

SABRAO Journal of Breeding and Genetics
 58 (5) 2480-2490, 2026
<http://doi.org/10.54910/sabrao2026.58.5.47>
<http://sabraojournal.org/>
 pISSN 1029-7073; eISSN 2224-8978



SUSTAINABLE MANAGEMENT OF SOIL RESOURCES TO IMPROVE FOOD SECURITY

**N.P. VOLKOVA^{1*}, R.H. KARLIBAEVA², N.V. BESHINSKAYA¹, A.A. TRUBCHENINOVA¹,
 and N.M. MASYUTINA¹**

¹Moscow Aviation Institute, Moscow, Russia

²Tashkent State University of Economics, Tashkent, Uzbekistan

*Corresponding author's email: npvolkova@mymail.academy

Email addresses of co-authors: raya.karlibaeva@mymail.academy, nvbeshinskaya@mymail.academy,
 aatrubcheninova@mymail.academy, nmmaryutina@mymail.academy

SUMMARY

In cropping systems, land serves as an operational foundation and an object of labor with productivity. The definition of land productivity can be a specific property—soil fertility, which proves land as an undisputed primary means of agricultural production that largely dictates the efficiency of crop production. The following study aimed to determine global trends, national challenges, and prospects for sustainable soil resources management in Central Asia. The research, comprising main theoretical concepts, especially involved problems of soil degradation. Comparative and correlation analysis of indicators and sub-indicators of the Global Food Security Index took place for the TOP 10 countries and Central Asian countries. These sought to determine the place of Central Asian countries in the world food security ranking, including the state of soil resources, and to establish the impact of the state of soil resources on food security. An expert survey succeeded in identifying relevant measures to manage the risks related to soil resources. The study concluded with proposed measures against soil resource risks. These responded with soil degradation, pollution, violation of the optimal land use ratio, and the unsatisfactory phytosanitary condition of crops, which can help prevent negative consequences for crop production in Central Asia.

Keywords: Crop production, land resources, soil resources, soil degradation, sustainable management, state of soil resources, Central Asian countries

Communicating Editor: Prof. Naqib Ullah Khan

Manuscript received: March 05, 2026; Accepted: June 13, 2026.

© Society for the Advancement of Breeding Research in Asia and Oceania (SABRAO) 2026

Citation: Volkova NP, Karlibaeva RH, Beshinskaya NV, Trubcheninova AA, Masyutina NM (2026). Sustainable management of soil resources to improve food security. *SABRAO J. Breed. Genet.* 58 (5) 2480-2490. <http://doi.org/10.54910/sabrao2026.58.5.47>.

Key findings: Based on the comparative analysis of Global Food Security Index (GFSI) indicators, the study identified soil degradation and low soil organic matter as the most critical constraints to crop production and food security in Central Asian countries. Expert assessment showed that integrated soil management measures—combining sustainable tillage, optimized crop rotations, soil remediation, and balanced land-use structure—can substantially reduce soil degradation risks and improve long-term crop productivity.

INTRODUCTION

Research problem

Land is one of the main resources of society and an important production factor for various industries, playing a key role in improving living standards. The land fund of Central Asian (CA) countries gains increasing effects from soil degradation processes covering large areas of the region (Andreeva *et al.*, 2022). Agricultural land-use practices emerged as the main causes of soil degradation (Rafikov *et al.*, 2024). Excessive anthropogenic pressure on land intensifies negative processes, particularly soil erosion (Petyukova and Dereglazov, 2024). These variations have shown an association with neglecting the ecological suitability of soils for particular crops, leading to the destruction of fertile soil layers and the depletion of humus, a key component of soil fertility (Logachev and Beresneva, 2024).

Soil, being a fundamental element of the natural environment, develops under the combined influence of climate, geological processes, geomorphology, vegetation, and human activities, with both positive and negative effects accumulating in the soil system (Shahbaz *et al.*, 2024). Arable land-use processes also entail shaping by social relations, which considerably contribute to the development of degradation processes (Nasiyev *et al.*, 2025). Global attention has significantly enhanced to soil health. The Global Forum for Food and Agriculture (GFSI, 2022) in Berlin highlighted soil health as the key factor of food security and climate stability, under the theme 'Sustainable Land Use: Food Security Starts with the Soil' (Kartini *et al.*, 2023). This reflects the growing concern that more than 90% of global food production depends on soil, while soil quality worldwide continues to decline (Belkharoev, 2024).

