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Development of the Systematic Approach to Studying Agricultural Land and Agrolandscape Management

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Abstract—This paper develops the methodological foundations of agrolandscape-environmental studies and management of agricultural land that are based on the concept of conservation and reproduction of land and other natural resources used in agriculture, soil fertility, productive longevity of agro-ecosystems and agrolandscapes (All-Russian Williams Fodder Research Institute), and the concept of the ecological framework of agricultural landscapes and ecological–economic balance (Moscow State University, Institute of Geography Russian Academy of Sciences). An integrative understanding of the essence of agricultural lands allows us to consider them as natural agricultural systems, which have a specific structure, functions, and links and are interrelated with other agrogeo-ecosystems and geo-ecosystems that form the environment. They supply agricultural products and other side derivatives of their functioning that are associated with the development of negative processes outside their limits. The features of study, construction, and management of agricultural land are determined by the dual nature-productive essence of agrogeo-ecosystems and the presence of three subsystems in them (abiotic, biotic, and anthropogenic). A special role is played by a control and monitoring unit. Agrogeo-ecosystems are characterized by the presence of three types of relationships (substance-energy, informational, and management); three main functions of agrogeo-ecosystems (productive, environment-forming, and nature-protective); the ability of agrogeo-ecosystems to respond to anthropogenic impacts; the ability of adaptation and recovery; and their distinctive openness and dynamism. The priorities of studies and management of agricultural land are formulated in several principles (systematic approach, emergence, environmental framework, landscape-ecological balance, multilevel and multifactor adaptation, etc.). They are intended to improve the adaptability, sustainability, productivity, and resource-saving and environmental role of agro-ecosystems and agricultural landscapes, which is only possible by creating favorable conditions for their functioning, ensuring a balance between the productive and protective agro-ecosystems and favorable conditions for the development of soil and soil biota, for the active life of major soil-formers (perennial grasses and microbes).

Keywords: systematic approach, agricultural land, agro-ecosystems, agricultural landscapes, study, rational nature usage

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INTRODUCTION

The development of a systematic approach in the study of Nature, agricultural lands, agro-ecosystems, and agrolandscapes is closely connected with the names of the outstanding Russian scientist V.V. Dokuchaev and his disciples and associates V.I. Vernadskii and V.R. Williams. They devoted their entire lives to solving the most important problems of conservation of the Earth on the basis of a systematic approach to its study, recognition of the laws of its existence and development, and a reasonable, careful attitude to it. They made great breakthroughs in the development of biology, geography, agricultural science, ecology, and rational nature management and in the use of their results in practice.

In solving the problems of the systematic study of Nature, they came to the conviction that man in nature deals not with individual natural bodies, but with their multicomponent complex, integral system. The process of understanding the systematic study of the interaction between Man and Nature and the need for rational nature management is constantly expanding from the human mind to the sphere of reason.

A SYSTEMATIC APPROACH TO THE STUDY OF AGRICULTURAL LANDS AND MANAGEMENT OF AGRICULTURAL LANDSCAPES

The essential shortcoming in understanding Nature was seen by V.V. Dokuchaev as the study of individual bodies and individual elements and not their relationships and regular connections. It is these relationships, these regular interactions, that make up the essence of knowledge about nature and are the

basis of all human life. In 1883, a book by Dokuchaev (1936) *Russkii chernozem* was published, in which he showed the natural regularities of soil formation and the influence of agricultural activities on soil formation and laid the foundations of a systematic approach not only to the study of soils, but also to the management of agricultural lands and agrolandscapes. In 1892, another book of his *Nashi stepi prezhde i teper'* was published, in which he assessed the state of our steppe lands and the results of interaction between Man and Nature and proposed measures for rational nature management on the steppe (Dokuchaev, 1953).

"Desiccation of the steppe," wrote Dokuchaev (1953, p. 133), "is largely associated with the activities of man who has destroyed natural vegetation, plowed up vast areas of the steppe, and, therefore, considerably undermined the resistance of steppe landscapes to erosion processes. A huge part of the steppe has lost its natural cover, i.e., the virgin steppe commonly with very dense vegetation and turf that retain snow and water mass and protect the soil from frosts and wind, and arable lands now occupying up to 90% of the total area, the granular structure inherent in the chernozem and most favorable for retaining soil moisture having been destroyed, have made it easily accessible to the wind and washing activity of all kinds of water."

