Environment, Development and Sustainability (2024) 26:17837–17848
https://doi.org/10.1007/s10668-023-03366-y

Minimizing the adverse effects of agriculture on the environment: the case of Russia

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Received: 16 February 2023 / Accepted: 5 May 2023 / Published online: 17 May 2023

Abstract
Agriculture plays a crucial role in global food production. Nevertheless, the concern about its impact on the environment and sustainability is increasing. This article addresses modern technologies that are used or can be used in sustainable agriculture. There are discussions of various technological innovations, including precision agriculture and remote sensing. These innovations have demonstrated the prospects of reducing resource use, increasing efficiency, and improving environmental sustainability in agriculture. The authors also highlighted the problems and limitations of these technologies, such as cost, availability, and possible unintended consequences. In addition, the article discusses the need for interdisciplinary cooperation between researchers, politicians, and farmers to ensure the successful implementation of these technologies in agriculture. In general, the findings emphasize the need for the introduction of technologies in agriculture for sustainable methods and the potential of technologies to contribute to sustainable agriculture in the future.

Keywords Agroecology · Environmental problems · Land resources · Melioration activities · Sustainable agriculture

1 Introduction

Due to the growth of the population on the planet, the demand for food is steadily increasing. This demand is met through agriculture (Anderson et al., 2022; Calicioglu et al., 2019). Land resources are fundamental in agriculture. Therefore, the availability of adequate farmland, including arable land, is important to countries and regions worldwide (Fitton et al., 2019). However, land plowing, intensive application of mineral fertilizers, pesticides, irrigation, drainage, and other reclamation activities, can negatively affect the

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environment (Solgi et al., 2018). It also leads to the deterioration of land quality, soil degradation, pollution and depletion of water resources, drying of wetlands, desertification of land (Rastgoo & Hasanfard, 2021), and deforestation (European Union, 2019). All of the above processes cause ecosystem disturbance, reducing biodiversity (Pimbert, 2018). Soil protection issues have to be addressed in depth and at a legislative level (Joshi et al., 2004).

In today's world, the main challenge for countries is the creation of an efficient agricultural system that would provide people with enough food and help to rationalize the use of natural resources, which in turn will reduce the negative impact of farming on the ecosystem (Benyam et al., 2018). The trend toward expanding agricultural land at the expense of surrounding natural complexes is relatively widespread (Bezner Kerr et al., 2019). Consequently, the question of sustainable land management remains outstanding in many countries. Therefore, although many scientists from different scientific fields have repeatedly studied this topic, it remains relevant. National and international scientists raised the issue of greening agricultural production several times.

High-tech solutions can also play a role, for example, to reduce methane emissions when raising livestock or improve crop quality for activities in the food chain. Barbedo and Koenigkan (2018) revealed the role and possibilities of using modern technology for the greening of agriculture. Unmanned aerial vehicles (UAVs) increase the convenience of land processing. Nevertheless, the increase in the area of cultivated land complicates the application of UAVs.

Japan, as well as the USA in recent years, achieved considerable success in using the latest technologies. In addition, unmanned aerial vehicles used in agriculture are essential in reducing dependence on human labor while providing accurate measurements. A careful analysis and interpretation of the data collected by UAVs can improve crop cultivation methods and increase overall productivity. In addition, UAVs are capable of performing various agricultural tasks, such as soil monitoring, fertilization, and weather analysis. Fast-moving and equipped with cameras, these unmanned aerial vehicles provide valuable workforce support for situation assessment and on-site surveillance. Moreover, UAVs can use multiple sensors at the same time, and a combination of sensors improves data analysis. For example, UAVs can register vegetation indices that allow farmers to constantly monitor crop variability and stressful conditions, helping to make decisions on crop management (Aslan et al., 2022).