The Food and Agriculture Organization (FAO) and the Global Soil Partnership with international initiatives emphasized the sustainable soil management, including the Voluntary Guidelines for Sustainable Soil Management (FAO, 2017) and the International Code of Conduct for the Sustainable Use and Management of Fertilizers (FAO, 2019). Events, such as the Global Symposium on Soils for Nutrition (GSOIL4N), have further promoted technologies for improving soil fertility and reducing harmful effects of various substances in soils to support food security and the UN Sustainable Development Goals (Bachinskaya *et al.*, 2023).

In this context, the relevance of the concerned study lies in the need to improve crop production efficiency in CA through better management of soil resources. The study aimed to identify the global trends, national challenges, and prospects for sustainable soil resource management in Central Asian countries. It addresses two research questions, viz., (1) Which global trends and national challenges affect soil resources in CA countries? and (2) Which measures can reduce negative impacts on these resources? Since the GFSI does not include all CA states, the analysis focuses on the countries like Kazakhstan, Uzbekistan, and Tajikistan.

The study also recognized the importance of accounting for the negative impacts on soil resources to further improve management decisions in crop production (Abdullayev *et al.*, 2025). The research explored the potential measures for managing soil resources and complemented existing approaches proposed in past studies for mitigating soil degradation. The remainder of the article reviews relevant literature, presents the methodology and results, and concludes with theoretical implications, practical recommendations, and study limitations.

Theoretical background

Historical retrospective of soil resources degradation

The soil degradation problems have long attracted the scientific attention. In the second half of the 19th century, V. Dokuchaev laid the foundation of modern soil science and proposed principles of soil conservation that remain relevant today (Mazhaiskii and Zakharova, 2006). Later debates on the loss of soil fertility emphasized the role of effective land reclamation and scientifically grounded agricultural practices, including mechanical tillage and organizational, economic, and technical measures aimed at restoring soil health and productivity (Rzayeva *et al.*, 2026).

Researchers also warned about negative consequences of intensive farming technologies in traditional agriculture around more than four decades ago (Beresneva and Kulibaba, 2024). The identified key causes of soil degradation comprise excessive land development, nutrient imbalance, low technological standards, insufficient soil protection measures, and the destruction of forests and meadows. Therefore, a suggestion came out that 30%–40% of land should remain in a natural state to maintain ecological stability.

Soil degradation problems in modern studies

Modern studies generally assessed soil quality in two ways: by analyzing soil properties and characteristics (Strassburg *et al.*, 2014) and by evaluating crop yields (Logachev and Goncharov, 2024). However, these approaches reflect different aspects of the same problem; crop productivity depends on many factors, including anthropogenic pressure. Several researchers, therefore, argued that soil quality determination should primarily be by measuring soil characteristics such as humus content, depth of the humus horizon, particle size distribution, salinity, and acidity (Virto *et al.*, 2015).

Stable negative processes of both natural and anthropogenic origins considerably

disrupt soil functions and lead to soil degradation, including salinization, wind and water erosion, dehumidification, and significant variations in agrochemical composition and pH (Yerzhanova *et al.*, 2025). Major risks associated with human activity include erosion, loss of humus, soil pollution with pesticides, radionuclides, and heavy metals, as well as acidification, salinization, and waterlogging (Saparov *et al.*, 2024).

Among these threats, chemical contamination of soils is particularly alarming. Irrational agricultural technologies and the long-term use of mineral fertilizers and pesticides significantly contribute to soil pollution (Ibraimova *et al.*, 2023). A small fraction of applied pesticides reaches only to the target crops, while most of the amount enters soil, water, and the atmosphere, disrupting ecosystems, reducing biodiversity, and posing considerable risks to human health (Kuanbay *et al.*, 2025). Heavy metals and radionuclides also affect the physicochemical properties of soils and substantially affect crop growth, potentially leading to contamination of crop products (Khudyakova *et al.*, 2025).

Additional factors contributing to soil degradation include irrational land-use structures and the disruption of ecological balance between arable land and stabilizing ecosystems such as forests and grasslands (Logachev *et al.*, 2023). Poor phytosanitary conditions in crops—caused by the spread of pests, diseases, and weeds—also reduce yields and negatively alter soil quality (Alpysbayeva *et al.*, 2024).

MATERIALS AND METHODS

Research approach

In line with the latest research approach for sustainable management of soil resources as a basis for crop production efficiency, a qualitative and quantitative case study seemed to be the most appropriate research strategy. This will analyze global trends and national challenges for CA countries for soil resource management. The results obtained through this strategy were more comprehensive than

the solely quantitative research due to their higher levels of detail, proving it possible to collect more information to develop recommendations and obtain the feedback from the experts' pool. Notwithstanding, one must bear in mind the limitations of this method. Therefore, in this connection, it is worth mentioning that the main aim of the presented study was to obtain qualitatively new knowledge about specific methods for managing the state of soil resources.