Dokuchaev (1953, p. 136) wrote about the injured, broken, and abnormal state of steppe farming of Russia at the end of the 19th century: "If we add to what has been said that all the just mentioned adversities have been in effect for centuries, if we add here the indisputable although not fully investigated fact of almost universal plowing and, consequently, slow depletion of our soils, including the chernozem, it becomes quite understandable that an organism, no matter how well it is organized, no matter with what good natural qualities it is gifted, once its strength has been broken and exhausted due to poor care, improper feeding, and excessive labor, is no longer able to work properly. It cannot be relied upon. It can suffer greatly from the slightest accident that it would easily survive in another, more normal state or, at any rate, it would not suffer much and would quickly recover." Here, the integral organism that is mentioned by Dokuchaev is the steppe landscape, which has been destroyed by man over many years as a result of irrational use and excessive loads.

The development of Dokuchaev's scientific ideas and the doctrine of soil and natural zones that had a significant impact on the development of the systematic approach in natural sciences in the first half of the 20th century is the scope of all activity of his disciples, Vernadskii, Williams, and their followers who devoted their lives to solving the most important problem of the systematic approach to the study and reasonable, careful attitude to the land.

Williams made a particular contribution to the development of the systematic approach to the study of objects and cognition of the biological essence of soil formation, a special role in which is played by living organisms, primarily green plants and microbes. Due to their influence, the paramount processes of transformation of rock into soil and the formation of its fertility take place.

In the early 20th century, Williams founded the biological field in the study of soils, creating the theory of the biological cycle of substances, soil organic matter, and single soil-forming process with management of soil fertility. Williams introduced many important elements into the new Dokuchaev doctrine of the soil and soil formation. He found new aspects in the understanding of the soil, the importance of perennial grasses in the formation of soil fertility, and the methodology of soil science and created a new science—meadow studies (Vil'yams, 1948, Kosolapov et al., 2011a).

Dokuchaev and Williams understood that the systematic approach to study and management of agricultural lands opens new prospects. They developed their agricultural land management system based on new principles, the principles of increasing not only productivity, but also sustainability of agricultural lands. They proceeded from the fact that agricultural lands are elements of a landscape, an agricultural system, a single whole living organism, which includes arable lands, meadows, forests, and waters. All these elements are closely interrelated and influence each other. The productivity of agricultural lands is a derivative of not only arable soils, but the entire natural complex; therefore, they need new effective levers to be managed.

In the opinion of Academician B.B. Polynov (1956), the two exceptionally prominent representatives of our national science, Dokuchaev and Williams, played an important role in the development of natural science and agriculture. From the genetic principle of soil formation, which was developed by both these scientists, they came, in fact, to the landscape-analogue principle of agricultural land management, cognizing and using the laws of nature.

The systematic approach to the research and management of agricultural lands has opened great prospects. Dokuchaev in the work *Nashi stepi prezhde i teper'* (1953, p. 136) wrote that the researcher must see "the entirety of integral and undivided nature rather than its individual parts, between which there is a very close relationship."

The role of man in management of the agro-ecosystem and agrolandscape is immeasurably high. It should not be to unconsciously destroy agro-ecosystems and agrolandscapes, as many generations of people and entire civilizations have done, undermining the very foundations of their life. Understanding the laws of development of nature, rational management of agricultural lands, and increase in productivity on their basis and sustainability were the purposes of the scientific and practical activities carried out by

Dokuchaev (mainly in the chernozem steppe) and Williams (mainly in the nonchernozem area).

The systematic approach to agricultural land management is necessary because the object of management itself is an agrogeo-ecosystem in which Man and Nature cooperate. This system has qualitatively different properties in comparison with its individual components (climate, soil, vegetation, humidification, and anthropogenic factors).

Based on his analysis of the long-term Russian experience in steppe farming and the conclusions drawn about the causes of droughts, Dokuchaev proposed in 1892 a fundamentally new system for managing steppe agrolandscapes to ensure their productivity and drought resistance that included new effective management levers (Dokuchaev, 1953; *Nauchnoe nasledie V.V. Dokuchaeva*..., 1992).