Most scientists agree that government restrictions on water and land use are necessary for greening the agriculture industry. Campbell et al., (2017) considered methods of reconciling agricultural production with environmental requirements and constraints. Excessive consumption is a particular concern. This issue disproportionately affects the planet. It needs urgent action to manage demand, not just satisfy it. Solving this problem requires a radical transformation of the entire food system with changes needed at every stage of production, increased attention to landscape-level management, and comprehensive changes in the broader food system (Campbell et al., 2017). Interventions to mitigate the impact of agriculture on planetary boundaries are possible at several points, including demand management strategies, expansion of cultivation with careful selection and management of land, and the introduction of improved land management practices for environmental, social, and economic benefits (Moran & Blair, 2021). The examples include increasing agricultural productivity per unit area of land, the use of fertilizers and water, the conservation and increase of organic matter in the soil, the use of agroforestry methods, and the preservation of local biodiversity and ecosystem. Reducing the use of phosphorus, increasing the use of recycled phosphorus from organic waste, reducing food waste, and promoting the reduction of meat and dairy consumption are essential measures (Liu et al., 2020).

Researchers emphasize the need for a balanced "consumption–production" approach to achieve sustainable development. This approach implies that agriculture is an integral part of a holistic and highly integrated food system (Ahmetzhanov et al., 2018; Mustafa et al., 2021). The efficient use of natural resources should become the basis of agriculture. In this case, it will lead to the optimization of the ecological situation on arable land. Meyfroidt et al., (2016) developed the theory of the rational use of land resources based on reintroducing abandoned farmland after its natural restoration. Reclamation and intensification of cultivated land interrelate. At the same time, the quality of the workforce, especially the availability of young, skilled, and motivated individuals with an entrepreneurial spirit. The latter is a stronger determining factor for reclamation than the total labor. Political and institutional support can indirectly strengthen reclamation trends by improving demographic and socioeconomic conditions and supporting investments in agriculture. However, it is worth noting that overcoming the restrictions on reclamation does not necessarily guarantee socioeconomic improvements. Large farms (agroholdings) that invest in labor-saving technologies can reclaim and cultivate large areas with minimal labor costs. In this case, they contribute insignificantly to overall employment and opportunities to earn a living in rural areas but rely on a functioning rural society to attract skilled agricultural labor. Although it is generally recognized that the potential of transformative agroecological training will be realized only to facilitate the territorial processes of agroecological dynamization, there is a gap in the knowledge of how to adapt it to different territorial conditions. Studying the regional characteristics of agriculture in Europe and Asia, Anderson et al., (2022), Bezner Kerr et al., (2019) proposed to improve agronomic efficiency by optimizing the structure of sown areas and carrying out agricultural activities considering the availability of moisture, weed, and pest control using biological methods.

In agriculture, the land is the main means of production. Correspondingly, the irrational use of natural resources can lead to changes and destruction of natural ecosystems, loss of biodiversity, soil degradation, pollution and depletion of water resources, and desertification of the territory due to the complex violation of soil and vegetation cover. Emissions from farm and livestock machinery are negatively affecting the Earth's atmosphere. Therefore, it is particularly important to comply with a country's current land law concerning the resources and recommendations of research institutions concerning the sustainable use of natural resources.

This study aims to provide a comprehensive evaluation of agriculture in countries with the highest agricultural productivity, as well as a multivariate analysis of environmental and agricultural indicators. The study highlighted key environmental issues in agriculture that arose in different regions due to active agricultural activities. It also considered the direct dependence of environmental indicators on the use of chemicals, greenhouse gases, and so forth.

Agricultural indicators that have the most substantial impact on changes in environmental performance, as well as the emergence of environmental problems associated with the development of the industry, were analyzed. The findings suggested a system of methods for their solution, according to the regional characteristics of the territory. The study also investigated the legislative framework on this issue.

The following tasks were set to achieve these goals:

1. Studying international experience in the protection, conservation, and restoration of terrestrial resources;

2. Analyzing certain environmental indicators of the country's economy (by industry) as it moves toward the green development path;
3. Determining the dependence of existing environmental indicators and problems based on correlation calculations with agricultural indicators and territorial features of the region, its physical and economic–geographical location;
4. Developing a system of approaches to address environmental problems.

