Methodology for environmental assessment of agrolandscapes in arid zones

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Abstract. The article presents materials on the development of methodological tools for environmental assessment of agricultural landscapes in the conditions of aridization and global climate change. The research purpose consists in assessment of the state of agricultural landscapes in the dry steppe zone of chestnut soils in the Volgograd region and development of a theory of the formation of ecologically balanced agroforest landscapes and adaptive farming systems for conditions of insufficient moisture. The research has been carried out in the agrolandscapes of the dry steppe zone of dark chestnut soils of the Volgograd region on the territory of 3 farms with various types of agricultural technologies and farming systems. The research methodology is based on extensive analysis and synthesis of scientific literature and includes special research methods. As a result of the research, we have determined the principles, classification and directions of ecological development of agrolandscapes. The method has been developed for the relative assessment of soil fertility in agroforest landscapes of the Volgograd region based on a system of indicators. The methodology and the system of criteria for direct, indirect and integrated assessment of the state of agricultural landscapes in the dry-steppe and semi-desert zones of the Volgograd region have been tested. The present research will become the basis for developing the theory of formation of ecologically balanced agricultural landscapes and adaptive farming systems for conditions of insufficient moisture zones in the south of Russia.

1. Introduction

Growing anthropogenic load on landscapes and global climate change explain the need for research on preservation of natural complex, greening of human economic activity, and identification of methods for balanced agriculture. Promising research areas include the use of new generation agrotechnologies with the aim of preserving and reproducing soil fertility, effective use of natural potential of agrolandscapes and production of high-quality agricultural products in required volumes. Search for a system of rational land use continues, including through the agroecological assessment of agricultural landscapes [1, 2, 3]. An ecologically balanced agricultural landscape is characterized by ecological balance and resistance to external factors.

Despite the existing data on the issue, a comprehensive assessment system for the formation of ecologically balanced agrolandscapes, especially taking into account zonal specifics of the territories under study has not yet been developed.

The research relevance consists in the need to improve the methodology of landscape science, develop principles and theoretical foundations for ecologically balanced agrolandscape formation in
the conditions of insufficient moisture in the south of Russia, since the vulnerability of landscapes under these conditions is much higher than in central Russia, and under systemic impact, leads to desertification of large territories in southern regions.

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2. Materials and Methods
The research object is represented with agrolandscapes of the dry-steppe zone of chestnut soils of the Volgograd region. JSC Ust-Medveditskoe, private farm of V.V. Isaev located in the Serafimovichsky district and the Cherensky agricultural industrial complex located in the Kletsky district have been used as stationary objects (figure 1).

The research methodology is based on analysis and synthesis of scientific literature (Grodzinsky M.D., 1986; Reimers N.F., 1990; Kiryushin V.I., 1996; Bannikov A.G., 1999; Volodin V.M., 2000; Volodin V.M., Masyutenko N.P., Eremina R.F., 2000; Isachenko A.G., 1992; Lopyrev M.I., 2012; Masyutenko N.P., 2000 2004; Belova I.B, 2005; Korchagina L.P., 2005; Aidarov I.P., 2005; Kiryushin V.I., Ivanov A.L., 2005; Fokin A.D., 1995, et al.) [3-14].

The special research methods include [15-24]:
1. Determination of intensity of agricultural activity by the method of analysis of techniques, technologies, farming systems (Sukhov A.N., 2007, 2011; Ermolenko V.P., 1999; Bondarev A.G., 1980).
2. Method for estimating the amount of subtracted and retracted nutrients (Pryanishnikov D.N., 1976; Krasilnikov N.A., 1996; Mishustin E.N., 1972; Radov A.S., 1974; Yudin F.A. 1980; Filin V.I., 1984, 1992).
3. Determination of types and volumes of anthropogenic load on landscapes by the method of ground survey, the use of aerospace images (Isachenko A.G., 1992; Pavlovsky E.S., 1985; Kulik K.N., 1989; Andronnikov V.L., 1988; VNIALMI, 1991).
4. Determination of research objects predisposition to manifestation of water and wind erosion (Barabanov A.T., 1993; Orlov V.N., 1972; Garshinev E.A., 1999; Zykov I.G., 1993).

5. System for assessing soil as an organizing component of agrolandscapes and determining the level of actual soil fertility and trends in its change over time under the influence of agricultural technologies and other factors (Radov A.S., 1974; Sabinin D.A., 1971; Krasilnikov N.A., 1996; Mishustin E.N., 1972; Filin V.I., 1987, 1992).

6. Identification of species, forest cover of a territory and the nature of impact on agrolandscapes (Molchanov A.A., 1966; Pavlovsky E.S., 1988; Lopyrev M.I., 1999; Manaenkov A.S. et al., 2000).