His plan to combat drought and, in fact, a new management system for agrolandscapes was simple and ingenious, but at the same time complete and sufficient, since it covered the entire agrolandscape and management of all its interrelated elements. The plan was practically real even at that distant time and did not require large expenditures for its implementation. The plan (system) included only five points:

(1) Regulation of large and small rivers.

(2) Regulation of ravines and gullies.

(3) Regulation of water management in open steppes and in watershed spaces by arranging ponds and field-shelter stands.

(4) Development of the norms that determine the optimal ratio between arable lands, meadows, forests, and waters.

(5) Development of soil cultivation methods that are the most favorable for better use of moisture and larger adaptation of cultivated plant varieties to local conditions.

Dokuchaev's complex of measures (Dokuchaev, 1953; *Nauchnoe nasledie V.V. Dokuchaeva*..., 1992) on the improvement of steppe agrolandscapes, where moisture is limited, offers the following as the main levers for managing agrolandscapes: management of moisture (conservation of water within the landscape and moisture in the soil); management of the agrolandscape structure (optimization of the ratio between arable lands, meadows, forests, and waters); anti-erosion and soil protection management levers (strengthening the banks of rivers, slopes of ravines and gullies with forest plantations, arrangement of field-shelter stands); and management of the biological adaptation of cultivated plants.

Thus, the late 19th and early 20th centuries gave rise to a new science, including agrolandscape studies, practical creation and management of agrolandscapes, in the conditions of special interest and continual attention to agricultural land and agricultural production, at the interface between agricultural science, geography, biology, ecology, soil science, and geobotany.

The greatest merit of Williams is that he, relying on the idea of Dokuchaev about the need to manage the entire system of the agrolandscape and all its interrelated and interdependent elements, perfected this management system during his entire life. He refined the smallest detail of every link in this indissoluble chain of agrolandscape management (the system of crop rotations, soil cultivation system, maintenance of soil structure, fertilizer system, melioration, etc.), created and improved new links (meadow cultivation, fodder production, animal husbandry) in a unified agrolandscape management system. Lastly, he purposefully and consistently promoted the development of the new agrolandscape management system in the agricultural practice of agriculture in our country (Kosolapov et al., 2011a).

These were the first decisive steps from management of arable land to management of the whole agrolandscape system. Dokuchaev and Williams were the first to take a step from the brilliant scientific idea to its implementation. In creating and improving the agrolandscape management system, Williams created a doctrine of the grassland farming system that is based on perennial grasses, meadows (creating and restoring the fertility of agricultural land), and fields (using this fertility). Having a huge general theoretical and practical importance, the works of both outstanding Russian scientists Dokuchaev and Williams joined in the creation of a new system for management of agricultural lands in Russia. The grassland farming system of Williams or the "Dokuchaev–Kostychev–Williams Complex" came as a more progressive system of agricultural land management to replace the fallow agricultural system on the territory of Russia in the 1930s. In the socio-economic conditions of the country's development in this period (after collectivization), the new farming system relied on Dokuchaev's ideas, numerous developments by Williams, and the global and domestic experience of farming and, as far as possible, followed the landscape-analogue principle of cognition and use of the laws of nature. At its core, it is a system for management of agrolandscapes (agroecosystems of higher order—systems of systems) and uses numerous levers for management of agrolandscapes and not only arable lands.

As Williams wrote, "The lea-rotation (grass and field) system is valuable just in its covering, uniting, and connecting all elements of production in absolutely equal measure. It pays attention to all lands without exception, to all agricultural production areas: fields, meadows, forests, and livestock and is imaginable in the form of a single, integrated system of agronomic measures" (Vil'yams, 1948, Kosolapov et al., 2011a).

Williams considered the lea-rotation (grass and field) system as a single and indissoluble complex that included the following elements of agrolandscape

management: (1) the correct organization of the agricultural territory, where the structure of agrolandscapes is optimized, and the field is combined with the meadow and forest; (2) the crop rotation system that provides rotation, combination of field and fodder crop rotations, and rational use of land; (3) the system of field-shelter stands at watersheds, along the borders of crop rotation fields, along the slopes of gullies and ravines, along river banks and lakeshores, around ponds and reservoirs, and the afforestation and fixation of sands; (4) the soil treatment system; (5) the system of application of organic and mineral fertilizers; (6) seeding with selected seeds of high-yielding agricultural crop varieties adapted to local conditions; and (7) development of irrigation based on the use of water from local runoff by constructing ponds and reservoirs.

