Preserving the fertility of Russian chernozems. Status, trends, forecast

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Abstract. As a result of our agrolandscape-ecological zoning performed for all natural and economic regions of Russia with the presence of steppe ecosystems with chernozem soils, the following patterns were revealed: unbalanced agriculture, unbalanced agricultural landscapes, unbalanced structure of sown areas and crop rotations (significant predominance of economically attractive crops); obtaining crop yields due to natural fertility of Russian chernozems. The high ploughing of the Russian Chernozem region and the insufficient number of tread elements leads to the creation of foci of erosion, deflation and desiccation. Open, unprotected or poorly protected by vegetation the surface of plowed soil, clean vapors, and row crops is significantly more exposed to the development of erosion and deflation processes. The long-term arable use of the chernozem soils of the steppe ecosystems of Russia without due attention to the reproduction of their fertility contributed to their degradation, erosion, dehumification, destruction of the structure and compaction. At present, they are in urgent need of rational use of natural resources and protection. Based on the analysis of the state and identified trends in nature management in forest-steppe and steppe landscapes, a forecast for the preservation of the fertility of Russian Chernozems is developed.

1. Introduction

Scientific support of the closely interrelated food and environmental security of Russia should be based on the maximum use of our advantages: the vastness of the country's territory, its significant regional differentiation, the richness and diversity of natural and climatic resources, the study of the patterns of geographical, biological and environmental factors in the development of highly productive, sustainable and environmentally friendly agriculture.

At present, most of the crop production and agriculture intensification factors are aimed at obtaining a rapid economic effect and lead to disagreement with nature, violation of a number of geographical, biological and environmental laws.

Thus, the excessive prevalence of economically attractive crops in the structure of sown areas and crop rotations, a decrease in protective ecosystems in the structure of agricultural landscapes, sown areas and crop rotations, an increase in the use of pesticides in plant protection, etc. contribute to the reproduction of pathogens, weeds, diseases and pests [1, 2]. They inhibit the development of beneficial microorganisms, flora and fauna, reduce soil fertility and the resistance of agroecosystems to the impact of negative factors [3, 4, 5]. They also lead to soils pollution, our habitats and food.
In order to study the spatial distribution of biological and ecological patterns, increase information support for rational environmental management, preserve the productive longevity of agricultural lands, ecosystems and agricultural landscapes of Russia, food independence of the country, management, development and targeted extrapolation of technologies for the use and design of regionally, landscape and ecologically differentiated, highly productive and sustainable forage agroecosystems and agrolandscapes, research on agrolandscape-ecological forage lands zoning in the Russian Federation is continuing.

2. Methodology
In previous years, zoning was developed for the Northern, North-Western, Volgo-Vyatka, Central, Central Black Earth, Volga, North Caucasian, Ural, West Siberian, East Siberian natural and economic regions. Work has begun on the zoning of the Far East.

As a result of zoning, modern highly informative maps of agrolandscape-ecological zoning have been developed for each natural and economic region of the Russian Federation with the allocation of zones, mountain territories, provinces, districts and subjects of the Federation. The maps have been provided with legends to add agroclimatic, agrolandscape-ecological and economic characteristics of all the selected agrolandscape-ecological zoning units. The structure of landholdings, and also the structure of natural forage lands and reindeer pastures have been presented. In addition to the legend, two classifications have been developed: 1) natural forage lands indicating the classes and types of forage lands, main plants, yield capacity and quality of forage, and 2) the classification of reindeer pastures, indicating the classes and types of reindeer pastures, relief, soils, main plants, reindeer pastures capacity and seasons of use. A detailed description of all selected units has been given. Explanatory notes and databases for maps on land and natural forage lands have been developed.

