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ORGANIZING SUSTAINABLE AGRICULTURAL LAND MANAGEMENT IN ALTAI KRAI: A GEO-ECOLOGICAL PROSPECT

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In recent decades, the agriculture of Altai Krai has been considered an agro-industrial complex. The total land area is 17 million hectares, and more than 11.5 million hectares are classified as agricultural lands. The area of arable land amounts to 6.5 million hectares. More than 90% of total agricultural land area, to various extents, is subject to erosion and soil blowing; less than 10 kg of mineral fertilizers are required. According to expert estimates, agricultural crops experience an acute lack of nutrients in the soil, which deteriorates the quality of the crop. In this regard, contemporary agricultural land management in Altai Krai is highly volatile and unsustainable. One example is the Strategic Direction of Scientific and Technological Development of the Russian Federation and other long-term regulatory documents defining the development of agriculture in the next 10–15 years, which establish the transition of some agricultural organizations to an alternative, high-tech, and environmentally friendly organic agricultural sector. Organic farming is based on the management of organic agricultural land. In those territories that conform to certification requirements, organic land management in Altai Krai can partly become an alternative path to an agro-industrial one. However, to move to a high-tech level of organization of contemporary agricultural land management in Altai Krai, it is necessary to implement all measures related to the geo- and agro-ecological justification of the use of the territory. To be exact, it is crucial to conduct (1) retrospective analysis of land management (based on the materials of soil surveys and land management systems for collective and state farms developed in the last century); (2) assessment of the ecology of the structure of the agricultural landscape and the structure of acreage and crop rotation system; (3) modeling of the agricultural landscape and the ratio of land; (4) ecological and economic analysis of land-use models.

Keywords: *Altai krai; organization of sustainable agricultural land use; agricultural landscape; geo-ecological assessment; modeling of the agricultural landscape*

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ОРГАНИЗАЦИЯ УСТОЙЧИВОГО УПРАВЛЕНИЯ ЗЕМЛЯМИ СЕЛЬСКОХОЗЯЙСТВЕННОГО НАЗНАЧЕНИЯ В АЛТАЙСКОМ КРАЕ: ГЕОЭКОЛОГИЧЕСКАЯ ПЕРСПЕКТИВА

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В последние десятилетия сельское хозяйство Алтайского края рассматривается в качестве агропромышленного комплекса. Общая площадь земель составляет 17 млн га, из них более 11,5 млн га отнесены к сельскохозяйственным угодьям. Площадь пашни составляет 6,5 млн га. Более 90% общей площади сельскохозяйственных угодий в той или иной степени подвержены эрозии и выдуванию почв; требуется менее 10 кг минеральных удобрений. По экспертным оценкам сельскохозяйственные культуры испытывают острую нехватку элементов питания в почве, что ухудшает качество урожая. В связи с этим современное управление сельскохозяйственными угодьями в Алтайском крае отличается высокой изменчивостью и неустойчивостью. В качестве примера можно привести Стратегию научно-технологического развития Российской Федерации и другие долгосрочные нормативные документы, определяющие развитие сельского хозяйства на ближайшие 10–15 лет, устанавливающие переход ряда сельскохозяйственных организаций на альтернативный, высокотехнологичный и экологически чистый органический сельскохозяйственный сектор. Органическое земледелие основано на управлении органическими сельскохозяйственными угодьями. На тех территориях, которые соответствуют сертификационным требованиям, органическое землепользование в Алтайском крае отчасти может стать альтернативой агропромышленному. Однако для перехода на высокотехнологичный уровень организации современного землеустройства сельскохозяйственного назначения в Алтайском крае необходимо реализовать все мероприятия, связанные с гео- и агроэкологическим обоснованием использования территории. А именно, крайне важно провести (1) ретроспективный анализ землеустройства (по материалам почвенных обследований и разработанным системам землеустройства в прошлом веке для колхозов и совхозов), (2) оценку экологии структуры агроландшафта и структуры посевных площадей и системы севооборотов, (3) моделирование сельскохозяйственного ландшафта и соотношения земель и (4) эколого-экономический анализ моделей землепользования.

