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Impacts of agri-food systems on the state and dynamics of land resources in Russia in the context of food security

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ABSTRACT
This article provides a comprehensive analysis of the dynamics and condition of Russia's land resources in the context of the functioning of agri-food systems for the period 2019–2024. The relevance of the study is determined by the key role of land resources in ensuring the country's food security against the backdrop of increasing anthropogenic impacts and climate risks. Based on statistical and structural analysis of the data, the following key trends were identified: increasing land use intensity, expressed in an increase in the application of mineral fertilizers (from 2.7 to 3.5 million tons) and expanding the scope of chemical reclamation, while the problems of anthropogenic soil disturbance persist. Particular attention is paid to the processes of reclamation and degradation of agricultural land. The author emphasizes the dual nature of the influence of agri-food systems: stimulating productivity is accompanied by the risks of qualitative soil depletion and dependence on chemical and technological inputs. A conclusion is drawn regarding the need for a transition to a restorative land use model to ensure long-term food sustainability, including improved monitoring of degradation processes and the development of a reclamation complex.

Keywords: agri-food systems, Land resources, Food security, Soil degradation, Reclamation, Land use intensity, Agricultural chemicalization, Sustainable development, Land monitoring.
Article Type: Perspective.

INTRODUCTION
Land resources are the fundamental natural resource foundation of agri-food systems and largely determine the sustainability of national food security. By increasing pressure on agricultural land, elevating anthropogenic impacts, climate variability, and the need for technological modernization in agriculture, the issue of land conservation, restoration, and rational use is particularly important. For Russia, which has significant land resources, not only the availability of resources but also their quality, use patterns, degree of involvement in agricultural production, and the level of degradation and restoration measures are crucial. In today's world, agri-food systems have a dual impact on land resources: on the one hand, they ensure food production, but on the other, they create risks of soil depletion, erosion, waterlogging, man-made land disturbance, and the reduction of the productive potential of territories. Therefore, studying the state and dynamics of Russia's land resources in the context of agri-food systems is an important scientific and applied task.
The purpose of this study is to assess the impact of agri-food systems on the state and dynamics of Russia's land resources from a food security perspective.
The study's objectives include:
Analyzing the structure of Russia's land resources by land and land use categories.
Identifying the dynamics of disturbed, depleted, and reclaimed lands.
Assessing the condition of agricultural lands susceptible to erosion and waterlogging.

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Considering the scale of land reclamation, chemical reclamation, fertilization, and the use of plant protection products.

Assessing the impact of these processes on the sustainability of the agricultural land base and the country's food security.

MATERIALS AND METHODS

The study's information base consisted of official statistical data characterizing the distribution of Russia's land resources by type, the area of disturbed and reclaimed land, the condition of agricultural land, the scale of reclamation activities, the use of pesticides, as well as the application of mineral and organic fertilizers and chemical reclamation. The analysis was based on data for 2019–2024, which allowed us to track changes in land resource dynamics and identify trends related to the functioning of agri-food systems. The study utilized methods of systems analysis, statistical comparison, dynamic analysis, structural analysis, and generalization. A systems approach allowed us to consider land resources as part of a broader agri-food system, where natural, technological, and organizational-economic factors are interrelated. Statistical analysis was used to assess year-over-year changes and identify consistent trends in land resource distribution, land disturbance and restoration, land reclamation, and the use of chemicals in land use. A comparative method was used to compare indicators between years and to assess the ratio of land disturbance and reclamation areas. The study's information base was formed by official state statistics and departmental reports reflecting land resources, land use, land reclamation status, and agricultural production measures. This approach ensured data comparability and the ability to objectively interpret trends in the context of food security.

RESULTS AND DISCUSSION

The study results show that Russia's land fund has generally remained relatively stable during the period under review, although its structure has undergone changes reflecting the impact of agrifood systems and other economic sectors. The area of agricultural land fluctuated slightly from 2019 to 2024: from 222.0 million hectares in 2019–2021 to 225.5 million hectares in 2024. This indicates that the resource base for agricultural production has been maintained and even indicates a slight increase in the area of agricultural land in the final year of observation. However, the share of agricultural land in the country's total land area remains virtually unchanged at approximately 13.0%–13.1%, indicating limited expansion of agricultural land across the entire land fund (see Table 1).