The limited range of resources available to researchers is on the one hand. The desirability of continued research on this issue is, on the other hand, to publish the obtained results to attract interested researchers and launch a discussion both in the scientific community and among the interested AIC specialists.

Empirical context and case selection

The relevant research proceeded within the framework of improving the efficiency of crop production in CA countries through effective management of the available soil resources. Since the GFSI does not cover all CA countries (Mazhaiskii and Zakharova, 2006), the scope of the study focused only on three countries, such as Kazakhstan, Uzbekistan, and Tajikistan. Crop production occupies a significant position in the agricultural sector of considered CA countries. These countries implement crop development programs and practice crop diversification with an increase in the area of highly profitable crops.

Following the purpose of the study, web pages of agricultural enterprises related to crop production underwent random selection via the website Google.com. The obtained samples of different enterprises became the source of experts for the study. For experts, the selection criteria relied on their higher agronomic (agrotechnical) education and at least 10 years of working experience in a managerial position at an agricultural enterprise related to the crop production sector.

Data recorded

The data collection for the study occurred between August 10, 2025, and October 10, 2025, through both desk and field research. The conduct of the desk study was according to the GFSI. In the course of field research, document search and analysis in the Scopus database (search object—"sustainable soil management" + "soil degradation"; search scale—all fields) yielded 325 works. The subsequent review of articles on sustainable land management in the context of crop production indexed in Scopus in 2013–2023 discovered specific research gaps needing attention. The study used GFSI data available at <https://impact.econom/> at the time of this work.

The field study consisted of the analysis of the current situation with soil management via an expert survey. The selected experts (59 people) received invitations to take part in the survey via email. The 53 people who agreed to participate answered the following question: "What measures can be applied to reduce the negative effects on soil resources?" The data obtained from the expert survey served to determine measures to reduce negative impacts on soil resources.

Data analysis

The study employed the following set of research methods: monographic (to analyze the place of CA countries in the food security ranking), economic and statistical (to analyze the problem of soil resource degradation and the indicators of soil resources in CA countries according to the GFSI), correlation analysis (to identify the strength of correlations between the GFSI and its components, indicators, and sub-indicators of the state of land resources in the countries of the world), and abstract logic (to generalize and analyze study results).

The GFSI (GFSI, 2022) consists of four components: (1) affordability, (2) accessibility, (3) quality and safety, and (4) sustainability

and adaptation, which incorporate 58 indicators of food security. As of 2022, the index calculation is for 113 countries. This study used the data as part of the correlation analysis performed in STATISTICA.

The use of the triangulation method in data analysis sought to ensure the validity and reliability of empirical results. Triangulation continued through the triangulation of researchers, with several researchers involved in the study participating in information processing. Following the analysis, each topic sustained discussion, recording the information agreed upon by all study participants. The process of triangulation made it possible to increase the reliability of survey results and raise the quality of the obtained information. All results obtained from the study entailed recording in the research report.

RESULTS

According to the 11th annual GFSI report (2022), in 2021, the CA countries (Kazakhstan, Uzbekistan, and Tajikistan) ranked 32nd, 73rd, and 75th, respectively, out of 113 countries. Evidently, the overall food security of CA countries, such as Uzbekistan and Tajikistan, remains rather weak, especially when compared to the TOP 10 (Table 1).

A comparative analysis of the GFSI indicators of Kazakhstan, Uzbekistan, Tajikistan, and the TOP 10 countries revealed significant scope for improvement. The GFSI of Uzbekistan in 2021 was 22.6 points below the TOP 10 average and 4.7 points below the average for the 113 countries. In turn, the GFSI of Tajikistan in 2021 was 23.2 points lower than the TOP 10 average and 5.5 points below the global average.

Considering individual components, the worst area was the affordability of food, with Uzbekistan and Tajikistan ranking 85th and 82nd, respectively. This situation with sustainability and adaptation prospects can also have a negative description. In absolute terms, the said indicator was the lowest of the four for Tajikistan (53.1 points).

In the studied CA countries, only Kazakhstan showed indicators higher than the world average. However, its sustainability and adaptation indicators still surpassed the global average by only 1.3 points and stayed 6.1 points below the TOP 10 level, which suggested considerable potential for further improvement in these indicators.

With our research objectives, this study focused on the 4th component of GFSI, covering the country's resilience to natural resource risks and ways of adapting to said risks and all other factors affecting food security levels for crop production efficiency. The Sustainability and Adaptation component first gained introduction in the GFSI in 2017 as a correction factor and became a separate category in 2020. As of 2022, this component contains six indicators, one of them was being the 'land resources,' including two sub-indicators that relate to soil conditions and crop cultivation (Table 2).