Ключевые слова: *Алтайский край; организация устойчивого землепользования; агроландшафт; геоэкологическая оценка; моделирование агроландшафта*

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Introduction

Current social and economic reforms radically changed land and property relations in Russia, its regions, and municipalities, significantly affecting the economy and society. As a result, various approaches and methods of regulation, planning, and organization of land management are required. Modern agro-industrial production has exhausted itself [13], as a result of which the direction of scientific and technological progress of Russia until 2035 and other long-term documents [16; 17; 23] outline areas related to greening production processes in the agricultural industry. Furthermore, many landowners employed in agricultural production often have different, even conflicting, interests, and those monitoring studies (soil, geobotanical, land management, etc.) conducted by state institutions for land design in the territory of the Russian Federation at the beginning of the 21st century became irrelevant and lost funding. Therefore, a system of land management, life support, and vital activity of the population and the state should be organized. It should also address the sustainable use of land resources [1; 8; 10; 15; 26]. Therefore, the problem raised in this paper is relevant, and research in this direction is essential to increase the sustainability of agricultural land management as a basis for the anthropogenic factor of geosystems.

For the first time, a multicomponent analysis of the medio-stabilizing role of the ratio of land and the structure of acreage was conducted for the studied territory over a long period of time. As a result, it was found that this is one of the main causes of its instability, which can be controlled. In this regard, innovative models of agricultural land use management were proposed, taking into account the reproduction of soil fertility and the stability of agricultural production, which will increase the stability of agricultural landscapes.

The scientific novelty of the research is determined by the following factors:

– the geoecological assessment of the impact of the composition of land on the sustainability of agricultural land use was conducted for the first time;
– the assessment of the erosion hazard of the structure of sown areas of agricultural land use of the municipal district was conducted for the first time;

– unique models of agricultural land use management that affect sustainability were developed taking into account the geoecological factors of the territory, offering different scenarios of its organization.

Materials and methods

The paper aims to determine the geo-ecological foundations in justifying measures for organizing sustainable agricultural land management based on the example of a municipal district in Altai Krai – Siberian Federal District. To achieve the research goal, it was necessary to analyze the land management system of the region and evaluate the ecological agro-landscape with a sowing crop rotation and perform modeling of agricultural lands.

This research is based on surveys of Altai Krai, including our municipal district, carried out by the Altai Research Institute of Land Design in 1970–2000. In addition, we presented the materials obtained as a result of the conducted research in the form of tables and diagrams.

A systematic approach or analysis was widely used to study natural systems (landscapes, biogeocenoses), create cultural systems for agricultural land management, and optimize agricultural landscapes and agroecosystems [6; 12; 18; 19]. When studying the local features of geosystems, various field, stationary, and office methods were used [3]. The geo-information system Mapinfo Professional 12.0 was applied to analyze and construct cartographic models. We analyzed and compared the obtained empirical models of agricultural landscapes using a comparative approach [7; 20; 21]. The cartographic method was a regular and integral part of the comparative analysis (approach).

We also used historical and abstract logical methods, mathematical processing of primary data, analysis, synthesis, and modeling of processes and objects [11; 24].

Results

The administrative territory of the Klyuchevskoy district and its dry steppe landscapes, which are geographically located in the west of Altai Krai, were the research object. From the west, the region borders Kazakhstan; the northern border runs past the Kulundinsky district, the eastern – past the Rodinsky district, and the southern – past the Mikhailovsky district of Altai Krai. The research area is a part of the Kulunda steppe, located in its central part, a lacustrine-alluvial plain. According to cadastral records, the area of the municipal district amounts to about 304.5 thousand hectares, of which 241.7 thousand hectares is agricultural land.

In accordance with agroclimatic zoning, the territory of Klyuchevskoy district is included in the warm (III) slightly humid region (east of the Klyuchevskoy Region), and the main part of the administrative district is located in the warmer arid region (IV) [25].