Table 1. Distribution of land by land use (at the beginning of the year; millions of hectares).

	2019	**2020**	**2021**	**2022**	**2023**	**2024**
Agricultural land	222.0	222.0	222.0	221.9	221.8	225.5
Lands under surface water and swamps	226.8	226.8	226.8	226.8	226.8	226.8
Lands under forests and forest plantations not included in the forest fund	897.0	897.0	897.0	897.0	897.0	897.8
Other lands	345.4	345.5	345.5	345.4	345.5	345.6
Lands withdrawn from productive use	21.2	21.2	21.2	21.3	21.4	22.0
Including:						
Lands under development	6.1	6.1	6.1	6.2	6.2	6.6
Lands under roads	8.1	8.1	8.1	8.1	8.2	8.2
Disturbed lands	1.1	1.1	1.1	1.1	1.1	1.2
Lands under waste landfills and dumps	0.1	0.1	0.1	0.1	0.1	0.1
Lands under sand and ravines	5.8	5.8	5.8	5.8	5.8	5.9

Source: Environmental Protection in Russia, 2024: Stat. collection/Rosstat. – Moscow, 2024 – 118 p.

At the same time, a high stability of land area under surface water and wetlands was recorded – 226.8 million hectares throughout the period, as well as land under forests and forest plantations not included in the forest fund, which amount to approximately 897 million hectares. These data demonstrate that Russia's land potential is characterized by a significant proportion of natural areas not involved in agricultural production, which increases the importance of intensive factors in agricultural development compared to extensive expansion of land area.

Land withdrawn from productive use is of particular interest. Its area increased from 21.2 million hectares in 2019 to 22.0 million hectares in 2024. The most significant increase was observed in land under development, which increased from 6.1 to 6.6 million hectares, as well as in land under sand and ravines. This indicates an increase in anthropogenic pressure and a reduction in the portion of the land stock potentially suitable for productive use. In the context of food security, this necessitates increasing the efficient use of existing lands, as well as strengthening measures to prevent further land abandonment. Disturbed land indicators show significant volatility. In 2019, 194,200 hectares were disturbed, in 2020, 174,500 hectares, in 2021, 195,200 hectares, in 2022, a sharp increase to 264,000 hectares, and in 2023, a decrease to 230,000 hectares (see Figs. 1-2).

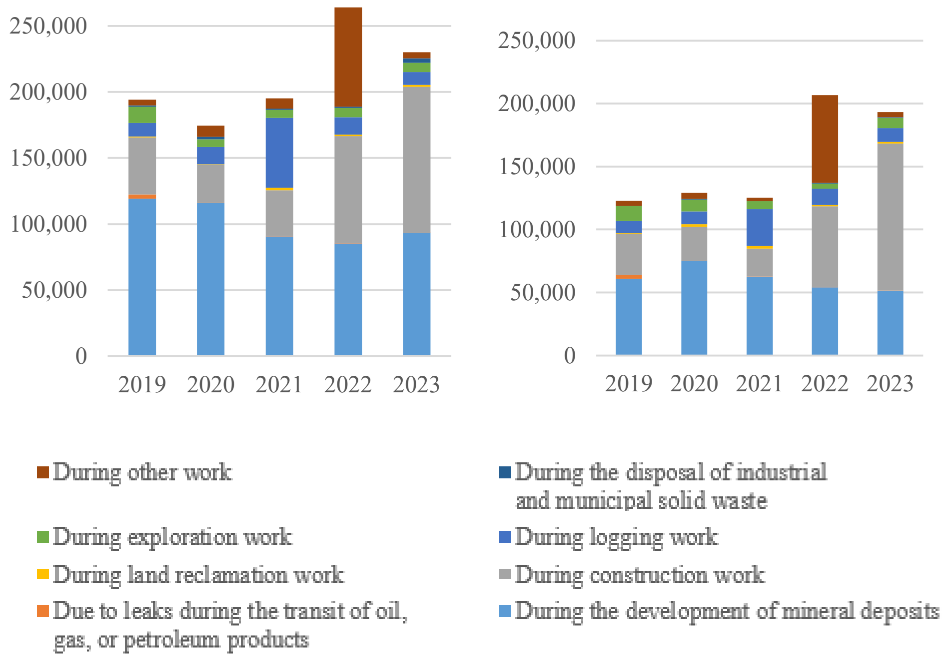

Fig. 1. Indicators of disturbed lands, thousand hectares: a) disturbed lands; b) developed lands. Source: Environmental Protection in Russia. 2024: Stat. collection/Rosstat. – M., 2024 – 118 p.