According to the GFSI 2021 and among the TOP 10 countries, the land resources indicator was the highest in Norway (85.1 points) and the lowest in Portugal (59.2 points), while the CA countries (Kazakhstan, Uzbekistan, and Tajikistan) earned 53.1, 53.6, and 46.0 points, respectively. These scores fall by 8–15 points short of the global average and 19–26 points below the average level of the TOP 10, which also suggests significant opportunities for considerable improvement.

On the global scale, the most unfortunate indicator of the four was soil organic matter content, which averaged at 29.1 points out of 100. Land degradation received a score of 69.6 points worldwide, while the examined CA countries had 41.7 points (Kazakhstan) and 53.6 points (Uzbekistan). The most severe situation with land degradation has developed in Tajikistan; however, according to the GFSI, it has 100% degraded land. Thus, one can cite land degradation as the greatest problem with the soil resources of CA countries.

In connection with the need to address the weaknesses of land resources in the CA countries, the study asked experts to propose

Table 1. TOP 10 countries in the GFSI and the placement of CA countries (2022)*.

Country	Components									
	GFSI		Affordability		Availability		Quality and Safety		Sustainability and Adaptation	
	place	score	place	score	place	score	place	score	place	score
Finland	1	83.7	7	91.9	15	70.5	4	88.4	2	82.6
Ireland	2	81.7	4	92.6	15	70.5	9	86.1	3	75.1
Norway	3	80.5	28	87.2	51	60.4	8	86.8	1	87.4
France	4	80.2	11	91.3	18	69.0	6	87.7	8	70.3
Netherlands	5	80.1	3	92.7	14	70.7	12	84.7	13	69.2
Japan	6	79.5	16	89.8	1	81.2	30	77.4	20	66.1
Sweden	7-8	79.1	7	91.9	21	68.3	11	85.0	14	68.3
Canada	7-8	79.1	25	88.3	6	75.7	1	89.5	29	60.1
UK	9	78.8	10	91.5	10	71.6	29	77.6	6	71.1
Portugal	10	78.7	15	90.0	4	77.0	21	79.8	23	64.5
Kazakhstan	32	72.1	48	78.0	23	67.2	31	76.3	20	65.4
Uzbekistan	73	57.5	85	56.7	67	59.8	65	56.3	54	56.5
Tajikistan	75	56.7	82	59.8	68	56.3	78	56.5	71	53.1
Average: TOP 10		80.1		90.7		71.5		84.3		71.5
Across all countries		62.2		69.0		57.8		65.9		64.1

Note: *Rating on a scale of 0–100 points, where 100 = best conditions.

Source: Compiled and calculated from data in Global Food Security Index (GFSI) 2022.

Table 2. GFSI soil health indicator and sub-indicators of the TOP 10 countries and CA countries (2021).

Country	Land resources, points*	Including	
		land degradation	soil organic matter content
Finland	75.9	100.0	41.4
Ireland	82.5	81.7	100.0
Norway	85.1	100.0	76.7
France	67.9	81.7	36.3
Netherlands	72.8	83.3	50.3
Japan	67.8	73.3	39.8
Sweden	73.1	100.0	32.5
Canada	72.0	81.7	49.9
UK	66.4	81.7	60.8
Portugal	59.2	48.3	26.7
Kazakhstan	53.1	41.7	22.5
Uzbekistan	53.6	53.3	2.2
Tajikistan	46.0	0.0	25.5
Average: TOP 10	72.3	83.2	51.4
Across all countries	61.3	69.6	29.1

Note: *Rating on a scale of 0–100 points, where 100 = best conditions.

Source: Compiled and calculated from data in Global Food Security Index (GFSI) 2022.

possible measures to considerably manage the condition of soil resources. As a result of the expert survey, we assembled a list of available measures to alleviate negative manipulations in the soil resources of CA countries for crop production (Table 3).

DISCUSSION

Particularly worth mentioning results came from the experts' survey. Similar expert-based approaches have been useful in past studies of sustainable land management to recognize

Table 3. Mitigation measures for soil resources.