2 Methods

Agricultural science focuses on the production of environmentally friendly products, agriculture, in particular breeding achievements, inventions relating to the cultivation of crops, animal husbandry, product processing technology, and so forth (Agroecology Bagandova & Ashuryuekova, 2011; Europe, 2017). It may facilitate an increase in production, reducing its cost, and increasing profits. Based on a systematic analysis of publicly available data from the Federal State Statistics Service (2022), compilations of UN food and agricultural statistics (2015–2020) (FAO, 2019, 2022), the World Data Atlas for 2015–2019 (Actualitix, 2022; World Data Atlas, 2022), the Official Site of the European Commission (2022), the OECD library (2022), the study conducted a comprehensive assessment of agriculture in the Russian Federation and the world. The method of mathematical analysis and systematization of statistical data, considered in the "Results" section, established the dependence of the existing environmental indicators and problems on the territorial features of the region, and its physical and economic–geographical position. The main environmental indicators of agriculture (consumption of mineral fertilizers and pesticides, water use for agricultural needs, CO_2 emissions in agriculture) were analyzed. In addition, the study showed their dynamics over the last five years in Russia and other countries with the industry's highest productivity (USA, Germany, France, Poland). The interdependency between environmental and agricultural indicators was established using Pearson's linear correlation method. The historical approach revealed the reasons for the presence of established models of the dynamics of the indicators examined. Considering territorial characteristics, the authors developed a system of methods for combating problems of the environment. By analyzing the dispersion of statistical data, it was possible to evaluate the effectiveness of using green agricultural methods in the countries studied.

3 Results

Further consideration will be given to analyzing the indicators that most strongly affect the ecological status of the most productive countries in agriculture (the USA, Russian Federation, Germany, France, and Poland). The results of the analysis of the aforementioned countries' environmental indicators for 2019 are systematized in Table 1.

The table shows that the USA is the leader in CO2 emissions, as well as water intake for agriculture. This tendency is due to irrational farming, large quantities of agricultural waste, and using fertilizers. The intensification of agriculture in the country has led to more exhaust emissions from agricultural machinery than all modes of transport combined. At the same time, states that actively grow cotton use water from rivers and lakes for irrigation; and these water resources are progressively drying up.

Table 1 Agri-environmental indicators

Indicators	Countries				
	Russia	Germany	France	Poland	USA
CO_2 emissions, thousand tons	31,023.8	28,669.75	32,039.6	16,630.12	174,287.32
Water intake for the needs of agriculture, mln m^3	3,615	676.4	2,691	75,81	267,808
Consumption of mineral fertilizers, kg/ha	18.5	197.2	163.1	172.8	138.6

Contrary to crop production, livestock production in the Russian Federation at actual prices increases yearly, which is confirmed by the diagram below (Fig. 1).

The increase in livestock production is due to the commissioning of some new pig farms that are technically very well equipped, resulting in a significant increase in pig production.

Although crop production is the main agricultural sector of the Russian Federation, in 2019, there was a decline in its profitability and productivity. This decline was due to a decrease in the cultivation of grain crops (wheat, barley, corn, and rice), leguminous crops (peas, beans, and lentils, as well as potatoes, sugar beets, sunflowers, soybeans, rapeseed, flax, cotton), and crops intended for livestock feed. In 2020, there was a resumption of development in both agricultural sectors. The positive momentum in crop production was collecting over 123 million tons of cereals, record oilseed production, and high sugar beet yields. Russia is one of the world leaders when it comes to exporting cereals and wheat. According to data provided by Rosreestr, as of January 1, 2019, the total area of agricultural land within agricultural land is 197.7 million hectares (197,720.7 thousand hectares) (European Commission, 2022). The structure of agricultural land is dominated by arable land (58.8%) and pastures (28.9%).