Agrolandscape-ecological zoning of natural forage lands in the natural-economic regions of Russia was carried out on the basis of the methodological foundations of the agrolandscape-ecological study on agricultural lands developed by us [6, 7], which are based on the concept of preservation and reproduction of land and other natural resources used in agricultural production, soil fertility, productive longevity of agroecosystems and agricultural landscapes (All-Russian scientific research institute of forages of W.R. Williams), the ecological frame concept of agricultural landscapes and ecological and economic balance (Moscow State University named after M.V. Lomonosov and the Institute of Geography, Russian Academy of Sciences) [8, 9], landscape-ecological and soil-ecological zoning of the territory [10].

3. Results and Discussion
In the context of modern political, social, economic, ecological and climatic changes, the most tremendous pressure and challenges are experienced by the Russian steppe ecosystems with chernozem soils. They occupy millions of hectares in the south of Russia, stretching from the Central Black Earth Region to the North Caucasus, the Volga Region, the Urals, Siberia and the Far East.

In Russian agriculture, on the most fertile chernozem soils of steppe ecosystems, there is a dangerous imbalance in favour of satisfying economic interests at the expense of environmental and social ones. A decrease in the livestock population led to a change in the structure and functioning of agricultural landscapes, sown areas and crop rotations, a decrease in the share of perennial grasses, the main soil formers, in the structure of sown areas by 8–10 times [6, 11].

Thus, in the Central Chernozem region, where forest-steppe and steppe landscapes occupy 92%, an unjustifiably high plowed-up area (55–63%) has been revealed, which covers erosion-hazardous lands (about 60%). In total, 19% of the arable land has been eroded and deflated. A significant part of the territory is characterized by a crisis state of forest-steppe and steppe agricultural landscapes, degradation of agricultural lands, the development of negative processes of erosion, dehumification, desertification, etc. The instability of agricultural production and fluctuations in the yield capacity of ecosystems are associated with an imbalance of productive and protective ecosystems in the distorted infrastructure of agricultural landscapes, the structure of cultivated areas and crop rotations of the
Central Black Earth Region. The required increase in the environment-forming components of the agricultural landscape in the plowed area is 15–20%.

The Volga Chernozem region with forest-steppe and steppe landscapes (43%) has turned out to have excessive plowing of the territory (52-60%), which covers erosion-and deflation-dangerous lands (more than 90%). More than 30% of the arable land has been eroded and deflated. A significant part of the territory is marked by a crisis state of forest-steppe and steppe agricultural landscapes, degradation of agricultural lands, the development of negative erosion processes, dehumification, desertification, etc. The necessary increase in the environment-forming components of the agricultural landscape in the plowed area is 15–25% [7].

On the territory of the North Caucasian Chernozem region with steppe and forest-steppe landscapes (48%), excessive plowing of the territory has been found out (62%). This entire territory is represented by erosion and deflation hazardous lands. 47% of the arable land has already been eroded and deflated. The ecological state of the forest-steppe and steppe agrolandscapes of the North Caucasian Chernozem region is generally tense and crisis.

On the territory of the Ural Black Earth Region with steppe and forest-steppe landscapes (35%), the plowed area is 41–46%. 74% of arable land is erosional and deflationary dangerous. More than 35% of the arable land has been eroded and deflated. About 30% of arable land is located on slopes of more than 2°. The ecological state of the forest-steppe and steppe landscapes of the Ural Chernozem region is generally tense and crisis.

On the territory of the West Siberian Chernozem region with steppe and forest-steppe landscapes (14.7%), the plowed area is 31–53%. 58% of arable land is erosion and deflation dangerous. More than 42% of the arable land has been eroded and deflated. About 10% of arable land is located on slopes of more than 2°. The ecological state of the forest-steppe and steppe landscapes of the West Siberian Chernozem region is, in general, tense and crisis.

It has been established that a reduction in the livestock population leads to an imbalance in agricultural sectors: crop production, agriculture and animal husbandry, a reduction in the areas of perennial grasses and herbal ecosystems in the structure of landscapes, sown areas and crop rotations [12].