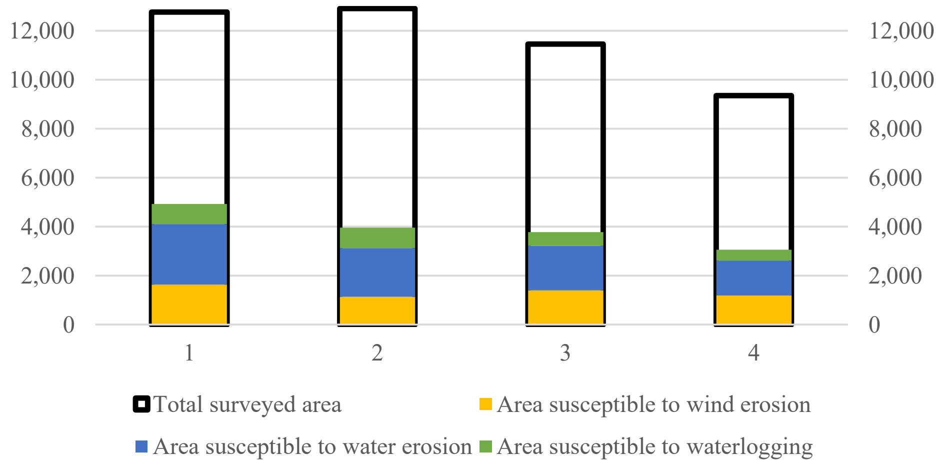

Fig. 2. The area of agricultural land subject to wind and water erosion and waterlogging, as a percentage of the total area of surveyed agricultural land (thousands of hectares); Source: Environmental Protection in Russia, 2024: Stat. collection/Rosstat. – Moscow, 2024 – 118 p.

Construction and mineral development contribute the most to land disturbance. The increase in construction disturbances is particularly noticeable in 2022–2023, reflecting the impact of infrastructure and industrial development. At the same time, the reclamation of disturbed lands is also increasing: from 102,200 hectares in 2019 to 171,400 hectares in 2023. However, the volume of reclaimed land remains lower than the volume of disturbed land in most years, indicating a persistent shortage of compensatory measures. The structure of reclaimed agricultural lands is noteworthy (see Table 2). Their area increased significantly in 2022 to 120,950 hectares, but decreased to 22,860 hectares in 2023. This trend may be related to the completion of individual major projects or changes in the structure of restoration work. At the same time, it demonstrates that reclamation has significant potential as a tool for returning land to agricultural use, especially in the context of the need to strengthen food security. An analysis of the condition of agricultural lands subject to degradation processes shows that from 2019 to 2022, a decrease in the area susceptible to wind and water erosion, as well as waterlogging, was recorded (Fig. 2).

Table 2. Area of reclaimed land (hectares).

	2019	2020	2021	2022	2023
Total	30 526	30 058	24 554	120 950	22 856
including:					
during the development of mineral deposits	9 364	4 246	5 309	5 537	5 332
due to leaks during the transit of oil, gas, and petroleum products	618	23	60	72	137
during construction work	11 705	12 259	10 161	42 583	12 270
during land reclamation work	89	2 029	1 254	739	1 009
during logging work	5,0	147	301	88	91
during exploration work	6 116	4 960	1 590	33	2 015
during the disposal of industrial and solid municipal waste	17	442	68	143	68
during other work	2 612	5 952	5 811	71 756	1 935

Source: Environmental Protection in Russia. 2024: Stat. collection/Rosstat. – Moscow, 2024 – 118 p.