Negative impacts on soil resources	Soil resource management
Land degradation (water and wind erosion, soil depletion)	Sustainable tillage. Adjustment (optimization) of crop rotation. Optimal use of reclamation measures. Regulation of the application of mineral and organic fertilizers.
Soil pollution (heavy metals, pesticides, radionuclides, etc.)	Comprehensive agroecological monitoring of chemically polluted areas. Measures to restore the quality of contaminated soils Creating methods to return rehabilitated soils to agricultural use.
Violation of the optimal land type ratio	Optimization of the land ratio: increasing the area of ecologically stabilizing land to a legally prescribed value. Returning ecologically disturbed land to land use.
Unsatisfactory phytosanitary state of crops (diseases, viruses, changes in the area and dynamics of crop damage, changes in weed species composition, quarantine species, etc.)	Implementing science-based crop rotations. Maintaining optimal nutrient and water regimes. Regulating the frequency of agrotechnical techniques depending on the phytosanitary state of crops. Applying alternative plant protection products. Strengthening quarantine measures to combat invasive and quarantine plant species.

Note: Compiled based on the expert survey.

priority responses to soil degradation and agricultural risks. Previous research has shown that expert assessment was crucial to capture the local agroecological constraints (Andreeva *et al.*, 2021; Virto *et al.*, 2015).

The management of soil degradation risks is pivotal to prevent the deterioration of soil properties due to natural and anthropogenic factors. Reducing these losses of potential and effective soil fertility can succeed with the following measures. a) Rational tillage, which was found consistent with proposals to utilize innovative anti-erosion methods and technological measures to neutralize the rapid worsening of the topsoil (Logachev and Beresneva, 2024); b) the regulation of crop rotation, in agreement with prior findings. These are the right alternations of crops in crop rotation that can contribute to the provision of soil with nutrients. Moreover, the protection of soils from erosion, the effectiveness of fertilizer use, and the prevention of the spread of weeds, pests, and pathogenic microorganisms. This helps in the development of an optimal balance of nutrients in the soil to increase crop productivity (Azhbenov *et al.*, 2024); c) the optimal execution of reclamation measures, including drainage, irrigation, amendment with gypsum, and liming to improve and preserve soil fertility

for future use (Andreeva *et al.*, 2021); and d) regulation of mineral and organic fertilization to ensure optimal balance of basic soil nutrients (NPK), humus content, microelements, and pH.

These results proved greatly analogous to earlier studies showing that anti-erosion tillage, crop rotation, and various reclamation measures were the most effective ways to preserve soil fertility and reduce topsoil degradation. Previous investigations emphasized the combined use of agronomic and meliorative practices helps maintain the nutrient balance, humus content, and the long-term productive capacity of arable soils (Logachev and Beresneva, 2024; Andreeva *et al.*, 2021). In conclusion, the methods for managing the risks of chemical pollution of soils, the priority tasks were:

- To conduct widespread agroecological monitoring of territories contaminated with pesticide residues, heavy metals, and radionuclides;
- To identify potential sources of pollution and the degree of chemical degradation of soils;
- To perform the ecotoxicological assessment of local soil pollution sources; and
- To employ methods for the remediation of contaminated areas, followed by their return to agricultural use.

Despite the greater diversity of environmental pollutants, most scientific developments focus on the pesticide load on arable soils. Particular attention has centered on developing scientific foundations to revitalize agricultural soils contaminated with pesticide residues. Researchers propose environmentally friendly methods for cleaning the soils based on their remediation (chemical remediation and phytoremediation) and rescuing the contaminated areas for agricultural use. Proceeding from these scientific developments, the following measures can be proposals to manage the risks of pesticide pollution of soils to improve the ecological state of soil resources:

- Chemical remediation of arable soils contaminated with stable organic pollutants using chemical ameliorations;
- Restoration of contaminated soils' quality using phytoremediation with cultivated and wild species of remediating plants; and
- Developing methods to return transformed soils to agricultural use.

Such types of measures received considerable support from earlier studies, showing that chemical remediation and phytoremediation can reduce the toxic load in contaminated soils and support their gradual restoration to agricultural use. Previous research also reported that remediation efficiency depends on the pollutant type, contamination depth, and the biological characteristics of the remediating plant species. The right directions for using restored soils in crop production should undergo development considering the following factors:

- the general environmental situation;
- the need for soil sanitization in areas contaminated with pesticide residues, including organochlorine;
- site specificity requiring purification;
- initial concentrations of pollutants and the volume of contaminated soils;
- migration of pesticides along the soil profile and the risk of pollutants leaching into groundwater;
- long-term efficiency and stability of soil purification;
- practical and economic efficiency of decontamination technologies;

- predictions for the further use of rehabilitated soils in the agricultural sector, such as development, planting protective forest strips, growing agricultural products, and using for recreational purposes (Kulibaba and Barinov, 2024); and
- the impact of refinement methods on the environment and human health (Strassburg *et al.*, 2014).