Agricultural plants differ significantly in their effect on soil fertility, mineralization, conservation and accumulation of humus, the development of erosional, deflationary processes and the stability of agroecosystems. In the flat conditions of different natural and economic regions of Russia under bare fallow and tilled crops, the highest average annual losses of humus (1.5–2.5 t/ha) have been detected. Under grain crops and annual grasses, average losses of humus have been revealed (0.4–1 t/ha per year). On erosion-hazardous slopes and deflation-hazardous territories, the loss of humus can multiply (tens and hundreds of times) and accelerate.

Among agricultural plants, only perennial grasses contribute to the expanded reproduction of organic matter in the soil. It has been detected that under perennial grasses in flat conditions, humus reserves increase by 0.3–0.6 t/ha per year. Perennial grasses and microorganisms are the main soil formers that have a positive effect on the preservation and increase of soil fertility. Under the perennial steppe vegetation, the best soils of the world - chernozems - were formed. Sowing cereal-legume herbal mixtures is equivalent to the introduction of 100–150 kg / ha of mineral nitrogen [6, 11, 13].

It has been revealed that the structure of agricultural landscapes, sown areas and crop rotations has a significant impact on the resistance of agricultural lands to the development of erosion, deflation and soil fertility. And it also has a significant impact on the modes of humidification or desiccation of the territory, especially aggravated in connection with the progressive warming of the climate.
A widespread violation of crop rotations and a scientifically grounded structure of sown areas has been detected. In all natural and economic regions of Russia, economically attractive crops prevail (cereals, sunflower, in the Far East - soya). This leads to a deterioration in the phytosanitary state of crops and agroecosystems, an increase in the use of pesticides, suppression of beneficial microorganisms and soil biota, soil fatigue and the development of negative processes of agricultural land degradation [12, 14].

In the conditions of the Russian black earth, strong winds, slopes of the relief and aridity of the climate, water and wind erosions of soils pose the greatest danger to agricultural nature management, weakening the stability of landscapes and reducing soil fertility.

The agricultural landscapes stability weakening is influenced by a change in their infrastructure, an increase in the plowing share due to a decrease in the share of environmentally stabilizing ecosystems (perennial grasses and herbal ecosystems, pastures and hayfields, forests and forest belts, water bodies, etc.).

Plowing virgin lands and sowing annual agricultural crops in place of perennial vegetation leads to disturbance of the soil and vegetation cover, sparse vegetation, poor soil fixation and the development of erosion processes.

Large sizes of fields, convenient for their processing, also contribute to the development of erosion processes. On large fields with sizes of many tens and hundreds of hectares, ideal conditions are created for the self-acceleration of water and wind erosion processes. Moreover, the greater the steepness of the surface slopes and the length of the fields, the more kinetic energy the moving water possesses, the faster it erodes the surface, the most fertile soil layer, and then the rock materials [14].

If the fields of forest belts are large, meadows and pastures can no longer hold back the water speeding on the slopes, their anti-erosion role is greatly reduced or can completely disappear. Watercourses over a long distance cut deeply into the soil and turn into gullies.

The intensive development of erosion processes in the forest-steppe and steppe landscapes of the Russian chernozem zone is caused by long-term irrational economic activity, excessive intensity of anthropogenic loads that exceed the threshold of ecosystem stability and cause their destruction.

Erosion and deflation wash away or blow out the topsoil and reduce soil fertility, the most important indicator of which is humus.

Losses of humus ("humus consumption") inevitably occur as a result of harvesting mainly due to the natural fertility of soils, in the absence or insufficient application of organic and mineral fertilizers.

The negative balance of humus is also the result of insufficient intake of organic matter (aboveground and underground biomass of perennial grasses, green manure, roots and crop residues of plants, organic fertilizers) into the cultivated soils. Removal of humus-rich arable soil layer during harvesting also reduces soil fertility [15].