7. Determination of landscape stability and ecological balance (Masyutenko N.P. et al., 2013; Fokin A.D., 1995; Glazovskaya M.A., 1988; Lopyrev M.I., 2005; Kiryushin V.I. , 2005).

8. Evaluation of agrolandscape productivity according to the system of generally used indicators (Dospekhov B.A., 1979; Gossotrtseti, 1985; Konstantinov P.N., 1952; Goryanskiy M.M., 1970).

The data obtained from satellite images have been compared with the results of ground-based studies. The indicated research methods have made it possible to obtain objective research information on the state of agroforest landscapes.

3. Results and Discussion

Experimental data of the research include the data on weather conditions during the years of research, moisture supply of soils at the beginning of growing season and at the period of full ripeness, the content of humus, nitrogen, phosphorus in soil, biometrics of crops and structure of crop yields, fertilizing system, balance of nutrients in soil and ecological effectiveness of protective complex, statistics of crop productivity and product quality, survey data of the terrain, nature of its composition and territorial organization, manifestation of water and wind erosion of soils, density of forest cover of the territory, impact of field-protective forest belts and forest reclamation on agrolandscapes and ecology, structure of lands and crops, characteristics of crop rotations and availability of tilled soils.

As a result of the research, conceptual-methodological and information-technological principles have been developed:
- integrity, consistency and complexity in research of agricultural landscapes;
- consideration of zonal features, ecological sustainability, adaptability and balance of landscape elements;
- priority of soil resources and socio-economic efficiency of preserving the use of natural resources.

Classification of the agrolandscapes of the dry steppe zone of dark chestnut soils [8] has been investigated and updated:
- by degree of degradation and the level of balance of land use area;
- by intensity of use and the level of anthropogenic load;
- by resistance to external impact and adaptability;
- by socio-economic significance and ecological-economic efficiency of the use of soil and climatic resources.

The classification of agricultural landscapes presented in the work of N.P. Masyutenko et al. (2013) was developed for the black soil zone, and in our studies we adapted and improved it taking into account zonal features of the dark chestnut soils of the Volgograd region.

The use of mosaics of satellite images from the Google Earth electronic globe has made it possible to compile electronic maps of the fields of research objects and to clarify their areas. Based on SRTM radar survey data, a digital elevation model (DEM) of the research objects has been built. Analysis of the model has shown that the relief elevation in this area lies within 90-200 m.

Total length of the gully-ravine network makes 235.32 km, and erosion roughness is equal to 0.63 km/km², which corresponds to the average roughness of the territory. A map of slope angles with plotted contours of fields has been compiled. Based on this map, we have revealed that prevailing range of slopes is 0.5-1.5º, and most of the fields (88%) are located on these slopes. 12% of fields are
located on slopes of 1.5 to 3.5°, and the fertile soil layer is washed away along with an actively developed trough-extended network in these fields.

The conducted studies have also made it possible to obtain photo standards of soil cover in relation to assessing the impact of agricultural technologies on the formation of stable and balanced agrolandscapes in the steppe, dry steppe, semi-desert zones of the Volgograd region.

We have also carried out survey of soil fertility at the stationary objects and obtained detailed results on the content of humus, nitrogen, phosphorus, and potassium. These results have been used as the basis for a new methodology for assessing the relative soil fertility in agroforest landscapes. The assessment of relative soil fertility in agroforest landscapes is based on the combined use of Earth remote sensing data, geoinformation technologies and field research and five agrophysical indicators: humus content, mobile forms of nitrogen, phosphorus, potassium, and water-soluble salts.

As a result, the following groups of relative soil fertility are distinguished: very low fertility, low fertility, medium fertility, high fertility. Based on the final point, the map of relative soil fertility is made up, which is the basis for supporting decision-making on agrochemical and agrotechnical measures to improve soil fertility. The predominant reserves of productive moisture in a meter layer of soil have been established by types of soil cultivation in various crops.

The optimal soil consistency under grain crops was provided by moldboard and non-moldboard cultivation. In spring, this indicator makes 1.03-1.10 g/cm³, in the harvesting period – 1.27-1.33 g/cm³ at moldboard cultivation and 1.24-1.3 g/cm³ at non-moldboard cultivation. Using the direct sowing technology ensured the following indicators of soil consistency: 1.19 g/cm³ in spring and 1.34 g/cm³ after harvesting.

In the agroforest landscapes of the semi-desert zone on light chestnut soils, stable productivity of winter wheat (3.4 t/ha) with a profitability level of 200-220% is provided by agricultural technologies based on chisel tillage.

Three main approaches aimed at building environmentally sustainable agroforest landscapes in the Volgograd region have been revealed:

1. Special-target program (examples from history: "Stalin's plan for nature transformation", "General plan to prevent desertification of black soils and Kizlyar pastures"; modern national projects such as "Ecology").