These results greatly aligned with prior studies in contention that the post-remediation use of soils should always be determined individually, considering ecological risks, pollutant persistence, and land-use suitability. Earlier studies emphasized that even restored soils may require long-term monitoring before their safe utilization in intensive crop production (Ibraimova *et al.*, 2023; Saparov *et al.*, 2024).

The technologically contaminated and degraded soils require significant investments for their rehabilitation and return to crop use. Hence, if such measures are not feasible, then such types of lands require removal from land utilization. Reports of similar conclusions have occurred in past research, which showed constraints in the rehabilitation of heavily contaminated soils are often due to extreme financial and technological costs. Previous studies also reported that where restoration is economically unjustified, such lands should entail withdrawal from active agricultural use (Andreeva *et al.*, 2021).

The risks of violating the optimal use ratio of land can incur counteractions with rational land use. This ensures conformity with the optimal ratio of land that accomplishes ecological equilibrium between the arable land area and the total area of ecologically stabilized land. These results support the earlier research work showing that balanced land-use structure was the key condition for ecological stability in agricultural landscapes. Previous studies reported that an increased share of ecologically stabilized lands helps reduce erosion risks, improves moisture regulation, and strengthens the resilience of agroecosystems (Virto *et al.*, 2015; Logachev *et al.*, 2023).

According to this research, the optimal ratio of land use (primarily arable land to ecologically stabilized land) tended to be 50:50. However, Virto *et al.*'s (2015) findings revealed that no universal standards read out the ratio of agricultural land types (arable land and perennial plantations, hayfields, pastures, and land under protective forest strips). This lack of uniformity owes to considerable variations in natural conditions between the different natural and agricultural provinces. Researchers argue that land use proportions for unstable areas require revising to withstand the dangers of deflation and water erosion.

Prerequisites for the environmental security of arable land use include the structural balance of agricultural landscapes, the main requirements of which provide for an increased share of ecologically stabilizing land in arable land structures. Earlier studies also stressed that the environmental security of arable land use depends on the structural balance of landscapes rather than on productivity indicators alone. Past studies showed forest belts, grasslands, and other stabilizing elements play a viable role in protecting soils from degradation and maintaining their ecosystem functions (Strassburg *et al.*, 2014; Andreeva *et al.*, 2021).

Thus, recommendations to reduce the negative consequences of violation of the optimal land use ratio would include increasing the area of ecologically stabilizing land, in particular, by increasing the area of protective forest plantations and the outskirts of fields. These comprise forest belts, edges, field roads, and hedges for recurring ecologically disturbed land back to land use. These recommendations were in line with prior research demonstrating that protective forest plantations and other stabilizing landscape elements reduce the wind and water erosion and improve the overall sustainability of land utilization. Earlier findings also suggested that increasing the area of such elements proved especially viable in regions exposed to intensive agricultural pressure (Logachev *et al.*, 2023; Virto *et al.*, 2015).

Measures employed to reduce the negative impact of the unsatisfactory phytosanitary condition of crops include the following:

- introducing scientifically grounded crop rotations;
- maintaining optimal nutrients and water regimes;
- controlling the frequency of agrotechnical techniques based upon the phytosanitary state of crops;
- using alternative plant protection products that increase plant resistance to diseases and adverse weather conditions; and
- strengthening quarantine measures to combat invasive and quarantine plant species.

These results were consistent with previous studies showing that scientifically sound crop rotations, balanced fertilization, and proper agronomic timing emerged as essential for controlling weeds, pests, and crop diseases. Earlier research enunciated that deprived phytosanitary conditions not only reduce crop yields but also accelerate soil exhaustion and increase dependency on chemical plant protection measures (Alpysbayeva *et al.*, 2024; Ibraimova *et al.*, 2023).

In general, the sustainable management of soil resources relative to soil pollution and degradation, violation of the optimal land use ratio, and the unsatisfactory condition of crops needs to influence environmental, economic, medical, and social analyses and legal mechanisms. This approach will enable the assessment of the extent of negative consequences, propose measures to combat them, and, thereby, improve the quality of soil resources.

In this way, the aim of sustainable soil resources management should be to protect lands from depletion, degradation, and pollution; restore and increase the soil fertility; and preserve the functions of soil cover, landscape, and biological diversity. Earlier studies have also proposed similar integrated approaches in sustainable soil management,

which emphasized that soil protection requires not only agronomic measures but also legal, economic, and public health instruments. Previous authors concluded that long-term soil sustainability was applicable only through interdisciplinary management of environmental monitoring and institutional regulations (FAO, 2017 and 2019).