Williams convincingly substantiates the importance and necessity of the study and rational use of perennial grasses and meadows and improvement of soil fertility and land sustainability in order to solve the problem of ensuring the country's food security. "In the case of continuous growing of grain plants, the most valuable property of the soil tends to decline, and there is no faster or more certain path to impoverishment than the path of continuous growing of grain plants. Only the root system of perennial plants can take on the role of restoring the strength of the soil" (Vil'yams, 1948, p. 198).

Russia's grassland ecosystems are an important part (by area, autotrophy, and productivity) in the agrolandscape infrastructure (landscape stabilization, soil-improvement, and environment-improving infrastructure). The most important role of grassland ecosystems in agrolandscapes and fodder production is due to large areas of natural forage lands in Russia, their important production, environment-forming, aesthetic, and nature-protective functions in agrolandscapes.

Due to a significant share of natural factors and renewable resources in the production of hayfields and pastures, meadow forage production also promotes the efficient use of nonrenewable resources, which corresponds to the globally recognized concept of rational farming (Kosolapov et al., 2010, 2015).

Modern studies have confirmed that the preservation of valuable agricultural lands and soil fertility is only possible by creating favorable conditions for soil formation and development of soil biota and ensuring the active life of the main soil formers—perennial grasses and microbes. The most important soil-forming role of perennial grasses is associated with the peculiarity of their root system. In perennial grasses in the steppe, the mass of roots exceeds by an order of magnitude or more the aboveground mass, a part of which is taken away with the harvest (Kosolapov et al., 2012, 2014; *Spravochnik po kormoproizvodstvu*, 2014).

Perennial herbal ecosystems perform the most important production, environment-forming, and nature-protective functions in agrolandscapes and have a significant impact on the ecological state of the country's territory. They contribute to the conservation and accumulation of organic matter in the biosphere. Thanks to perennial grasses, forage production like no other branch of agriculture is based on the use of natural forces, renewable resources (energy of the sun, agrolandscapes, lands, soil fertility, photosynthesis of grasses, and creation of biological nitrogen from the air by nodule bacteria).

Grass ecosystems of perennial grasses are an important component of the biosphere (by area, autotrophy, and productivity), an important component in the agrolandscape infrastructure (landscape-stabilizing, soil-improving, and environment-improving infrastructure), and an inexhaustible, renewable, and autotrophic sustainable resource (energy, fodder resource). Perennial grasses are traditionally used in agrolandscape management as one of the most effective factors of soil formation, soil improvement, and soil protection (*Kontseptsiya*..., 1999; Trofimov et al., 2011, 2014).

Perennial grasses create and maintain a lumpy or granular soil structure, which is one of the most important tasks of agriculture. Perennial grasses are necessary to restore the soil structure, which is inevitably broken during cultivation of only one-year crops with high loads of machinery and chemicals on agroecosystems. A mixture of perennial grasses with perennial leguminous plants plays an important role in soil formation; it supplies soils with a sufficient amount of humus and calcium, which is necessary for the formation of the soil structure, and ensures the creation of a sufficiently thick structural soil layer. This remarkable property of grass mixtures of perennial grasses and leguminous plants allows controlling the structure and fertility of soils.

Vernadskii, developing the ideas of Dokuchaev, brought the systematic approach to the study of Nature to the planetary level, having laid the foundations of the doctrine of the biosphere and noosphere. Life is the determining geological factor of development in the biosphere, and the growing influence of scientific thought and human activity in the biosphere transforms it into the noosphere (Vernadskii, 1989).

At the end of the 19th century, Dokuchaev initiated complex physical and geographical studies, the tasks of which he associated closely with the solution of national economic problems. The specification of this idea was carried out at the beginning of the 20th century by his disciple L.S. Berg, who developed the doctrine of Dokuchaev about natural zones and worked out the doctrine of landscapes. The specification of the doctrine led to formulating the concept of a landscape as a natural territorial unity that constitutes the main object of geographical research (Berg, 1931).

The bases of the complex (landscape) approach to land study that were laid by Dokuchaev, Vernadskii, Williams, and Berg were developed by L.G. Ramenskii (1938), who developed the bases of the theory of the complex soil geobotanical study of lands and natural types of agricultural lands.

