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On the Formation of Ecologically Balanced Agrolandscapes in the Dry-steppe Zone of Chestnut Soils

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ABSTRACT

Background: Intensive agricultural technologies without proper scientific support violate the existing natural balance, both in landscapes and in agricultural landscapes and lead to soil degradation and often to desertification of large areas. Research in areas of insufficient moisture, the most environmentally vulnerable due to the growth of anthropogenic load and the use of unbalanced agricultural technologies, are very relevant.

Methods: This study assessed the ecological balance of three agrolandscapes in the dry-steppe zone of chestnut soils of Volgograd region (objects “Ch”, “I” and “U”) formed under the influence of direct seeding, classical (mouldboard) and combined agricultural technologies.

Result: As a result of the research the system of direct, indirect and integrated assessment of the state of agricultural landscapes for conditions of insufficient moisture was developed. The average score of object “Ch” had 2.3 points, which corresponds to weak balance, object “I” - 2.9 points or medium balance and object “U” - 3.6 points or relatively balanced agrolandscape. The results show that the formation of ecologically balanced agrolandscapes in the dry-steppe zone should be carried out according to specific developed parameters-requirements.

Key words: Agricultural landscapes, Agrotechnologies, Ecological balance, Evaluation system.

INTRODUCTION

Landscape, as a territorial unit of a whole district or region, is an object of impact of global climate change and with the development of civilization and intensification of human economic activity undergoes significant stress and changes. These changes are reflected in the relief, soil, flora and fauna create prerequisites for the development or degradation of the landscape and, consequently, change the ecological environment (Chopra, 2016; Kiryushin, 2015, 2020; Mueller *et al.*, 2021).

The state of the landscape is affected by the most numerous external factors, such as the laying of various communications (communication lines, power lines, roads), gas and oil pipelines, planting and (or) cutting of forests, mining, construction of cities and settlements, industrial facilities, *etc.*

However, the most direct influence on the landscape is agriculture, which in recent years has been using the most modern tools (heavy machinery, pesticides, fertilizers, herbicides, growth-regulating preparations, *etc*.) and thus shapes the agrolandscape and contributes to its changes.

Intensive agricultural technologies without proper scientific support violate the existing natural balance, both in landscapes and in agricultural landscapes and lead to soil degradation and often to desertification of large areas (Salvia *et al.*, 2019; Kulik *et al.*, 2019; Kopittke *et al.*, 2019; Tsoraeva *et al.*, 2020).

In this regard, agrarian science is faced with the task of developing fundamentally new agricultural technologies and farming systems that would form ecologically balanced agricultural landscapes, both for different soil and climatic zones and for individual land users (Kiryushin, 2018).

The purpose of these studies was to develop comprehensive zonal requirements for the formation of ecologically sustainable and balanced agrolandscapes in the dry-steppe zone of chestnut soils based on the generalization of our own research material and the experience of other researchers.

The objective of the research was to summarize and analyze the research experience in the direction of ecologization of agriculture and the formation of balanced agrolandscapes; define a system of criteria for assessing the condition of agrolandscapes; organize special research in different agrolandscapes to assess them and obtain the

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necessary experimental material; develop zonal comprehensive requirements for ecologically balanced agrolandscapes.

MATERIALS AND METHODS

We studied agroforestry landscapes of the dry-steppe zone of chestnut soils of Volgograd region (Fig 1). The studies were conducted from 2018 to 2022 on the stationary sites of land use of JSC Ust-Medveditskoye (object U), private farm of Isayev V.V. (object I) located in the Serafimovichi district and Cherensky agricultural industrial complex (object Ch) located in the Kletsky district, where agricultural landscapes of one soil and climate zone were formed under the influence of different agricultural technologies, namely classic with rotation of the formation, direct seeding and their combinations in combination 70 by 30%.

Cherensky agricultural industrial complex is located on the territory of Verkhnecherenskoye rural settlement in the south-west of Kletsky district of Volgograd region. The area of the farm is 39400 ha.

The individual private farm Isayev V.V. is located on the territory of Proninskoe rural settlement in the southwest of Serafimovichi district of Volgograd region. The area of cultivated arable land in the farm is 13500 ha.

JSC Ust-Medveditskoye is located between the Tsutskan and Srednaya Tsaritsa rivers and borders on the farms of Isayev V.V. and Cherensky agricultural industrial complex. The total area of the territory is 15640 ha, arable land - 10137 ha.