CONCLUSIONS

The results identified the key global trends, national challenges, and opportunities for sustainable soil management to support effective crop production and help close gaps in the existing research. The global trend supported the idea that food security depends on sustainable land use, while comparison of GFSI indicators between CA countries and the top 10 countries showed an obvious scope for improvement despite limited capacity to achieve it. The most serious weaknesses in CA land resources were the low soil organic matter and widespread soil degradation. Therefore, this study recommended priority actions focused on soil pollution, degradation, poor land-use balance, and weaker crop phytosanitary conditions. Although the study also offered useful theoretical and practical insights, its focus on one region limits broader conclusions, highlighting the need for similar studies in other countries and regions to build a general model for sustainable soil resource management.

REFERENCES

- Abdullayev I, Rozhok A, Levichev O, Litwinowa M, Trubcheninova A, Levicheva S (2025). Digital transformation in agricultural cluster management: Interrelated factors and model applicability. *J. Glob. Innov. Agric. Sci.* 13(4): 1301–1308. <https://doi.org/10.22194/jgias/25.1840>
- Alpysbayeva K, Sharipova D, Nurmanov B, Seitzhan A, Naimanova B (2024). Enhancing biological control efficiency: Predatory potential of *Phytoseiulus persimilis* against *Tetranychus urticae* in greenhouse conditions. *Org. Farming* 10(2): 133–141. <https://doi.org/10.56578/of100204>
- Andreeva O, Sebentsov A, Kust G, Kolosov V (2022). The nexus between land degradation, climate change and migration in Central Asia. Research. UNCCD. Available: <https://www.unccd.int/sites/default/files/2023-02/LDM%20Central%20Asia%20full%20text%20RUS.pdf>
- Andreeva OV, Lobkovskiy VA, Kust GS, Zonn IS (2021). The concept of sustainable land management: Modern state, models and typology development. *Arid Ecosyst.* 11: 1–10. <https://doi.org/10.1134/S2079096121010029>
- Azhbenov V, Shamuratov D, Niyazbekov Zh, Dinassilov A, Arystangulov S, Baibussenov K, Bashkarayev N, Zhumagaliyev A (2024). Localized biopesticide application using UAVs for the control of migratory locusts in Kazakhstan. *Org. Farming* 10(3): 175–184. <https://doi.org/10.56578/of100302>
- Bachinskaya VM, Deltsov AA, Akulova SV, Karasenkova YaN, Tarasova EK, Egorov EA (2023). Bactericidal hydrosols' properties of metal nanoparticles and their oxides in relation to *Escherichia coli*. *AIP Conf. Proc.* 2921(1): 020001.
- Belkharoev KhU (2024). Legal problems of ensuring food security in modern Russia, in the context of globalization and mutual restrictive measures. *Lobbying in the Legislative Process* 3(2): 11–16. <https://doi.org/10.33693/2782-7372-2024-3-2-11-16>
- Beresneva Ya, Kulibaba I (2024). Simulation model of crop yield on individual land plot. *BIO Web Conf.* 130: 01019. <https://doi.org/10.1051/bioconf/202413001019>
- FAO (2017). Voluntary guidelines for sustainable soil management. Food and Agriculture Organization of the United Nations, Rome. Available: <https://www.fao.org/3/i6874r/i6874r.pdf>
- FAO (2019). International Code of conduct for the sustainable use and management of fertilizers. Food and Agriculture Organization of the United Nations, Rome. Available: <https://www.fao.org/3/ca5253ru/CA5253RU.pdf>
- Global Food Security Index - GFSI (2022). Economist Impact, London. Available: <https://impact.economist.com/sustainability/project/food-security-index/download-the-index>
- Ibraimova DMK, Rozhkova OV, Musabekov KB, Tazhibayeva SM, Rozhkov VI, Yermekov MT (2023). Development of methods to obtain composite materials from organoclays. *Eurasian J. Chem.* 112(4): 101–111.