2. Science-based approach consisting in development of a special land use project.

3. Informational and consulting approach, which is implemented on the basis of general and special knowledge and methods of constructing ecologically balanced agrolandscapes taking into account zonal features.

A point-based system has been developed for assessing the heterogeneity of arable land in agroforest landscapes. The methodology and the system of criteria for direct, indirect and integrated assessment of the state of agricultural landscapes in the dry-steppe and semi-desert zones of the Volgograd region have been tested [25].

Assessment of the ecological balance of agrolandscapes of the dry-steppe zone at 3 stationary objects (the Cherensky agro-industrial complex (object "C"), private farm of V.V. Isaev (object "I"), JSC Ust-Medveditskoe (object "U")) has been carried out according to the method of A.V. Gostev [26], which includes 7 types of criteria.

1. Assessment according to the criterion of sowing structure has been carried out by the mathematical method taking into account the presence of crops unacceptable for cultivation in the given soil and climatic conditions and the degree of cultivated crops variability. Object "C" received 2 points, object "I" – 3 points, and object "U" – 4 points.

2. Assessment according to the criterion of crop rotation system has been carried out by determining the ratio of the number of crop rotations to the number of agrolandscapes and the degree of landscape saturation with crops. Object "C" received 2 points, object "I" – 3 points, and object "U" – 5 points.
3. Assessment according to the criterion of tillage system has been carried out by determining the ratio of conformity and non-conformity of the tillage method. Object "C" received 2 points, object "I" – 3 points, and object "U" – 4 points.

4. Assessment according to the criterion of the system of fertilizers and ameliorants has been carried out by determining the balance of organic matter, incoming and outgoing soil humus, optimization of applied doses of mineral fertilizers, their impact and aftereffect on soil productivity and improvement, correspondence of the actual amount of applied fertilizers to the calculated ones. Object "C" received 2 points, object "I" – 3 points, and object "U" – 4 points.

5. Assessment according to the criterion of the plant protection system has been carried out by determining the use/non-use of an integrated plant protection system on an area of more than 50% of crops, as well as the level of pesticide load (4 kg/ha – complies with the requirements, 4-7 kg/ha – partially complies with the requirements, and more than 7 kg/ha – does not comply with the requirements). Object "C" received 1 point, object "I" – 3 points, and object "U" – 4 points.

6. Assessment according to the criterion of forest reclamation. According to this criterion, all objects have 2 points or characterized by partial correspondence to the requirements. Differentiation of forest belt structures, types of protective forest plantations as well correspondence of the assortment of tree species have been assessed according to the formula of G.T. Balakay. The results show that 80-99% of agrolandscapes comply with the criteria, 50-79% – partially comply, and 20-49% – are not balanced.

7. Assessment according to the criterion of farm machinery gave the following results – object "C" received 2 points, object "I" – 4 points, and object "U" – 4 points. We have determined the provision of farms with technical means and the level of modernization. Thus, farms with a deficit level of 10% comply with the requirements, 10-20% – partially comply, and more than 20% – do not comply.

As a result, according to the sum of the criteria, the first object scored 13:7 = 1.86 points, the second object 21:7 = 3.00 points, and the third object 27:7 = 3.86 points.

Thus, all objects in terms of their summing results do not comply with balanced farming systems, and only object "U" (had 5 compliance indicators) is very close to the compliance requirements.

4. Conclusion
As a result of the research, a methodological tools have been developed for the ecological assessment of agricultural landscapes in conditions of insufficient moisture, namely:
– conceptual-methodological and information-technological principles for the formation of ecologically balanced agricultural landscapes and their classification have been developed;
– influence of modern agricultural technologies on the agricultural landscape in the dry steppe zone of dark chestnut soils of the Volgograd region on soil fertility, on the proportion of agricultural land, crop structure, type of crop rotation and other components has been described. The nature of agricultural technologies is largely determined by the methods of basic tillage, fertilizing systems, protective complex, the cycle of nutrients, manifestation of water and wind erosion;
– methodology for assessing the relative soil fertility in agroforest landscapes using GIS technologies has been developed;
– methodology and system of criteria for an integrated assessment of the state of agricultural landscapes in dry-steppe and semi-desert zones of the Volgograd region have been tested.

From the point of view of practical significance, the results obtained, taking into account the zonal features of the study area, have made it possible to give an objective assessment of the state of agricultural landscapes, to establish quantitative values of the main parameters of the formation of ecologically balanced agricultural landscapes using a system of direct and integrated indicators and modern aerospace methods and GIS technologies for dry steppe and semi-desert zones of the Volgograd region, which ultimately will be put into the development of a system for rationing the anthropogenic load on the agrosphere.
Acknowledgments
This work was carried out as part of State Assignment of the FSC of Agroecology RAS No. 0713-2019-0007.