The landscapes of the Kulunda steppe are characterized by instability; they are subject to changes in the process of economic activity [9]. This situation is due to several factors: (1) the ease of soils in terms of the distribution of its particles by size and their formation in an arid climate; (2) the absence of biogeocenoses formed under natural conditions; and (3) the low water reserves collected on the surface of the earth. These factors determine the development of desertification, soil degradation, weathering, salinization, and alkalinization. It is critical to increase the stability of agricultural landscapes and protect the water and soil resources of territories of this category [5; 22]. The characteristics of the studied agricultural lands are presented in Table 1. Negative factors for agricultural soils such as erosion, deflation, salinization, and alkalinization are of global importance [5; 22].

The characteristics of the studied agricultural lands (as of January 1, 2020) are given in Table 1 [18]. Air erosion is one of the negative factors of agricultural soils. For the studied region, air erosion is a common and dangerous phenomenon.

Table 1.

Characteristics of agricultural land, area (ha)

Type of agricultural land	Total area	Eroded	Highly wind-eroded	Saline	Alkalinized
Agricultural land	221,263	700	16,632	5,134	24,859
Arable land	157,982	659	14,697	1	11,348
Fallow land	2,571	–	–	–	–
Perennial plantations	120	–	67	–	–
Hayfields	3,962	41	402	185	1,729
Pastures	56,628	–	1,466	4,909	23,954

When analyzing land management, one should assess the relationship between the ecological stability of the territory and the structure of land within the boundaries of the district. The environmental indicators used for the assessment should reflect the ecological stability and diversity of the landscape of the territory. These indicators include (1) the level of surface tillage, (2) forest cover, the ratio of natural and agricultural land (arable land, meadows, and forest

plantations), (3) the coefficient of environmental sustainability of the territory (Kes), (4) anthropogenic load (Kal), and (5) the index of ecological diversity [4]. The evaluation indicators are presented in Table 2.

Table 2.

Environmental indicators of the Klyuchevskoy district (as of January 1, 2020)

Indicators	District (total area)	Agricultural land	Cultivated land
Cultivated land area, ha	304,333	241,730	221,623
Arable land, ha	157,982	157,982	157,982
Fallow land, ha	2,571	2,571	2,571
Hayfields, ha	3,896	3,896	3,896
Pastures, ha	56,898	56,898	56,898
Forests, trees, and bushes, ha	52,721	3,718	3,568
Water objects, ha	8,372	273	273
Built-up areas, ha	2,626	1,471	1,276
Ploughness, %	51.9	65.3	71.3
Forest cover, %	17.3	1.5	1.6
Land ration: arable land, meadows and forest, %	51.9:20.8:17.3	65.3:26.2:1.5	71.3:28.6:1.6
K_{es}	0.41	0.27	0.30
K_{al}, grade	3.15	3.50	3.82

It is necessary to conduct a comprehensive analysis of agricultural land and cultivated land for the studied region since the environmental sustainability of territories can vary significantly. In particular, the degree of surface tillage, the condition of the forests, and the percentage of soil types indicate the high stability of the landscape. Therefore, there will be different proposals for optimizing natural territories and agricultural lands. Priority should be given to measures aimed at farmland optimization.

Fig. 1 shows the results of an assessment of the erosion hazard of cultivated area structure in the research area (as of July 1, 2019).

The analysis of the ratio of the area of crops as a percentage is required to establish an optimum for creating favorable conditions for maintaining the stability of the territory in anti-erosion and anti-icing issues and ensuring the planned amount of crop products. Fig. 1 shows that cereals in the dry steppe should occupy 40%, grasses – 40–50%, accompanying crops – 10%–20% of the total area of crops.

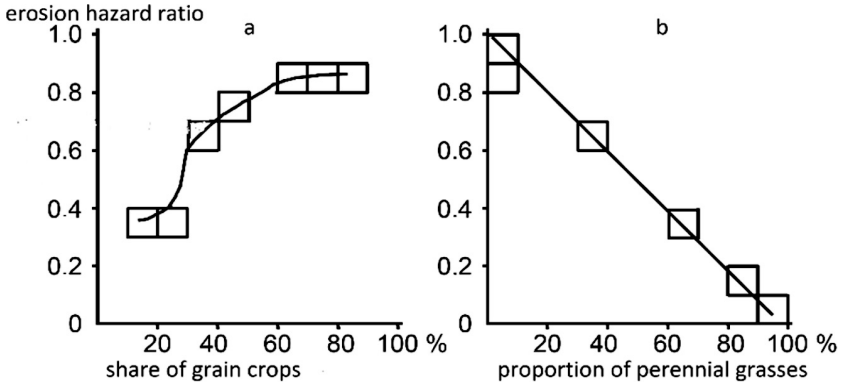

Fig. 1. The coefficient of erosion hazard for cereals (a) and perennial grasses (b) in the crop structure