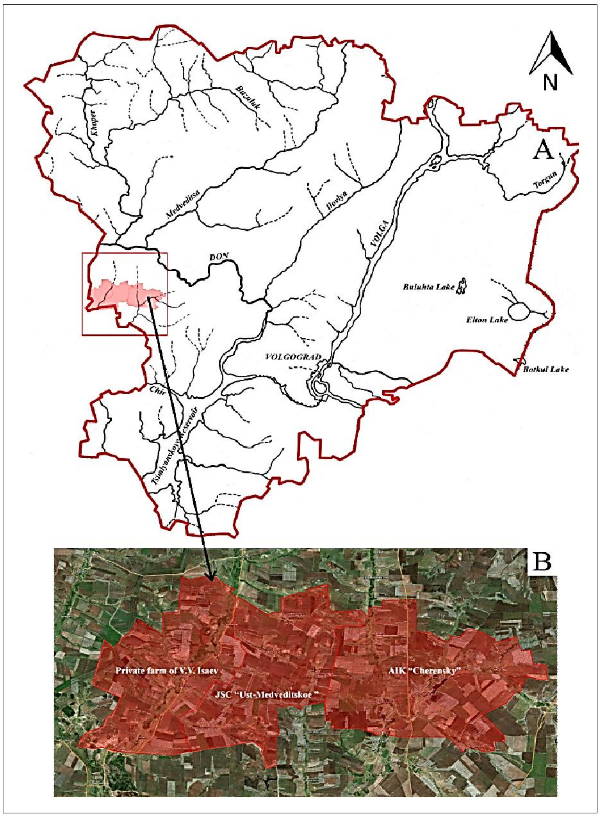

Fig 1: Location map of the research object: A - Volgograd region; B - Test farms.

The territory of land use of three designated farms belongs to the southeastern end of the Sredne-Russkaya Upland to the East Don tectonic denudation ridge and is a gentle-swollen plain with a slope in the south and south-east directions with predominant relief elevations of 150-200 m. The relief is heavily dissected with a dense gully and gully network.

The soils have a cloddy, cloddy-grained structure of the humus horizon of virgin lands and a dusty-cloddy structure of the arable one (Perekrestov, 2013).

The territory of the economic entities belongs to the arid region and the southwestern arid-steppe region. It is characterized by the following indicators for the period with an air temperature of 10°C: beginning on April 21, end on October 4, duration of 165 days, hydrothermal coefficient 0.6-0.7, sum of positive temperatures – 3050-3150°C, sum of precipitation 260-290 mm (Sazhin *et al.*, 2017).

Winter is moderately cold. The absolute minimum is -37-40°C. The average height of snow cover is 15-20 cm. The depth of soil frost is 30-60 cm. Summers are hot and dry. Average July temperatures rise from +21.8°C to +23.6°C southward. Absolute maximum is 41-42°C. The frostless period lasts 160 to 177 days. The number of days with atmospheric drought increases to the south from 35 to 50 days.

In our work, we relied on own experimental research, analysis and synthesis of the scientific literature (Kiryushin and Ivanov, 2005; Pavlovsky and Vavin, 2012; Masyutenko *et al.*, 2016; Gostev *et al.*, 2017; Belyakov and Nazarova, 2018, 2019, 2021; Belyakov *et al.*, 2022). Assessment of the balance of agrolandscapes and farming systems for the conditions of the dry-steppe zone of dark chestnut soils according to the method of Gostev A.V. (Gostev *et al.*, 2017) on the basis of 7 types of criteria: 1 - by crop structure, 2 - by crop rotation system; 3 - by tillage system; 4 - by fertilizer and ameliorant system; 5 - by plant protection system; 6 - by forest amelioration system; 7 - by agricultural machinery system.

Agricultural landscapes and farming systems of the research objects were evaluated in points according to the scale of balance we proposed: 5 points (absolutely balanced), 4 points (balanced), 3 points (medium balanced), 2 points (weakly balanced), 1 point or less (not balanced). The average balance score of the study objects was calculated using our proposed scale (Belyakov *et al.*, 2022).

RESULTS AND DISCUSSION

The main requirements for the conservation and restoration of agrolandscapes in the dry-steppe zone should include indicators, which are formed under the influence of such factors as the selection of crops and their placement in the rotation, tillage, the introduction of compensatory fertilizer and building an optimal plant nutrition system, the presence

Table 1: Assessment of the state of agrolandscapes of the studied farms in the dry-steppe zone of Volgograd region according to the system of direct criteria (average for 2018-2022).