Underestimation of the need to comply with the laws of nature and their violation (excessive plowing and ignoring the balance of landscapes, the balanced structure of sown areas and crop rotations, the excessive prevalence of economically attractive crops and the associated use of pesticides, an insufficient share of soil-forming crops, protective ecosystems, plowing of slopes, large fields, etc.) lead to destructive anthropogenic loads on steppe and forest-steppe landscapes with chernozem soils.

The lack of agriculture and crop production adaptability to natural conditions leads to economic losses (an increase in the cost of agricultural production in a confrontation with nature), environmental losses (degradation of land and ecosystems, a decrease in soil fertility), social losses (deterioration of the habitat, a decrease in the quality of food and public health).

The forecast for the preservation of the Russian chernozems fertility is closely related to the further development trends of rational nature management in Russian agriculture and is possible according to 4 scenarios: inertial, predominantly inertial, predominantly rational and rational.

The 1st scenario extrapolates the current trends in agricultural development. Agroecosystems with economically attractive crops will occupy the largest areas. Protective ecosystems in the structure of agrolandscapes, sown areas and crop rotations will occupy minimal areas. The use of pesticides in
plant protection will increase and further contribute to the proliferation of pathogens, weeds, diseases and pests. The development of beneficial microorganisms, flora and fauna will be inhibited, which will lead to a decrease in soil fertility and the resistance of agroecosystems to the effects of negative factors. Contamination of soil, our habitat and food will increase. This will negatively affect the development of the entire economy, ecology and society.

The second scenario preserves the current trends in the development of agriculture with elements of its rational development and qualitative transformation.

The third scenario can be implemented on the basis of the rational development of highly productive, environmentally sustainable and clean agriculture with elements that preserve the current trends of its development.

The 4th scenario means its qualitative transformation and can be implemented on the basis of innovative development of highly productive, environmentally sustainable and clean agriculture.

The preservation of valuable agricultural lands and soil fertility is possible only if favorable conditions are created for the functioning of balanced agricultural landscapes, agricultural lands, the structure of sown areas and crop rotations from productive and protective ecosystems, soil formation and development of soil biota, and ensuring the active life of the main soil formers - perennial grasses and microorganisms. In the strategy of adaptive agriculture and the system of preventive measures, protective natural ecosystems - steppes, meadows, forests, as well as multi-species agroecosystems and agricultural landscapes, which have much greater resilience and the ability to withstand various weather, climatic and other stresses, should take an important place [16, 17, 18].

The lack of a balanced harmonized interaction between man and nature without taking into account environmental, geographical and biological laws leads to negative consequences (land degradation, deterioration of their phytosanitary condition, dehumification and decrease in soil fertility, increased costs of agricultural production).

Agricultural activities need to be brought in line with the capabilities and endurance of nature in order to ensure the productive longevity of agricultural lands and agricultural landscapes of the regions for present and future generations.

The priority area for the development of agriculture, designed to increase its efficiency, should be the widespread use of the latest technologies focused on the use of biological, ecological and geographical methods for managing the production and environment-forming potential of agroecosystems and agricultural landscapes based on the differentiated use of resources, the use of aerospace and positional sensing, modern digital technologies.

4. Conclusion
As a result of our agrolandscape-ecological zoning in all natural and economic regions of Russia with the presence of steppe ecosystems with chernozem soils, from the Central Chernozem to the Far East, analysis and assessment of the state of the study area, the following patterns were revealed: an imbalance in agriculture (agriculture, crop production, animal husbandry), imbalance of agricultural landscapes (there are few environmentally stabilizing elements that make up their ecological framework); imbalance in the structure of sown areas and crop rotations (a significant predominance of economically attractive crops); the orientation of the overwhelming majority of agricultural producers towards obtaining agricultural crops due to natural fertility or with insufficient fertilization, degradation and depletion of Russian chernozems. Based on the analysis of the state and identified tendencies of nature management in forest-steppe and steppe landscapes, a forecast for the preservation of the fertility of Russian chernozems has been developed.