Soil-protective crop rotations are the factor with the most remarkable ability to protect land under arable land. The erosion hazard coefficient is 0.3–0.4.

The results of the evaluation of crop rotation used by agricultural organizations in the municipal area are given in Table 3. Crop rotation is discussed in terms of its ability to balance organic matter. A sustainable positive balance of organic matter is provided by soil-protective crop rotation, fodder 3-field with sweet clover, and irrigated 5-field with forage three-year perennial grasses. Field crop rotation in dry steppe conditions does not contribute to fertility reproduction; furthermore, it negatively affects the balance of organic matter.

Table 3.

Humus balance and the need for organic fertilizers

Type of crop rotation	Humus balance, t/ha	Manure application, t	
		1 ha	1 ha of crop rotation
Soil-protective			
1. Herbal 6-field	+2.59	–	–
2. Grain-herbal with strip placement of crops 5-field	+0.1	–	–
Field			
1. Grain-herbal 4-field	–2.4	24	6
2. Grain-herbal 6-field	–2.5	25	4
3. Grain fallow with sweet clover as fertilizer 6-field	–2.76	28	5

The end of a table

4. Grain fallow 5-field	–3.43	34	7
5. Grain fallow 4-field	–3.46	35	8.7
Forage (without irrigation)			
1. Forage 3-field with sweet clover	+0.3	–	–
2. Forage 7-field, including perennials 4 years	0	–	–
3. Forage 2-field	–1.6	16	8
By-farm (with irrigation)			
1. Forage 5-field, including perennials 3 years	+1.5	–	–
2. Forage 2-field	–1.3	13	6.5
3. Forage 3-field	–2.7	27	9

Having analyzed land use in the Klyuchevskoy district of Altai Krai, we proposed 10 land management models (Table 4). The first three models have sufficient resource intensity, models 4–8 support the functioning of agricultural landscapes, but landscapes, nevertheless, remain ecologically unstable. The last two models are environment-restoring.

Table 4.

Land management models in the municipal district (as of January 1, 2020)

Models	Share of lands, %					
	agricultural	arable	forage	cultivated	stabilizing	non-agricultural
Resource-consuming (to a high degree)	79.4	51.9	20.7	72.6	22.7	6.7
Resource-consuming (to a medium degree)	78.7	47.1	24.8	72.0	27.6	7.3
Resource-consuming (to a lower degree)	78.7	43.3	28.6	72.0	31.3	7.3
Ecologically stable	78.0	40.0	27.5	67.5	34.66	10.5
Balanced	76.5	33.0	32.9	66.0	46.2	10.5
Balanced (from the medical point of view)	78.0	29.1	38.2	67.5	45.5	10.5
Lea tillage	78.0	14.6	52.9	67.5	58.7	10.5
Soil-protective	79.4	14.7	54.2	68.9	60.0	10.5
Virgin	78.0	0	67.5	67.5	73.3	10.5
Nature-protective	14.0	0	8.5	8.5	79.2	10.5

Table 5 presents indicators of the efficiency of agricultural land management under the proposed land management models.

Table 5.

Indicators of land management efficiency (as of January 1, 2020)

Indicators	Models of land management									
	1*	2	3	4	5	6	7	8**	9	10
Productivity per 100 hectares at comparable prices, thou. RUB										
Gross products	640	600	619	588	571	603	510	–	445	1,824
Consumed products	520	486	501	476	463	489	413	–	361	410
Profits	343	332	338	322	307	318	259	–	254	270
Productivity per 100 hectares of cultivated land, centner										
Cereals	784	718	661	616	518	448	224	–	no	no
Milk	171	167	216	211	245	307	336	–	362	414
Meat	5	5	6	6	7	9	10	–	15	14
Break-even level, %	115	124	120	121	115	111	103	–	133	192

*Note**: Model names are given in Table 4; ** economic indicators of Model 8 and Model 9 are practically identical.