Indicators	Farms		
	Object "Ch"	Object "I"	Object "U"
Ecological indicators			
Area of arable/clear fallow, ha	10176/5424	9890/3610	10137/-
Yield of winter wheat/oilseed crops, t/ha	3.23/1.36	4.41/1.62	2.03/0.98
Terrain dissection, %	25.9	29.7	30.6
Share of water erosion of soil/deflation, %	16.8/24.6	10.2/10.2	3.1/0.08
Total forest cover, %	4.2	4.2	3.5
Technological indicators			
Type of basic tillage	Moldboard with plow	Combined	Direct seeding
Number of chemical treatments, pcs.	2-3	3-4	5-6
Fertilizer application, kg/ha	26	47	84
Soil moisture in 1st soil layer: early spring/by harvesting, mm	132/16	138/27	124/42
Soil density for harvesting in 0.0-0.6 m layer, g/cm^3	1.24	1.25	1.27
Plowing coefficient, units	0.71	0.67	0.66
Balance of agrolandscape, score	**2 (unstable)**	**3 (medium)**	**4 (good)**

of legumes and perennial grasses in the cropping pattern, the size of fallow fields, the proportion of forest cover and methods of complex soil amelioration, including forest reclamation (Table 1).

The results indicate that the fertilizer application rate in site "I" is higher by 21 kg of active ingredient/ha than site "Ch" and in site "U" is higher by 58 kg of active ingredient/ha than site "Ch" and 37 kg of active ingredient/ha than site "I". Soil compaction density by harvest on all stationary sites is approximately equal, but with greater compaction by 0.2-0.3 g/cm^3 under direct seeding technology. The best soil moisture reserves in the meter layer, 138 mm, were obtained by combined technology and the lowest, 124 mm, by direct seeding technology, but by harvesting the advantage remained for the technology without tillage, 42 mm and the least, 16 mm, by classical technology.

The manifestation of water and wind erosion was marked on the classical technology -16.1% and 24.6%, respectively, of the arable area. When using direct seeding technology these two disasters had zero values. Combined technology on a number of indicators occupied an intermediate value. The obtained data indicate the advantages in productivity of combined technology.

In general, the intensity of arable land use is high under classical and combined technologies and medium under direct seeding. High balance and sustainability of agro-landscape is achieved only with direct seeding technology, medium with combined technology and low with classical technology. Direct seeding technology had the best results in a number of environmental indicators (return of nutrient elements, deterrence of water and wind erosion, moisture conservation), but was inferior in terms of reproduction of products per unit area.

According to the results of research, we can conclude that the most balanced agrolandscape, 4 points, is formed by direct seeding technology on a number of environmental indicators (return of nutrients, deterrence of water and wind erosion, moisture conservation) and is inferior in terms of reproduction of products per unit area. Classical technology is inferior to direct seeding technology and combined variant, combined technology occupies an intermediate position.

The research results allowed us to determine the key areas of greening agricultural landscapes and develop that the following; sowing structure, crop rotation, methods of basic tillage, level of nutrients subtraction, fertilization rates, protective complex of phytocenoses, methods of territorial planning, forest cover and anti-erosion protection measures are the factors that significantly affect the ecological balance of agrolandscape and cropping systems.

We have assessed the actual state of agrolandscapes on a set of agrotechnological factors on the 7 types of criteria (1-2 points, does not correspond; 2-3 points, partially corresponds; 4-5 points, corresponds).

As a result of applying this assessment (Table 2) to the test farms located in the dry-steppe zone of dark chestnut soils, the following results were obtained: for object "Ch" - 5 criteria were not balanced, 3 criteria were partially balanced and only 2 criteria were balanced. On object "I" - 4 indicators are not balanced, 4 are partially balanced and 2 are balanced. For the object "Y" - 5 indicators are not balanced and 5 are balanced.

According to our proposed point scale (Belyakov *et al.*, 2022) we calculated the average score of balance of the objects of research. Thus, the object "Ch" had 2.3 points or weak balance, the object "I" - 2.9 points or average balance and the object "U" - 3.6 points or relatively balanced agrolandscape. Consequently, the studied agrolandscapes are characterized by different types of ecological balance depending on the technology applied.

Thus, the system of direct, indirect and integrated assessment of the state of agricultural landscapes was developed for the conditions of insufficient humidity (Belyakov, 2018) which allows for objective evaluation of agricultural objects in terms of their ecological balance. The system can be used as the basis for the theory of formation of ecologically balanced agrolandscapes and farming systems, for regulation of anthropogenic load on the agricultural sphere as well as for timely adoption of organizational and technological measures on restoration of ecological balance in the conditions of insufficient humidity peculiar of the southern regions of the Russian Federation.