The area susceptible to wind erosion decreased from 1.644 to 1.192 million hectares, while that susceptible to water erosion decreased from 2.468 to 1.421 million hectares. Areas susceptible to waterlogging decreased from 817,000 to 447,000 hectares. This may indicate a gradual improvement in agricultural landscape management, an expansion of erosion control and reclamation measures, and more rational land use. Positive trends are also observed in the area of reclaimed agricultural land. The total area of such land increased from 9,448,100 hectares in 2019 to 9,469,700 hectares in 2023, but decreased to 9,380,400 hectares in 2024 (Table 3). At the same time, the area of land used for agricultural production decreased from 7,128.5 to 6,961.3 thousand hectares. This indicates that the reclamation fund requires not only preservation but also more efficient use and technical renovation. The reduction in the area of drained land while maintaining irrigated land indicates a possible transformation of the structure of reclaimed lands and the need to adapt to changing natural and climatic conditions. Pesticide use in agriculture overall decreased. The total area treated with pesticides decreased from 101.7 million hectares in 2019 to 85.9 million hectares in 2023 (Table 4). At the same time, the share of agricultural land treated with pesticides decreased from 45.8% to 38.8%. This decrease may reflect both the optimization of crop protection technologies and changes in cropping patterns. Weed control treatments, typical for crop production, continued to account for the largest share. The reduction in aerial application from 5.1 to 1.3 million hectares may indicate a shift to more targeted and, possibly, more environmentally friendly technologies. Mineral fertilizer application demonstrated steady growth. In terms of 100% nutrient content, its volume increased from 2.7 million tons in 2019 to 3.5 million tons in 2023 (Table 5).

Table 3. Area of reclaimed agricultural land (at the beginning of the year; thousands of hectares).

	2019	2020	2021	2022	2023	2024
Total area of reclaimed agricultural land	9 448.1	9 455.4	9 465.6	9 459.2	9 469.7	9 380.4
including:						
irrigated	4 667.3	4 673.9	4 686.2	4 679.1	4 690.1	4 667.9
drained	4 780.8	4 781.4	4 779.5	4 780.1	4 779.7	4 712.5
Of which used in agricultural production	7 128.5	7 138.1	7 201.9	7 079.8	7 075.2	6 961.3
including:						
irrigated	3 859.9	3 890.3	3 961.3	3 963.4	3 965.5	3 960.4
drained	3 268.6	3 247.8	3 240.5	3 116.4	3 109.6	3 000.9

Source: Environmental Protection in Russia, 2024: Stat. collection/Rosstat. – Moscow, 2024 – 118 p.

The proportion of the area fertilized with mineral fertilizers increased from 61.1% to 72.4%. This is an important factor in maintaining crop yields and compensating for soil depletion, but it also increases the risk of environmental impacts if application rates are not met. Organic fertilizer use was relatively stable: its volume fluctuated around 70-71 million tons, and the share of the fertilized area was approximately 9.2-9.6%. This indicates that organic fertility restoration remains limited and does not yet play a dominant role. Chemical reclamation also indicates attempts to maintain soil quality. Liming volumes for acidic soils remained at 0.3-0.4 million hectares, and the application of limestone flour ranged from 2.1 to 2.9 million tons (Table 6).

Table 4. Pesticide application to protect plants (thousands of hectares).

	2019	2020	2021	2022	2023
Pesticide treatments	101 730	101 522	94 848	93 703	85 896
including:					
pest control	27 976	26 916	23 754	27 156	24 228
disease control	20 316	20 418	18 357	20 877	17 615
growth regulators	1 600	2 345	2 975	1 722	1 581
weed control	49 691	49 789	47 594	42 334	41 068
defoliation and desiccation	2 147	2 054	2 975	1 612	1 401
Of the total volume, aerial method	5 114	3 750	3 233	1 887	1 329
The proportion of agricultural land area treated with pesticides in the total agricultural land area, percent	45.8	45.7	42.7	42.2	38.8

Source: Environmental Protection in Russia, 2024: Stat. collection/Rosstat. – Moscow, 2024 – 118 p.

Table 5. Application of mineral and organic fertilizers for crops in agricultural organizations.

	2019	2020	2021	2022	2023
Total mineral fertilizers applied (based on 100% nutrients), million tons	2.7	3.0	3.3	3.4	3.5
including:					
nitrogen	1.7	1.9	2.1	2.2	2.2
phosphorus (including rock phosphate)	0.6	0.7	0.7	0.7	0.7
potassium	0.4	0.5	0.5	0.5	0.5
Proportion of area fertilized with mineral fertilizers in total sown area, percent	61.1	66.9	71.1	71.5	72.4
Organic fertilizers applied, million tons	70.7	70.5	70.2	70.6	71.2
Proportion of area fertilized with organic fertilizers in total sown area, percent	9.5	9.4	9.6	9.2	9.3

Source: Environmental Protection in Russia, 2024: Stat. collection/Rosstat. – Moscow, 2024 – 118 p.