In the work *Vvedenie v kompleksnoe pochvenno-geobotanicheskoe issledovanie zemel',* Ramenskii (1938, p. 6) defines the subject of studies as follows: "... on the one hand, territory, land, on the other hand, plants, animals, and microbes are the main natural factors of agriculture... . To substantiate the measures, we need a synthetic approach. It is necessary to study the soil, vegetation, and water balance of the territory, its microclimate, etc., in their mutual connection, in interaction, against the background of cultural regimes and transformations. The synthetic study of natural features and life of a territory in the prospect of its economic use and transformation is the content of production land typology. The method of land typology is comprehensive study of a territory... ." These traditions and principles are developed at the Institute of Fodder.

Today, these principles are the basis not only for the school of geobotany of the ARWFRI, the leader and founder of which Ramenskii was; these principles are the basis for modern agrolandscape studies and the doctrine of agro-ecosystems, which are promising modern scientific trends developing at the interface between agricultural science, geobotany, landscape studies, and ecology (Nikolaev, 1992, Kosolapov et al., 2011b).

Ramenskii (1938, p. 40) wrote: "The typology of lands should be a deeply synthetic discipline that links the facts of climatology, hydrology, soil science, geobotany, etc., into a single whole, grouping and evaluating them in the economic perspective. The production perspective, in turn, brings to the forefront the issues of environmental study of a territory and analysis of it as a habitat for wild and cultivated plants. All indicators and classifications (soil, geobotanical classifications, etc.) should be environmentally evaluated and justified. In addition to the ecological characterization of the territory in its current state, a prospective ecological characteristic depending on the possible measures is of major importance."

Formation of the ideas about ecosystems and geosystems and agro-ecosystems and agro-geosystems significantly expands the concept of agricultural land. From the standpoint of the geosystemic concept, they are not a natural and economic territorial complex, but a natural and agricultural geoecosystem (Odum, 1971; Sochava, 1986; Nikolaev, 1992).

In the late 20th and early 21st centuries, works by A.A. Zhuchenko, A.N. Kashtanov, G.V. Dobrovolskii, V.A. Nikolaev, B.I. Kochurov, V.I. Kiryushin, and other scientists substantiated at a new stage that there is a need for a systematic approach to the study of interaction between Man and Nature and the reorientation of the country's agricultural activities from the path of conquering nature to the path of cooperation with it. Only in this way will it be possible to create a sustainable system of nature management that, satisfying human needs for agricultural products, simultaneously supports the natural functions of agro-ecosystems and agrolandscapes (Nikolaev, 1992; Lopyrev, 1995; Kiryushin, 1996; Kochurov, 1997; *Ekologo-landshaftnoe zemledelie*..., 1997; Kashtanov, 2008; Zhuchenko, 2009, 2011).

The development of the systematic approach to the study of agro-ecosystems and agrolandscapes is characterized by a trend towards increasing knowledge, which is due to an increase in the number of problems, the solution of which requires unification of achievements in various sciences—geography, biology, ecology and agricultural science, geoinformatics, and aerospace research methods, which make it possible to reflect rapidly and effectively the state of agrogeo-ecosystems over large areas (Trofimov, 2001; Kosolapov et al., 2012).

In order to increase the adaptability, sustainability, resource-saving, environment-forming, and nature protection role of agriculture and advance the development of the system approach to its adaptive intensification, as well as assess the importance of agricultural lands for rational nature management and optimization of agrolandscapes, we have developed a model and principles for studying, assessing, using, improving, and designing agro-ecosystems and agrolandscapes (Kosolapov et al., 2010).

They are based on the concept of conservation and reproduction of land and other natural resources that are used in agricultural production, soil fertility, productive longevity of agro-ecosystems and agrolandscapes developed at the All-Russia Williams Fodder Research Institute (*Kontseptsiya*..., 1999) and the concepts of the ecological framework of agrolandscapes and ecological-economic balance of Moscow State University (Nikolaev, 1992) and the Institute of Geography, Russian Academy of Sciences (Kochurov, 1997).

The study, management, and design of fodder agrogeo-ecosystems are based on 17 principles, which were developed on the basis of the agrogeo-ecosystem approach (Table 1).

