morphological features of the soil profile under the forest belt that we have established are in agreement with the data of other researchers (Haddaway *et al.*, 2016; Kaganov, 2012; Smirnova *et al.*, 2020; Prikhodko *et al.*, 2013; Sauer *et al.*, 2007; Yu *et al.*, 2020 and others). The identified trends of increasing calcium carbonate content when moving from the forest belt to zone 20H are original.

As can be seen from the analysis of the literature, the main studies are devoted to the accumulation of organic carbon under forest plantations and comprehensive studies of the spatial vertical and horizontal transformation of soils under forest belts are insufficient. The question of changes over time in the content of humus in soils under protective forest plantations is quite controversial, which does not allow a number of scientists to come to a unified informed opinion. This is due primarily to contradictory judgments in scientific circles and the paucity of information. Thus, the question is often raised about the spatial influence of forest belts, it is not clear to what length the influence of forest belts on soil attributes extends (Kogut *et al.*, 2009; Kaganov, 2012; Kretinin, 2009).

In this regard, it is quite appropriate to conduct research aimed at identifying and analyzing changes over time in chestnut soils of the dry-steppe zone, caused by planting and long-term use of the forest belt.

Thus, the obtained results of studies on the influence of forest strips on soil properties in the dry-steppe zone of chestnut soils are the first step for modeling the spatial and temporal dynamics of soils in the forested ameliorated area for decision-making on soil fertility management under the conditions of intensification of agricultural activities and climatic changes. The issue of organic carbon accumulation under current climate change conditions is very important. The practical significance of the obtained results of the study lies in the development of a differentiated approach to the cultivation of crops in the intercropping area for leveling soil properties affecting fertility, including the content of humus (organic carbon) and determining crop yields.

CONCLUSION

A number of studies allowed us to determine the physico-chemical and morphological parameters of post-agrogenic chestnut soil. These parameters can be used for identifying soil changes, which take place under the influence of forest belts, taking into account the time factor. The result was a preliminary digital map showing the contours of the forest-meliorated soils of the test site. Our future studies will be devoted to combining this map with the original soil map of the area under study with the aim of identifying changes in the structure of soil cover under the influence of the PFP.

The obtained materials will become the basis for conducting large-scale studies on modeling and identifying the regularities of the space-temporal dynamics of forest-reclaimed soils' properties in the zonal aspect, as well as for developing a methodology for digital mapping of forest-reclaimed soils.

The conducted research is the first experience in the development of this direction, which will make a significant contribution to the development of agroforestry soil science and can be used to study chestnut soils in the forest-meliorated area under similar soil-climatic conditions, in order to improve the fertility of chestnut soils and to identify the causes of uneven distribution of soil properties in the field to level out their impact on crop yields.

ACKNOWLEDGEMENT

The work was carried out within the framework of the state task of the research work of the FSC of Agroecology RAS No 122020100312-0 "Theory and principles of the formation of adaptive agroforest reclamation complexes in the dry steppe zone of the south of the Russian Federation in the context of climate change".

Conflict of interest

The authors declared that there is no conflict of interest.

REFERENCES

Berlin, N.G., Mashtakov, D.A., Medvedev, I.F. (2015). Influence of phytomass of forest shelter belts on humus content and soil pH in chernozems of southern agroforestry landscape steppe south of the Volga upland. Agrarian Scientific Journal. 9: 6-10.

Brandle, J.R., Hodges, L., Zhou, X.H. (2004). Windbreaks in North American agricultural systems. Agroforestry Systems. 61: 65-78.

Chendev, Y.G., Soer, T.D., Hall, R.B., Petin, A.N., Novykh, L.L., Zazdravnykh, E.A., Cheverdin, Y.I., Tishchenko, V.V., Filatov, K.I. (2013). Assessment of organic carbon stocks and balance in the ecosystems of forest belts of East-European forest-steppe. Problems of Regional Ecology. 4: 7-14.

Gao, X., Huang, R., Li, J., Wang, Ch., Lan, T., Li, Q., Deng, O., Tao, Q., Zeng, M. (2020). Temperature induces soil organic carbon mineralization in urban park green spaces, Chengdu, southwestern China: Effects of planting years and vegetation types Urban Forestry and Ur-ban Greening. 54: 126761. doi: 10.1016/j.ufug.2020.126761.

Gromovik, A.I., Korolev, V.A., Yonko, O.A. (2013). Influence of shelterbelt forests on the main indicators of soil fertility of the stone steppe. Bulletin of VSU, series: Chemistry. Biology. Pharmacia. 1: 105-114.