Table 6. Carrying out work on chemical land reclamation in agricultural organizations.

	2019	2020	2021	2022	2023
Acidic soils limed, million hectares	0.3	0.4	0.3	0.3	0.3
Limestone powder and other calcareous materials applied:					
total, million tons	2.3	2.9	2.4	2.1	2.3
per hectare, tons	7.6	7.8	7.1	6.9	7.5
Gypsum application performed on solonetzic soils, thousand hectares	2.4	4.5	5.0	7.4	12.2
Gypsum, phosphogypsum, and other gypsum-containing rocks applied:					
total, thousand tons	15.3	20.6	24.2	48.5	59.9
per hectare, tons	6.2	4.6	4.9	6.6	4.9
Acidic soils phosphoritization performed, thousand hectares	21.7	21.1	20.7	17.9	10.7
Phosphate powder applied:					
total, thousand tons	20.6	18.2	15.4	13.7	9.9
per hectare, tons	1.0	0.9	0.7	0.8	0.9

Source: Environmental Protection in Russia. 2024: Stat. collection/Rosstat. – M., 2024 – 118 p.

Gypsum treatment of solonetzic soils gradually increased: from 2,400 hectares in 2019 to 12,200 hectares in 2023. This is a positive trend, as it indicates intensified efforts to restore soil properties. However, phosphoritization of acidic soils, on the contrary, decreased from 21,700 to 10,700 hectares, which may indicate a shift in priorities in the chemical reclamation system.

CONCLUSION

The results obtained are generally consistent with the findings of many studies, according to which agri-food systems have a dual impact on land resources (Migunov 2018), including greenhouse gas emissions (Sobolev 2023). On the one hand, they stimulate the intensification of land use, increased use of fertilizers, pesticides (Makoeva *et al.* 2015), and land reclamation measures, which contributes to increased agricultural land productivity (Guseva *et al.* 2021). On the other hand, they increase pressure on land resources through expanded economic development, anthropogenic soil disturbance, and an increasing share of degraded areas. A comparison with other studies shows that the trend toward stabilization of agricultural land area with a simultaneous increase in its intensive use is characteristic not only of Russia but also of many large agricultural countries (Kolesnikov *et al.* 2006). Moreover, the specific features of Russia include the significant spatial extent of the land fund, a high proportion of natural areas, and heterogeneity in the quality of agricultural land (Usenko & Chepik 2024). Many studies emphasize that ensuring food security requires not simply preserving land area, but also maintaining its quality, fertility, and resistance to degradation, including preserving the agrobiosphere (Aristova 2024). The data obtained support this position: the increase in fertilized areas and the development of land reclamation are accompanied by the persistent problem of disturbed lands (Makoeva *et al.* 2015) and a reduction in effectively used reclaimed areas. A number of studies indicate that land reclamation and restoration play a key role in ensuring sustainable agricultural development. Our results confirm this position, demonstrating an increase in reclaimed areas (Seredina, *et al.* 2006), including those returned to agricultural use. However, in contrast to optimistic estimates, this data set exhibits significant instability in dynamics (Ovsyannikov 2000), which precludes the complete elimination of technogenic damage. A comparison with soil erosion studies also shows that the reduction in areas subject to wind and water erosion is often associated not only with improved soil conservation practices, but also with the scale of the surveys. Therefore, the interpretation of such indicators should be cautious. This is consistent with the scientific position that land degradation monitoring should be continuous and comparable in methodology; otherwise, conclusions about soil improvements may be overstated. Overall, it can be concluded that Russian agri-food systems during the period under review, in the context of increasing external and internal risks to agricultural development (Migunov *et al.* 2023), ensured increased land use intensity and partial compensation for degradation processes through land reclamation, fertilizers, and reclamation. However, risks remain (Migunov & Syutkina 2022) associated with land disturbance during construction and mining, insufficient sustainability of reclamation infrastructure, limited scale of organic fertility restoration (Zaruk *et al.* 2022), and high dependence of agriculture on chemical-technological means of maintaining crop yields. This means that long-term food security requires not only increased productivity, but also a more careful, restorative model of land use.

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