The territorial organization of agriculture shows its highest development in Krasnodar Krai (leader in grain harvesting, meat, and dairy farming), Rostov Oblast (fishery, grain, eggs, vegetables, and dairy industry), Belgorod Oblast, Republic of Tatarstan, Republic of Bashkortostan (leading regions in dairy production and potato cultivation), Voronezh region (grain, potatoes), Stavropol Territory, Altai Territory (grains),

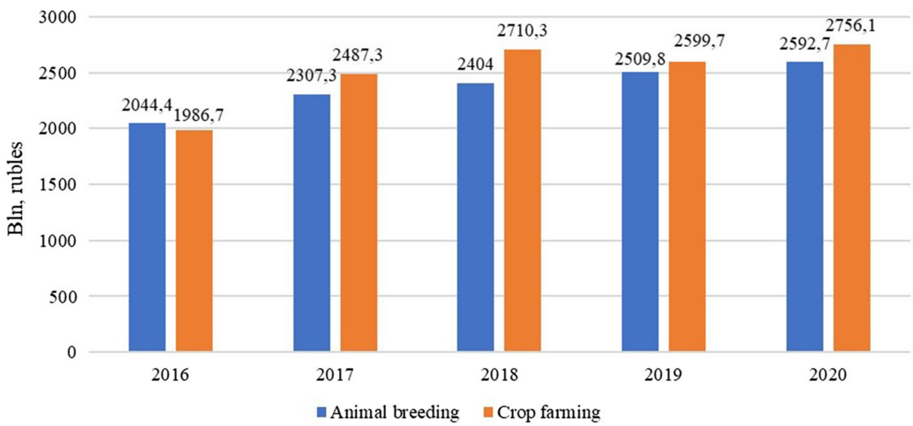

Fig. 1 Agricultural produce by farm category

Volgograd and Tambov regions (potatoes, sugar beets, corn, forage crops), which are leaders in the production of industry.

Agriculture relies directly on environmental conditions since it uses environmental resources such as land, soil, water, and energy. For all countries, the issue of greening in agriculture is reasonably acute. Under active and, at the same time, irrational use of arable land, application of large amounts of mineral fertilizers, and plowing of coastal protective strips lead to the degradation of soils and changes in ecosystems. The depletion of natural resources, in turn, causes a decline in the industry's productivity.

Agriculture involves the pollution of water resources by nitrates, while the application of improved agricultural methods is expected to reduce the degree of environmental pollution. It was noted that the total loss in productivity of arable land is due to irrational land use, which is currently averaging 0.2% per annum. For example, in 2019, the use of 5.38 tons of organic nitrogen fertilizer resulted in 4.85% nitrogen release into the atmosphere and 5.32 mg/l nitrate pollution of the surrounding surface water and groundwater. The figures for France were 69.6 tons, 68.8%, and 12.5 mg/l, respectively. In the USA, the same categories totaled 29.6 tons, 55.9%, and 10.2 mg/L. At the same time, the use of nitrogenous fertilizers was lower in the countries surveyed in 2018 (according to the statistical services). Therefore, it is necessary to prove that nitrate pollution of water is also less important.

In areas not affected by the green revolution, farming continues to develop. In order to increase the area of arable land, forests are cut, steppes are plowed, and the area of natural landscapes intact by human activity on Earth is constantly reducing. In Europe, agro landscape replaced hardwood forests, in Ukraine, the fields were replaced with steppe landscapes, reducing biodiversity. Planting riparian strips and destroying natural vegetation can lead to water erosion, shoreline abrasion, flooding, and, in drier areas, wind erosion. Overgrazing, depleting water resources, and deforestation ultimately lead to desertification. Problems of this kind are specific to the Middle East and Central Asia. The only desert in Europe formed due to agricultural activity is in Kalmykia, with most of the republic's land subjected to desertification due to active cattle breeding.

These processes had consequences. Thus, 1/6 of the country was not eco-friendly and 60% of the farmland was exhausted. Scientists have therefore started to search for ways of greening the industry. To date, the situation has improved considerably. By 2020, 32% of recovered land was in poor condition.

Agriculture accounts for about 30 percent of greenhouse gases in the atmosphere, significantly contributing to climate change.

Sources of greenhouse gas emissions are allocated as follows: 31% of all emissions come from heat and electricity production, 15% from transportation, up to 17% from agriculture, 6% from forestry, and 12% from manufacturing (Fig. 2).

Among other types: fossil fuel combustion, garbage, and gas leaks are distributed as the remaining 36% of emissions.