CONCLUSIONS

The system developed for studying, managing, and constructing agrolandscapes is based on the primacy of the unity of the economy and ecology and the harmonization of relations between Man and Nature in the process of agricultural production. The main rule of the balanced interaction between Man and Nature is the preservation of natural ecosystems, valuable agricultural lands, and soil fertility, which can only be achieved by creating favorable conditions for the func-

Table 1. Principles of agrolandscape-environmental study, assessment, management, and protection of agrogeo-ecosystems and agrolandscapes

Principles	Content of principles
Principle of systemic approach	Adequate reflection of the agrogeo-ecosystem essence of agricultural lands (natural forage lands, perennial plantations, and arable lands sown with agricultural crops)
Principle of emergence approach	Consideration for the appearance of special properties of a whole system that are not inherent in its subsystems, blocks, and components, which are not integrated by system-forming links; consideration for a special form of integration of the system that is subject to other laws of design and management, functioning, and evolution
Principle of landscape boundaries	Land use and land management must be carried out with the maximum allowance for the boundaries of landscapes (agrolandscapes), which are existing natural and agricultural territorial complexes
Principle of environmental framework	Natural fodder lands with perennial vegetation, forests, protected areas, tree–shrub and wetland ecosystems, perennial plantations, and perennial grasses in arable land are the most important elements, an integral part of the environmental framework of the agrolandscape, and determine its stability
Principle of landscape-environmental balance	Management and construction of agrogeo-ecosystems must be performed with supporting a harmonic balance between environment-stabilizing and environment-disturbing elements of the agrolandscape structure to ensure its stability
Principle of optimal functioning	Management and construction of agrogeo-ecosystems must be oriented towards their optimization, i.e., the optimal ratio of their production, environment-forming, and nature-protective functions
Principle of balanced interaction between Man and Nature	Preservation of natural ecosystems, valuable agricultural lands, and soil fertility can only be implemented by creating favorable conditions for the functioning of agrolandscapes, ensuring a balance of productive and protective agro-ecosystems, active life of major soil-formers (perennial grasses and microbes), and favorable conditions for soil formation and development of soil biota
Principle of multilevel and multifactor adaptation	Adaptive intensification of agriculture must be carried out at different levels (molecular genetic, organism, population, cenotic, landscape, and biosphere levels), covering all levels and all sides (factors) of the objects under study, since ignoring any information on agro-ecosystems leads to violating the principle of adaptation. Multilevel and multifactor adaptation is necessary
Principle of active and passive adaptation	Adaptive intensification of agriculture must be carried out both actively (by creating additional elements of the environmental frame) and passively (by preserving the existing environment-stabilizing elements of the agrolandscape)
Principle of agrolandscape management	Creation and use of agro-ecosystems is an integral part of the construction and management of agrolandscapes. By acting on individual agro-ecosystems, we manage agrolandscapes (agro-ecosystems of the regional level)
Evolution-analogue principle	This principle focuses the management of agro-ecosystems and construction of agrolandscapes on the repeatedly tested experience of nature, on imitation of nature, optimal use of favorable natural properties of agro-ecosystems
Principle of biodiversity	Creation, management, and construction of agrogeosystems must be oriented to their maximum biodiversity as a real mechanism for ensuring their reliability, sustainability, and stability
Principle of the environmental approach	This principle orients the management of agrogeosystems to strengthening the environmental framework of agrolandscapes, key environmental problems, and their causes
Principle of creating a healthy environment	This principle focuses agricultural production on obtaining environmentally friendly products, the absence of contamination of agrolandscapes, and creation of a healthy environment for humans, animals, and plants

Table 1. (Contd.)

Principles	Content of principles
Principle of the aesthetic approach	This principle is aimed at preserving the existing agrolandscapes and creating new harmonious agrolandscapes with valuable aesthetic properties
Principle of ensuring the unity of the economy and ecology	This principle provides inseparable unity of economy and ecology
Principle of ensuring practical and economic expediency	This principle is aimed at obtaining the necessary results at a minimum cost

tioning of agricultural landscapes, ensuring the balance of productive and protective agro-ecosystems and active life of the main soil formers (perennial grasses and microbes), and forming favorable conditions for soil formation and development of soil biota.

Agriculture must ensure the maintenance of an ecological balance in agrolandscape systems. Compliance with the requirements of rational nature management, environmental protection, and optimization of agrolandscape management is becoming one of the main conditions for increasing the productive longevity of agro-ecosystems and efficiency of agricultural production.

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