Data in Table 5 were obtained based on the study of an extensive land management system. Table 5 shows that the value of gross and marketable output is determined by the ratio of land areas.

A decrease in the area of arable land leads to a decrease in the number of products received from arable land. The increase in livestock production is caused by an increase in the area of forage lands. In our calculations, we took two nominal heads of cattle on 5 hectares of forage land. Thus, the existing reserves of intensifying the land use of the territory were not taken into account.

Discussion

The geo-ecological assessment of modern land exploitation in the Klyuchevskoy district revealed that the stability of the territory of the district is higher (Kes= 0.41) than the territory of agricultural land (Kes = 0.27-0.30) due to the presence of pine forests. The territory with agricultural land is characterized by the lowest level of ecological stability. This situation objectively proves an increase in the coefficients of topsoil cultivation and anthropogenic load, a decrease in the index of forest coverage, and the coefficient Kes <0.33, a negative balance of natural territories and arable land. The territory of the district is "unstable stable" (Kes = 0.41). The coefficient of anthropogenic load shows a change in the ecological state of land and agricultural lands (an increase from 3.15 to 3.82) towards deterioration. The ecological assessment of the exploitation of agricultural lands shows the deterioration of the ecological

condition of the private territories and those used by legal entities. These territories are less resistant to negative processes due to their narrow production specialization [14].

An ecological assessment of the crop ratio and the crop rotation system indicates that the erosion hazard coefficient increases with an increase in the proportion of grain crops and a decrease in the part of the perennial grasses. Soil-protective crop rotations protect arable land most effectively when four or five out of six fields are covered with perennial grasses.

This fact is evidenced by the coefficients of erosion hazard. Conservation crop rotations provide a positive balance of organic matter [2].

The results of the efficiency of using arable land indicate that the structure of crops has a positive impact on profitability. Indicators of economic efficiency and profit show the high economic efficiency of using arable land [4].

Quantitative analysis reveals that the productivity of arable land exploitation in the Belgorod region is four or five times higher, and in the Rostov region – six or seven times higher than in the Klyuchevskoy district of Altai Krai.

Optimization of dry steppe agricultural landscapes is built following the principles of sufficiency, environmental requirements, and economic potential.

Based on the calculations above, 10 algorithms or models of land management and optimization of agricultural landscapes in the region were proposed. So, the area of arable land from the first pattern to the last one decreases from 158 thousand hectares to 0. At the same time, forage areas (hayfields and pastures) increased from 60.5 thousand hectares in the 1st model to 205.3 thousand hectares in the 8th model. While the percentage of arable land to forage areas is changing, the total area of land and agricultural areas is decreasing since part of them is allocated to protective forest belts, microrelief, water protection zones around residential areas, along road and railway communications, and those for strengthening light soils. The ninth and fifth models are characterized by the most significant forest cover.

Conclusion

The territory of the studied object has a weak stability of economic operation; it differs significantly in the character of agricultural lands and areas of natural conditions. Deflation is a limiting factor for land use.

The erosion hazard coefficient is 0.3–0.4. Land-use models that we developed will significantly improve the stability of the territory. To increase the environmental sustainability of the agricultural landscapes of the dry steppe zone, and, in particular, of the Klyuchevskoy district of Altai Krai, it is necessary to reduce the arable land area to an environmentally acceptable level (30%–40% of

the total area of the municipal district) and bring the area of field-protective forest plantations to the norm of 1 hectare per 25–30 hectares of agricultural land.

Additionally, the resulting livestock products and intensive technologies of land exploitation in field cultivation compensate for the drop in crop yields.

This study shows that the geoecological assessment of agricultural land use is obligatory and integral, which allows one to optimize the use of land and economic and social resources, ensuring its competitiveness and efficiency.

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