Livestock production accounts for about 16.6% of the country's greenhouse gas emissions. By 2030, this is expected to account for 50% of all air emissions, with a temperature increase of almost 1.7 °C. Forests are cut down to increase pasture, and sheep and cows emit a lot of methane and carbon dioxide, causing considerable air pollution.

Using pesticides and mineral fertilizers to increase agricultural productivity also has devastating environmental impacts. Pesticides harm the environment and human health, and their overexploitation reduces biodiversity. The accumulation of pesticides in agricultural products and water causes various human diseases.

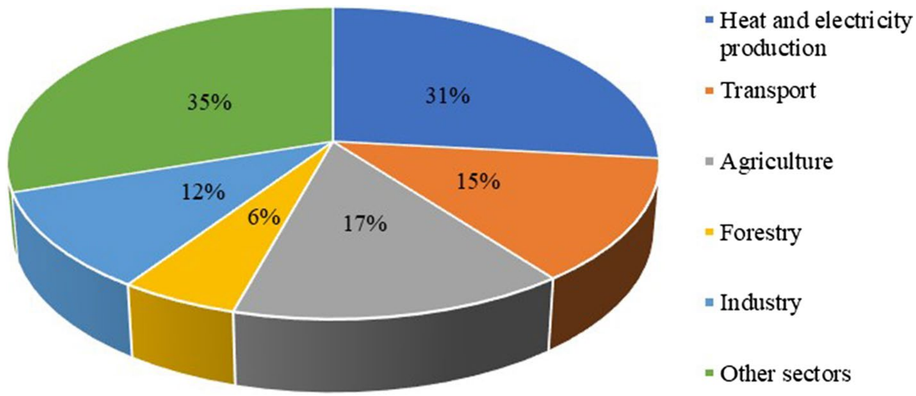

Fig. 2 Distribution of greenhouse gas emission sources

According to the Russian Ministry of Natural Resources and Environment, 42.7% of Russian farmland was found treated with pesticides in 2019, which is a 1% decrease from 2018. Detailed data on changes in the area of land treated with pesticides can be found in Table 2.

The trend is that up until 2019, there has been a steady increase in pesticide-treated agricultural land. This was due to the need to increase agricultural productivity due to the steadily growing food requirements of the population. In 2019, the use of pesticides in Russia decreased owing to the introduction of state restrictions and alternative methods (biological, microbiological, agrophysical, and others) for pest control.

Within the Russian Federation, there are established standards for pesticide levels in the fields. However, according to 2019 statistics, within 13 constituent entities of the Russian Federation, it was found that the permitted standards for soil pesticides were higher. A total of 65 thousand tons of pesticides have been used in the fields, virtually all of which (63 thousand tons) are plant protection chemicals, representing 97.8% of the total amount of pesticides applied.

As in previous years, herbicides were the most widely used (36,000 tons, representing 55.7% of the total pesticides). Insecticides were used in 5.2 thousand tons, representing 7.9% of the total pesticides. More than 3.8 thousand tons of desiccants, defoliants, and approximately 0.6 thousand tons of rodenticide were also used. The application volume of plant growth regulators stands at 0.65 thousand tons.

The irrational use of water resources for irrigation can also lead to some environmental problems (exhaustion of water resources, salinization and soil erosion, desertification, etc.). The agriculture industry is one of the world's greatest water consumers. In the territory of Russia, 6,566.76 million m^3 of water was used for irrigation in 2019. Over the last few years, there has been a decreasing trend in the use of water resources for irrigation purposes (Fig. 3).