- <https://doi.org/10.31489/2959-0663/4-23-14>
- Kartini NL, Saifulloh M, Trigunasih NM, Narka IW (2023). Assessment of soil degradation based on soil properties and spatial analysis in dryland farming. *J. Ecol. Eng.* 24(4): 368–375. <https://doi.org/10.12911/22998993/161080>
- Khudyakova NE, Safonova OV, Bolbukh TV, Okasheva NA, Kocheeva NA (2025). Accumulation and migration of heavy metals in the soil-plants-bees-honey chain under different environmental conditions in Altai. *Int. J. Ecosyst. Ecol. Sci.* 15(4): 251–258. <https://doi.org/10.31407/ijeess15.431>
- Kuanbay Zh, Admanova G, Bazargaliyeva A, Kozhamzharova L, Ishmuratova M, Abiyev S (2025). Comparative floristic analysis for biodiversity conservation and sustainable land management in Central Asia's arid zones. *Int. J. Des. Nat. Ecodyn.* 20(4): 785–793. <https://doi.org/10.18280/ijdne.200409>
- Kulibaba I, Barinov V (2024). Software solution for growing crops on an individual land plot. *BIO Web Conf.* 141: 01018. <https://doi.org/10.1051/bioconf/202414101018>
- Logachev M, Beresneva Ya (2024). Simulation modeling of forest plantation condition. *BIO Web Conf.* 93: 01017. <https://doi.org/10.1051/bioconf/20249301017>
- Logachev M, Chernova V, Kovaleva V (2023). Information system for the creation and support of the ecological settlements' framework. *AIP Conf. Proc.* 2560(1): 020013. <https://doi.org/10.1063/5.0124704>
- Logachev M, Goncharov B (2024). Simulation model of crop yields. *BIO Web Conf.* 93: 02015. <https://doi.org/10.1051/bioconf/20249302015>
- Mazhaiskii IuA, Zakharova OA (2006). Agroekologicheskaya otsenka sostoiianiia pakhotnykh zemli reshenie prodovolstvennoi problemy [Agroecological assessment of arable land and solving the food problem]. Federal Scientific Center for Hydraulic Engineering and Land Reclamation named after A.N. Kostyakov; Ryazan State Agrotechnological University by P.A.Kostychev, Ryazan, pp. 118.
- Nasiyev B, Karynbayev A, Mukhambetov B, Ongayev M, Nurgaziyev R, Akhmetaliyeva A, Sungatkyzy S, Auzhanova M, Okshebayev A (2025). Development of agriculture under the influence of ESG principles: Opportunities for sustainable soil management. *Int. J. Sust. Dev. Plan.* 20(5): 2115–2125. <https://doi.org/10.18280/ijdsdp.200527>
- Petyukova ON, Dereglazov AA (2024). Transformation of the land use system in Russia in the late XIX – early XX centuries. *Gaps Russ. Legis.* 17(3): 31–36. <https://doi.org/10.33693/2072-3164-2024-17-3-031-036>
- Rafikov T, Zhumatayeva Zh, Mukaliyev Zh, Zhildikbayeva A (2024). Evaluating land degradation in East Kazakhstan using NDVI and Landsat data. *Int. J. Des. Nat. Ecodyn.* 19(5): 1677–1686. <https://doi.org/10.18280/ijdne.190521>
- Rzayeva A, Gurbanov E, Mammadova Z, Huseynova H, Bayramova A, Mammadova M, Asadova K (2026). Comparative study of different pretreatment on seed germination of *Juniperus communis* L. *J. Glob. Innov. Agric. Sci.* 14(1): 115–120. <https://doi.org/10.22194/JGIAS/26.1717>
- Saparov G, Dutbayev Y, Amanzholkyzy A, Islam KR, Tireuov K, Hakimov N, Zudilova E, Shichiyakh R, Shoykin O, Ganiyev B, Otcheskiy I, Trushin M, Kozlov A (2024). Assessing heavy metal contamination for soil reclamation: Implications for sustainable urban development. *Int. J. Des. Nat. Ecodyn.* 19(6): 2197–2204. <https://doi.org/10.18280/ijdne.190636>
- Shahbaz M, Kuziboev B, Pícha K, Abdullaev I, Minani LM, Jumaniyazova S (2024). Mediating role of energy uncertainty for environmental management in electricity generation: The evidence from Pakistan. *Energy Nexus* 16: 100327. <https://doi.org/10.1016/j.nexus.2024.100327>
- Strassburg BN, Latawiec AE, Barioni LG, Nobre CA, da Silva VP, Valentim JF, Vianna M, Assad ED (2014). When enough should be enough: Improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil. *Glob. Environ. Change* 28: 84–97. <https://doi.org/10.1016/j.gloenvcha.2014.06.001>
- Virto I, Imaz MJ, Fernández-Ugalde O, Gartzia-Bengoetxea N, Enrique A, Bescansa P (2015). Soil degradation and soil quality in Western Europe: Current situation and future perspectives. *Sustainability* 7: 313–365. <https://doi.org/10.3390/su7010313>
- Yerzhanova A, Baranovskaya N, Khussainov A, Zhumay Ye, Niyazova A, Akhmetzhan A, Sarsembin U (2025). Statistical indicators of the concentration of chemical elements in biological tissues in the Akmola Region. *Int. J. Environ. Imp.* 8(3): 501–510. <https://doi.org/10.18280/ijei.080308>