The timing and method of harvesting should correspond to the complete safety of the formed crop and not violate the qualitative water-physical parameters of soil composition, which implies that grain harvesting should be carried out within 6-8 days, when grain from the ear does not fall off and without vehicles entering the field to avoid over-compaction of the soil.

Thus, technologies should have an acceptable level of their intensity in terms of the contribution of material, monetary and energy investments and not exceed the acceptable criteria for the stress of natural resources and energy costs. In terms of adaptability to terrain and soil and climatic conditions, they should ensure safety and high restorative capacity of natural landscapes.

As a result of the studies carried out by comparing various agricultural landscapes, we came to the conclusion that farming systems and crop cultivation technologies should integrate the main elements of territory development (field size and configuration) and provide a balanced proportion of key categories of farming land (structure of lands), as well as adaptive crop rotation (by the number of fields, set and alternation of crops), recommended amount of forest cover, appropriate type and design of field-protective forest belts, tillage techniques depending on terrain and humus content. The combination of these factors should improve soil fertility, humus increase, availability of macroelements, improvement of water parameters, soil structure.

Generalization of the experimental material on farming systems and agricultural technologies for the dry steppe zone of chestnut soils allowed us to develop a zonal concept of ecologically balanced agrolandscapes (Fig 2), which includes the following parameters and their quantitative values.

Table 2: The balance of agro-technological criteria at the research sites.

Subjects of research	Applied agro-technologies	Number of agrotechnological criteria		
		Unbalanced	Partially balanced	Balanced
«Ch»	Classics	5	5	2
«I»	Combination	4	4	2
«U»	Direct seed	5	-	5

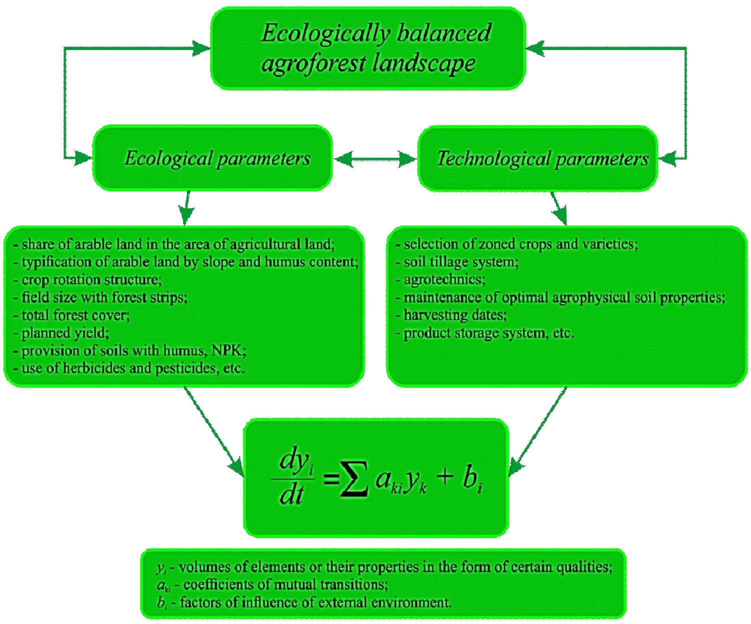

Fig 2: General scheme of zonal ecological-technological concept of formation of ecologically balanced agroforest landscapes.

The share of arable land in the area of agricultural land should not be more than 55-60%.

It is necessary to work out mandatory land use by typification of arable land, slopes and content of humus for subsequent use by levels of intensity.

Crops and released varieties (hybrids) for cultivation should be selected according to growing conditions (frost and drought resistance) and market demand for products.

A 3-4-field crop rotation with the recommended share of steam not more than 16-18%, perennial grasses – 6-8%, alternation of crops by type of root systems (sagebrush-rod) is allowed.

The optimal size of the field is 160-240 ha with an forest shelterbelts and an interstrip space of 600-800 m. The total forest cover should be not less than 3% of the land use.

Yields should be planned not higher than 70% of the calculated bioclimatic potential with full compensation of removal at the expense of fertilizers and crop residues;

Differentiation of soil cultivation should be carried out (ploughing 0.25-0.27 m or deep tillage without soil turnover to 30% of the planned volume of work, shallow tillage to a depth of 0.06-0.12 m to 30% of the planned volume of work, direct seeding 30% of the planned volume of work. Variants of other various combinations are possible, such as deep tillage without turning the soil in combination with shallow and surface tillage and increased share of direct seeding.