Perennial grasses and agrolandscapes are the main objects of study of forage production - the largest and most multifunctional branch of agriculture, which combines crop and livestock production, agriculture, ecology, rational use of natural resources and environmental protection. They provide animal husbandry with fodder, crop production – with effective crop rotations and an increase in the yield of grain and other crops, agriculture – with an increase in soil fertility, agricultural land – with
sustainability and stable production, ecology – with rational use of natural resources and a favorable environment.

In general, the research results obtained are relevant, correspond to the priorities of the scientific and technological development of the Russian Federation - the transition to a highly productive, environmentally friendly agricultural sector, the creation of nature-like technologies, ecosystem management. They are aimed at solving the most important state tasks: obtaining fundamental environmentally friendly agricultural sector, the creation of nature and technological development sustainability and stable production, ecology

References
[1] Rybalsky N G, Muravyova E V, Snakin V V and Trofimov I A 2017 State Report "On the State and Protection of the Environment of the Russian Federation in 2016" (Moscow: Ministry of Natural Resources of Russia/NIA-Priroda) p 760
[2] State (National) 2020 Report on the State and Use of Land in the Russian Federation in 2019 (Moscow: Rosreestr) p 206
[3] Dobrovolskiy G V 2008 Soil degradation - the threat of a global ecological crisis Age of Globalization 2 pp 54-65
[4] Dokuchaev V V 1936 Russian Chernozem (Moscow: ASBMP Selkhozgiz) p 551
[5] Dokuchaev V V 1953 Our Steppes Before and Now (Moscow: ASBMP Selkhozgiz) p 152
[6] Kosolapov V M, Trofimov I A, Trofimova L S and Yakovleva E P 2015 Agricultural Landscapes of the Central Black Earth Region. Zoning and Management (Moscow: Moscow State University Press) p 198
[7] Kosolapov V M, Trofimov I A, Trofimova L S and Yakovleva E P 2010 Agricultural Landscapes of the Volga Region Zoning and Management (Kirov: Vyatka Press House) p 335
[8] Nikolaev V A 1992 Fundamentals of the Agrolandscapes Doctrine (Moscow: Moscow State University Press) pp 4-57
[9] Kochurov B I 1997 Geography of Ecological Situations (Ecological Diagnostics of Territories) (Moscow: IG RAS) p 132
[10] Landscape-ecological Zoning of the Territory (Fundamentals of Methodology and Zoning Scheme) 1993 (Moscow: Rosselkhozakademiya) p 42
[11] Trofimov I A, Trofimova L S and Yakovleva E P 2010 Herbal ecosystems in Russian agriculture Use and protection of natural resources in Russia 4(3) pp 7-40
[12] Trofimov I A, Trofimova L S and Yakovleva E P 2011 Increasing the productivity and sustainability of agricultural lands in Russia Grain economy of Russia 4 pp 46–56
[13] Shpakov A S and Volovik V T 2012 The main factors of the productivity of forage crops Feed production 6 pp 17-19
[14] Zhuchenko A A 2011 Adaptive Strategy for Sustainable Development of Agriculture in Russia in the XXI Century Theory and Practice (Moscow: Publishing house Agrorus) p 624
[15] Kiryushin V I 2019 Management of soil fertility and productivity of agroecosystems in adaptive landscape farming systems Pochvovedenie 9 pp 1130-39
[16] Skripnikova E V and Skripnikova M K Features of the development of soil microbiota after exposure to the pyrogenic factor Bull. of the Tambov University 18(3) pp 905-909
[17] Dezhkin V V, Snakin V V and Popova L V 2008 Restorative nature management - the basis of sustainable development Age of Globalization 2 pp 95-113
[18] Trofimov I A, Trofimova L S, Yakovleva E P, Rybalsky N G, Snakin V V, Emelyanov A V, Skripnikova E V, Gorbunov A S and Bikovskaya O P 2019 Biodiversity, anthropogenic transformation and development priorities of agricultural landscapes in southern Russia Conf. Biodiversity and anthropogenic transformation of natural (Saratov) pp 224-226