This was due to the optimization of irrigation to increase water use efficiency. The rationalization of using this resource uses the concepts of precision agriculture, drip

Table 2 Farmland of the Russian Federation processed with pesticides

Parameters	2016	2017	2018	2019
Area, thousand hectares	87,020	91,441	97,211	94,731
Area, %	39.2	41.2	43.8	42.7

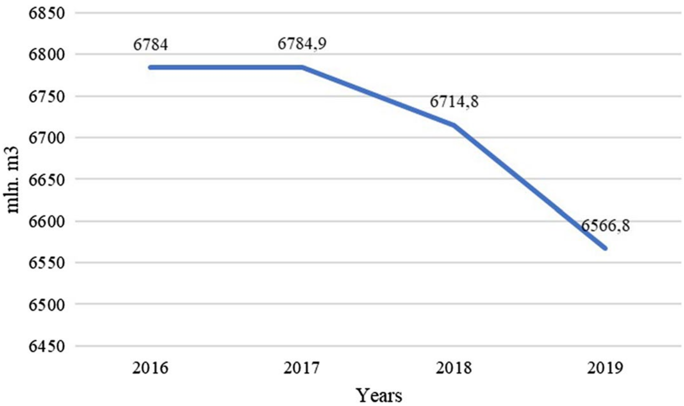

Fig. 3 Use of water supplies for irrigation purposes

irrigation, and reduction of losses due to the evaporation of water. In other words, the interdependence of environmental and agricultural indicators was determined using the Pearson linear correlation method. All the indicators calculated above were examined using the linear correlation coefficient (r-Pearson). The latter is a tool to examine the relationship between two variables measured in metric scales on the same sample. It is applied to determine the strength of the statistical relationship between at least two random variables. Pearson's correlation coefficient describes the existence of a linear relationship between the two amounts.

Below is an example of the calculation for a sample of greenhouse gas emissions (X) of agricultural enterprises engaged in livestock production (Y), which represents about 16.5% of all emissions to the atmosphere:

$$x^m = (x_1, \ldots, x_m),\ y^m = (y_1, \ldots, y_m) \tag{1}$$

where m is the number of statistical observations, $\overline{x}, \overline{y}$ are sample averages, x^m and y^m are sample variances, $r_{xy} \in [-1, 1]$.

Hence, the Pearson correlation coefficient is calculated according to the formula:

$$r_{XY} = \frac{\sum\left(X - \overline{X}\right)\left(Y - \overline{Y}\right)}{\sqrt{\sum\left(X - \overline{X}\right)^2 \sum\left(Y - \overline{Y}\right)^2}} \tag{2}$$

where $\overline{X} = \frac{1}{n}\sum_{t=1}^{n} X_t$, $\overline{Y} = \frac{1}{n}\sum_{t=1}^{n} Y_t$ is the average sample value.

After the calculations, $r_{xy} = 0.65$.

This implies a positive correlation between the indicators, that is, a high degree of interrelationship between them. In that case, if the values of the variable (greenhouse gases) increase, the state of the environment in the country will also worsen. The same principle was used to calculate all dependencies on the environment and agriculture indicators discussed in the article.

4 Discussion

Agriculture is one of the most developed and important economic sectors in Russia. It supplies the population with food and produces raw materials for the light and food industries. By 2020, livestock production accounted for 45.7%, and crop production for 54.3% of the total industry. Agricultural output in all categories in actual prices is 5348.8 billion rubles, 239.3 billion rubles more than in the previous year (World Data Atlas, 2022). Livestock production comprises animal-origin cheese products, cattle and poultry raising for the year, and beekeeping. The more developed branches of farming are pigs, poultry, sheep, cattle, bees, and fishing.

Most mineral fertilizers are used in the fields of developed Western European countries. In this case, Germany is one of the leading producers of potassium fertilizers. This trend is a result of the historical tradition of increasing crop yields through mineral fertilizers following the Green Revolution. Although since the mid-2000s, there has been a trend in these countries to reduce the use of mineral fertilizers in agriculture. They have tried to apply mineral fertilizers in a more balanced and limited way, replacing them with organic ones, although the demand for them is still only 5% of global consumption. These countries are also characterized by the downgrading of agricultural land and the restoration of forest areas instead. It means that the countries of Western Europe fight against the consequences of intensive agriculture (Agroecology Europe, 2017).