Haddaway, N.R, Brown, C., Eggers, S., Josefsson, J., Kronvang, B., Randall N., Kämppä J.U. (2016). The multifunctional roles of vegetated strips around and within agricultural fields. A systematic map protocol, Environmental Evidence. 5: 18. doi: 10.1186/s13750-016-0067-6.

Hernandez-Ramirez, G., Sauer, T.J., Cambardella, C. (2011). Sources and Dynamics of Carbon in Forested and Cultivated Soils of the Corn Belt. Soil Sci. Soc. Am. J. 75: 216-225.

Jiang, L., Shan, H., Xu, W., Zhang, W. (2022). Influence of Alfalfa (*Medicago sativa* L.) at various growing years on the Physico-chemical properties and microbiology of irrigated Desert Soils. Legume Research. 45(6): 711-718. doi: 10.18805/LRF-676.

Kaganov, V.V. (2012). Changes in ecosystem carbon stocks during afforestation in steppe and semi-desert zones of the European part of Russia. Problems of Regional Ecology. 4: 7-12.

Klimchenko, A.V., Bezkorovainaya, I.N., Borisova, I.V., Shabalin, O.M. (2015). Carbon deposition in phytodetritus on the soil surface in the middle reaches of the Podkamennaya Tunguska River. Vestnik Krans GAU. 10: 3-5.

Kogut, B.M., Titova, N.A., Buleyeva, V.S. (2009). Anthropogenic transformation of the qualitative composition of humus of chernozems of Kamennaya steppe. Bulletin of the Soil Institute. Dokuchaev. 64: 41-49.

Kort, J. (1988). Benefits of windbreaks to field and forage crops. Agr Ecosyst Environ 22: 165-190.

Koshelev, A.V. (2018). Digital mapping of soils using SRTM data, Bulletin of the Nizhne-Volzhsky agrouniversity complex: Science and Higher Professional Education. 4: 153-160. doi: 10.32786/2071-9485-2018-04-22.

Kotlyarova, E.G. (2014). Value of afforestation in the creation of an environmentally friendly design of the agricultural landscape. Bulletin of the Kursk State Agricultural Academy. 9: 62-66. doi: 10.5539/sar.v2n2p11.

Kretinin, V.M. (2009). Agroforest melioration of soils. Volgograd, Russia.

Kretinin, V.M., Kulik, K.N., Koshelev, A.V. (2020). Agroforestry-meliorative soil science: development, achievements, problems. Vestnik of Russian Agricultural Science. (1): 23-26. doi: 10.30850/vrsn/2020/1/23-26.

Kulik, K.N. (2018). Protective forest plantations as the basis of agricultural territories ecology. Bulletin of Russian Agricultural Science. 1: 18-21.

Kulik, K.N. and Pugacheva, A.M. (2016). Forest reclamation is the basis for creating sustainable agricultural landscapes in the conditions of insufficient moisture. Forestry Journal. 3: 29-40.

Lisetsky, F.N. (2008). Soil-forming potential of forest plantations at afforestation of sands in conditions of forest-steppe and steppe. Izvestiya vysokikh obrazovanii. Forest Journal. 4: 13-20.

Mayer, M., Prescott, C.E., Abaker, W.E.A., Augustoe, L., Cécillonf, L., Ferreirah, G.W.D., Jamesi, J., Jandlj, R., Katzensteinera, K., Laclauk, J.P., Laganierem, J., Nouvellonk, Y., Parém, D., Stanturfn, J.A., Vanguelovao, E., Vesterdalp, L. (2020). Influence of forest management activities on soil organic carbon stocks: A knowledge synthesis. Forest Ecology and Management. 466: 118127. doi: 10.1016/j.foreco.2020.118127.

McBratney, A.B., Mendonca Santos, M.L., Minasny, B. (2003). On digital soil mapping, Geoderma. 117: 3-52. doi: 10.1016/S0016-7061(03)00223-4.

Methodological Guidelines on Complex Monitoring of Agricultural Soil Fertility (2003). Moscow, Russia.

Mineev, V.G. (2004). Agrochemistry: Textbook. 2nd ed. Moscow, Russia.

Nevedrov, N.P., Protasova, M.V., Babkina, L.A., Mironov, S.Y., Borisichev, O.A., Shlykova, E.V. (2018). Realization of ecosystem services by soils of forest-park landscapes of Kursk agglomeration. Auditorium. 2: 37-42.

Pansu, M. and Gautheyrou, J. (2014). Handbook of Soil Analysis. Mineralogical, Organic and Inorganic Methods, Ed. by Pankratov, D.A., Berlin, Germany. doi: 10.1007/978-3-540-31211-6.