Zonal farming techniques should be differentiated in terms of timing, seeding rates, depth of seeding. It is necessary to follow zonal scientific recommendations. For example, sowing rate for winter wheat in the zone of light chestnut soils is 3.0-3.5 million germinated seeds per 1 ha, optimal sowing dates are September 1-10 and sowing depth is 0.06-0.08 meters. In this case, in early sowing dates before 01.09. seeding rate should be reduced by 0.5 million pieces, in late sowing dates, after 10.09. to increase.

It is necessary to maintain the average provision of soil with humus at 2.4-3.0%, with the content of mobile phosphorus above 15 mg/100 g of soil and exchangeable potassium above 300 mg/100 g of soil through the abandonment of crop residues, sedation and the introduction of organic and mineral fertilizers.

It is also necessary to keep optimal agrophysical properties of soil (soil structure 50-58%, porosity 52-56%, density of soil (bulk weight) at sowing 1.8-2.2 g/cm^3, stocks of productive moisture in the meter soil layer in early spring at 138-142 mm.

Harvesting is carried out within 6-8 working days without the arrival of vehicles on the field. Product storage is carried out in accordance with the developed regulations and recommendations.

Past research has developed methods for designing the optimal infrastructure of agrolandscape ecosystems (Lopyrev and Makarenko, 2001), methods for ecologizing landscape-based farming and technology for designing agrolandscapes in farming systems (Lopyrev and Linkina 2012; Lopyrev, 2017), methods for evaluating agrolandscape balancing, optimizing farming systems (Vladimirov *et al,* 2020), considered the optimization of agrolandscapes from the perspective of agroforestry amelioration (Pavlovsky and Vavin, 2012; Kulik and Pugacheva, 2016), studied approaches to improving the ecosystem services of agricultural landscapes (Mueller *et al.*, 2021).

The search for methods of greening agricultural landscapes and agricultural technologies has led to an understanding of the need for integrated research approaches, constant monitoring of the state of various agricultural landscapes, analysis of causal relationships and impact factors, development of organizational and technological measures for the conservation of natural resources, as well as restoration of disturbed land use areas (Masyutenko *et al.*, 2015; Sukhoi *et al.*, 2015; Kiryushin, 2015; Pismennaja *et al.*, 2015; Belyakov, 2018; Belyakov and Nazarova, 2018; Trofimov *et al.*, 2018; Kiryushin, 2020).

Research in areas of insufficient moisture takes a special place, since the southern provinces are the most environmentally vulnerable due to the growth of anthropogenic load and the use of unbalanced agricultural technologies. However, the zonal aspect has not yet been sufficiently studied.

Researches on the formation of ecologically balanced agrolandscapes were mainly conducted in the steppe zone of chernozem soils (Lopyrev, 2017; Masyutenko *et al.*, 2016; Gostev *et al.*, 2017) the dry-steppe zone was not covered by such researches. In our research, we attempted to conduct a comprehensive approach to assessing the ecological balance of agrolandscape in the dry-steppe zone of Volgograd region, to assess the factors affecting the formation of agrolandscape and to develop a general conceptual scheme of ecological-technological model. Such studies were conducted for the first time in the dry-steppe zone and will be continued in the semi-desert zone to develop the theory of formation of adaptive agroforestry complexes under conditions of climate change.

Our research is aimed at adaptation of farming to droughts and dry spells through a complex of factors (selection of crops, breeding, cultivation techniques, agro-technologies and forest amelioration, where the final result of the search is a balanced agrolandscape. In practice, agricultural producers in the region with the help of science managed to raise crop productivity from 0.7-0.8 t/ha in the 60-70s to 2.6-3.2 t/ha in grain units in recent years, which indicates an improvement in soil fertility, field microclimate, including the stability and balance of agrolandscapes.

Accordingly, the formation of ecologically balanced agricultural landscapes in the dry-steppe zone of chestnut soils is carried out according to specific developed parameters-requirements, which provides the necessary ecologization of the environment and agrarian sphere of production.

CONCLUSION

Thus, we have developed a system of criteria for comprehensive assessment of landscape areas for agro-ecological balance and justified the agrotechnological requirements for the formation of ecologically balanced agrolandscape for the dry steppe zone of the Volga-Don interfluves. It was found that the agrolandscapes and farming systems in the land use of JSC Cherensky, which uses classical tillage, poorly balanced, the average score was 2.3. In the farm Isayev, combined system - medium balanced, 2.9 points and in JSC Ust-Medveditskoye, direct seeding - relatively balanced agrolandscape, 3.6 points. Proposed zonal concept of ecologically balanced agrolandscapes, which includes the above parameters and their quantitative values. The results of the research can make a significant contribution to the implementation of the idea of rational agriculture and land use.

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Conflict of interest

All authors declare that they have no conflicts of interest.

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