The consumption of mineral fertilizers is the lowest in the Russian Federation since the farmers tend to use organic fertilizers. However, unlike the countries of Western Europe, there is an increasing trend in the consumption of mineral fertilizers to boost industrial productivity. Nevertheless, the past few years have demonstrated the tendency to reduce the use of pesticides in the country's fields every year in favor of biological methods for pest control and the improvement of soil properties. It includes the wise use of land, crop rotation, which increases soil fertility, the combination of crops, and the planting of grasses, shrubs, and trees (Abate et al., 2000). Global experience shows that while applying optimal amounts of organic and mineral fertilizers is impossible, it is necessary to increase the area under perennial grasses and legumes. Due to phyto-based ameliorative activities, the restoration of Kalmykia's land resources is occurring, followed by a considerable reduction in the degraded desert land area.

Water use for irrigation is important in improving land productivity and crop yields. According to the FAO, 70% of freshwater withdrawals worldwide are used for agriculture, and 85% in developing countries. Water demand is increasing in agriculture and other sectors, but water use efficiency is below 50%. From an ecological standpoint, the irrational and indiscriminate use of water resources leads to their exhaustion.

Demand for water for agricultural irrigation needs worldwide is increasing every year. However, the Russian Federation and the countries of Asia (India, China, etc.) are implementing policies to reduce the use of water resources. It is, therefore, necessary to ensure sustainable agricultural production in the main aquatic and land systems and develop transition strategies toward sustainable land and water management at the state level. An integrated approach to managing soils, water, plants, and nutrients and developing more efficient irrigation systems, such as drip irrigation, will help address this issue. Agricultural water use efficiency can also be enhanced by minimizing soil water losses and using modern irrigation and monitoring technologies, for example, video recording or the use of UAVs.

It follows from all of the above that the environmental performance of land resources, biophysical limitations of agriculture, and the choice and effectiveness of methods to improve the state of natural resources depend on the physical and geographical features of the region. Each situation requires appropriate measures.

5 Conclusions

The study confirmed the dependence of environmental indicators of agriculture on its biophysical characteristics, territorial features of the region, and its physical and economic–geographical position. Accordingly, a set of methods to improve soil conditions was developed. To solve the environmental problems associated with the development of the agricultural industry, the authors determined effective agricultural technology to restore the environment and degraded soils without compromising the industry's productivity.

The first step, in the author's view, is to use organic fertilizers in acceptable quantities, preferably minimum. Indeed, there is a positive correlation between the use of mineral fertilizers, according to the study's results ($rxy = 0.65$). In that case, if the values of the variable (greenhouse gases) increase, the state of the environment in the country will also worsen. In 2019, the use of pesticides and mineral fertilizers in Russia decreased due to the introduction of state restrictions and alternative methods (biological, microbiological, agrophysical, and others) for pest control.

Consequently, another effective measure is pest control without chemicals. Modern science provides alternative methods of pest management in the fields. One of the most widespread is ultrasound, which is not harmful to plants. The replacement of pesticides with microbial insecticides will also contribute to combating environmental problems.

The appropriate waste processing will also help to solve environmental problems. Reducing agricultural pollution is facilitated by filtering and disinfecting effluents, purifying soils, and preserving natural vegetation as natural filters. It is also essential to plant tree belts and perennial grasses to control land degradation. In addition, control over the plowing of coastal protective strips is of particular importance.

The precision farming method is a scientific concept based on the presence of heterogeneities within a field. The method will improve the condition of the areas and make the industry more efficient. Monitoring soil conditions and characteristics is performed using innovative technologies such as aerial photography, remote sensing, and geo-information technology.

Soil-protective farming includes ameliorative measures related to moisture accumulation in the fields. It also provides the observance of crop rotation systems, synergy within agroecosystems, and strip sowing of crops. This type of farming uses tillage methods that do not disturb the soil structure.

Another method is reusing farmland that has already been abandoned. In the optimization of livestock breeding, the priority is specialization and concentration of production, the transition to efficient technology of fodder production, and new feeding rations. These approaches increase productivity while reducing the unit cost of resources.

Acknowledgements Svetlana Germanova has been supported by the RUDN University Strategic Academic Leadership Program.

Funding This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability Data will be available on request.

Declarations

Competing interests The authors declare that they have no competing interests.

Consent to participate Not applicable.

Consent for publication Not applicable.

Ethics approval Not applicable.

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