Prikhodko, V.E., Cheverdin, Y.I., Titova, T.V. (2013). Changes in the forms of organic matter of chernozems of the Kamennaya Steppe under different use, location and increasing degree of hydromorphism. Soil Science. 12: 1494-1504. doi: 10.7868/S0032180X13120095.

Rulev, A.S. and Koshelev, A.V. (2012). Forest reclamation as a way of agrolandscape management in the south of Russia. News of Orenburg State Agrarian University. 6: 68-70.

Sauer, T.J. and Nelson, M.P. (2011). Science, ethics and the historical roots of our ecological crisis: was the white man right? Maintaining soil productivity in response to global climate change: Science, policy and ethics. Chichester, United Kingdom. doi: 10.1002/9780470960257.ch1.

Sauer, T.J., Cambardella, C.A., Brandle, R.B. (2007). Soil carbon and tree litter dynamics in a red cedarscotch pine shelterbelt. Agroforestry Systems. 71: 163-174. doi: 10.1007/s10457-007-9072-7.

Sauer, T.J., James, D.E., Cambardella, C.A., Hernandez-Ramirez, G. (2012). Soil properties following restoration or afforestation of marginal cropland. Plant and Soil. 360: 1-2. doi: 10.1007/s11104-012-1258-8.

Savin, I.Y., Ovechkin, S.V., Shermet, B.V. (2000). Geoinformation mapping of soils, Modern soil science issues. Moscow, Russia.

Smirnova, M.A., Gennadiev, A.N., Chendev, Y.G., Kovach, R.G. (2020). Influence of field-protective forest plantations on local diversity of soils (Belgorod region). Soil science. 9: 1041-1052. doi: 10.31857/S0032180X20090166.

Solovyev, P.E. (1967). Influence of forest plantations on soil formation and steppe soils fertility. Moscow, Russia.

Sorokona, O.A. and Petrova, L.E. (2014). Modern condition of field-protective forest plantations in the Russian Federation. Land Management, Cadaster and Land Monitoring. 12: 23-27.

Tanyukevich, V.V. and Poluectov, E.V. (2011). The impact of robenium forest strips on the humus of chestnut soils agroforest landscapes in the Rostov region. Fertility. 4: 34-35.

Taryono, Suryanto, P., Supriyanta, Wulandari, R.A., Putra, E.T.S., Widyawan, M.H., Purba, A.E., Arsana, I.G.K.D., Widowati, R., Aisya, A.W., Alam, T. (2023). Morpho-physiological and biochemical fingerprints of the soybean agroforestry system in different crop rotation models. Indian Journal of Agricultural Research. 57(4): 481-486. doi: 10.18805/IJARe.AF-762.

Trots, V.B. (2016). Agroecological impact of shelterbelt forests. Proceedings of the Orenburg State Agrarian University. 4: 189-192.

Tumin, G.M. (1930). Influence of forest belts on the soil in the Stone Steppe. Voronezh, Russia.

Ukenov, B.S. and Voropaev, S.B. (2015). Impact of the state forest belt “Cherry Mountain - Caspian Sea” on the soils of the surrounding areas. Bulletin of the Orenburg State University. 10: 192-194.

Verin, A.Y. and Medvedev, I.F. (2020). Ecological state of the soil in the system “soil - forest plantations”. Izvestiya Saratov University. New Series. Series: Chemistry. Biology. Ecology. 2: 226-231. doi: 10.18500/1816-9775-2020-20-2-226-231.

Verkhoshentseva, Y.P., Khardikova, S.V., Ukenov, B.S. (2015). Changes in the physical and chemical properties of soils of roadside areas under the impact of reforestation plantations. Bulletin of the Orenburg State University. 10: 152-156.

Yu, Z., Zhou, G., Liu, S., Sun P., Agathokleous, E. (2020). Impacts of Forest Management Intensity on Carbon Accumulation of China’s Forest Plantations. 472: 118252. doi: 10.1016/j.foreco.2020.118252.

Yuferev, V.G., Kulik, K.N., Rulev, A.S., Mushaeva, K.B., Koshelev, A.V., Dorokhina, Z.P., Berezovikova, O.Y. (2010). Geoinformation technologies in agroforest melioration. Volgograd, Russia.

Zaychenko, K.I. (1986). Role of forest plantations in increasing the fertility of washed-out soils of the steppe and forest-steppe of the European territory of the RSFSR: PhD thesis abstract. Volgograd, Russia.

Zhang, Y., Liao, X., Wang, Z., Wei, X., Jia, X., Shao, M. (2020). Synchronous sequestration of organic carbon and nitrogen in mineral soils after conversion agricultural land to forest. Agriculture, Ecosystems and Environment. 295: 106866. doi: 10.1016/j.agee.2020.106866.