References
[1] Kiryushin V I 2011 Theory of Adaptive Landscape Agriculture and Design of Agrolandscapes (Moscow: Kolos) p 443
[2] Lopyrev M I, Nedikova E V and Kharitonov A A 2015 Agrolandscape as a Factor of Sustainable Land Use and Land Management Bulletin of the Voronezh Agrarian University 4-2(47) pp 179-183
[3] Agroecological Assessment of Lands. Design of Adaptive Landscape Systems of Farming and Agricultural Technologies2005 ed V I Kiryushin and A L Ivanov (Moscow: Rosinfor-Magrotech) p 794
[4] Kiryushin V I 2000 Greening the Agriculture and Technological Policy (Moscow: Publishing house of the Moscow Agricultural Academy) p 473
[5] Kiryushin V I 2019 Scientific prerequisites for optimizing the use of land resources Bulletin of Russian agricultural science 4 pp 7-10
[6] Lopyrev M I 2012 Organization of Agricultural Landscapes for Sustainable Agriculture (Voronezh: Voronezh GAU) p 108
[7] Masyutenko N P, Chuyan N A, Bakhirev G I, Kuznetsov A V, Glazunov G P, Dubovik E V and Pankova T I 2011 The System of Indicators for Assessing the Ecological Capacity of Agricultural Landscapes for the Formation of Environmentally Sustainable Agricultural Landscapes (Kursk: RAAS) p 42
[8] Masyutenko N P, Chuyan N A, Bakhirev G I, Kuznetsov A V, Breskina G M, Dubovik E V, Masyutenko M N, Pankova T I and Kaluzhsky A G 2013 A System for Assessing the Sustainability of Agricultural Landscapes for the Formation of Ecologically Balanced Agricultural Landscapes (Kursk: RAAS) p 50
[9] Isachenko A G 1991 Landscape Science and Physical-Geographical Zoning (Moscow: Higher school) p 366
[10] Isachenko A G 1980 Methods of Applied Landscape Research (Leningrad: Science) p 224
[11] Armand D L 1975 Landscape Science: (Fundamentals of Theory and Logical-Mathematical Methods) (Moscow: Mysl) p 288
[12] Odum E P 1971 Ecology (Holt London) p 152
[13] Malezieux E 2012 Designing cropping systems from nature Agronomy for Sustainable Development 32 pp 15-29
[14] Dore T, Makowski E, Munier-Jolain, Tchamitchian M and Tittonell P 2011 Facing up to the paradigm of ecological intensification in agronomy: revisiting methods, concepts and knowledge European Journal of Agronomy vol 34 pp 197-210 doi:10.1016/j.eja.2011.02.006
[15] Kashtanov A N, Lisetskiy F N and Schwebs G I 1994 Fundamentals of Landscape-Ecological Agriculture (Moscow: Kolos) p 127
[16] Zhuchenko A A 1994 Strategy of Adaptive Intensification of Agriculture (Conception) (Pushchino: RAS) p 148
[17] Nikolaev V A 1979 Problems of Regional Landscape Science (Moscow: Publishing House of Moscow University) p 160
[18] Sukhoy P A et al 2015 Environmental Assessment of Agrolandscape Systems at the Regional Level Bulletin of the Tyumen State University. Ecology and nature management vol 1 3 (3) pp 6-16
[19] Kosolapov V M, Trofimov I A, Trofimova L S and Yakovleva E P 2010 Agricultural Landscapes of the Volga Region. Zoning and Management (Moscow-Kirov: Press House VYATKA) 335 p
[20] Avessalomova I A 1992 *Environmental Assessment of Landscapes* (Moscow: Moscow State University) p 87
[21] Aydarov I P 2007 *Organization of Agricultural Landscapes in Russia* (Moscow: MGUP) p 159
[22] Pavlovsky E S 1992 *Conception of Modern Agroforest melioration* (Volgograd: VNIALMI) p 39
[23] Barabanov A T 1993 *Agroforest melioration in Soil-Protection Agriculture* (Volgograd: VNIALMI) p 155
[24] Methodology of State Variety Testing of Agricultural Crops 1985 Issue 1 (Moscow) p 269
[25] Belyakov A M and Nazarova M V 2019 Assessment of the ecological state of agricultural landscapes in the areas of insufficient moisture in the south of Russia *Proceedings of Nizhevolzhskiy agrouniversity complex: science and higher vocational education* 3(55) pp 5-42 doi:10.32786/2071-9485-2019-03-3
[26] Gostev A V, Pykhtin I G, Plotnikov L B and Pykhtin A I 2017 A System for Assessing the Ecological Balance of the Agricultural Landscape and the Degree of Compliance with the Farming System *Agriculture* 8 pp 3-6