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Development of Agriculture Under the Influence of ESG Principles: Opportunities for Sustainable Soil Management

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ABSTRACT

In agricultural production, land serves as the basis for operations and the object of labor owing to its productivity determined by a specific property – soil fertility. Because of this property, land undeniably constitutes the main means of production in agriculture. Soil fertility largely determines the effectiveness of crop production. The study aims to identify the global trends, national challenges, and prospects of sustainable soil resource management in Central Asian countries. The study examines the core theoretical concepts pertaining to soil degradation. Through comparative and correlation analysis of the scores of the top 10 and Central Asian countries on the indicators and sub-indicators of the Global Food Security Index, the study identifies the place of Central Asian countries in the global ranking, including the condition of soil resources and its influence on food security. Recommended measures for managing soil resource risks are identified using an expert survey. The study concludes that the proposed measures for managing soil resources risks associated with soil degradation, soil pollution, violation of the optimal land use ratio, and the unsatisfactory phytosanitary condition of crops can mitigate the negative consequences for crop production in Central Asian countries.

1. INTRODUCTION

1.1 Research problem

Land is a fundamental resource for the life of society and a production factor in many industries. Land is one of the main tools for improving the living standards of individuals and society. The land fund of Central Asian countries is marked by soil degradation processes covering significant areas of the region [1]. Among the factors causing soil degradation, the most important are those stemming from agricultural land use [2]. Excessive anthropogenic load on land activates negative processes, among which erosion has become especially strong [3]. This situation results from neglecting the ecological suitability of soil resources to cultivate agricultural crops. The condition of agro-landscapes is deteriorating significantly due to the destruction of fertile soil layers and the most important component of the soil – humus [4].

Being a basic component of the natural environment, the soil cover functions under the reciprocal influence of climate, geological processes, geomorphological elements, vegetation, and human activity. Soil accumulates the positive results and negative consequences of these factors [5]. The processes in agricultural land use are determined by social relations, and degradation is an inherent component of these processes [6].

The Global Forum for Food and Agriculture (GFFA) held in Berlin from January 24 to 28, 2022 was the first to deal with soil health and the influence of soils on food security and global climate problems. The primary theme of the 2022 GFFA "Sustainable Land Use: Food Security Starts with the Soil" is among the critical problems in global food security that require worldwide cooperation [7]. This owes to the fact that, on the one hand, more than 90% of the world's food production depends on soil. On the other hand, the quality of the world's soil is increasingly deteriorating, and fertile land is becoming scarce [8]. As a result of the Forum, 68 ministers signed a detailed final communiqué titled "Sustainable Land Use: Food Security Starts with the Soil", which constitutes a call to action and is part of the current international discourse on global agricultural policy [9].

The Plenary Assembly of the Global Soil Partnership held on May 23-25, 2022 based on the Food and Agriculture Organization (FAO) of the UN and other international documents examined such initiatives as the Voluntary

Guidelines for Sustainable Soil Management [10] and the International Code of Conduct for the Sustainable Use and Management of Fertilizers [11].

The Global Symposium on Soils for Nutrition (GSOIL4N) held on July 26-29, 2022 by the GSP and supported by numerous international organizations based on the FAO was an important step in implementing the Voluntary Guidelines for Sustainable Soil Management [10]. The Symposium provided an objective assessment of the current state of soil fertility and the dissemination of soil fertility improvement technologies, which aim to ensure better human nutrition, reduce harmful substances in soils, and serve to preserve the world's healthy soils and food safety, in line with the UN Sustainable Development Goals. The motto of the symposium ("Soils, where food begins") once again emphasizes the essential role of soil resources as a foundation for food security.

Thus, the study's relevance is centered on increasing the efficiency of crop production in Central Asia using measures to manage the condition of soil resources.

The study aims to identify global trends, national challenges, and prospects of sustainable soil resource management in Central Asian countries.

Thus, the following objectives of the study were proposed: (1) To identify global trends affecting soil resource conditions with a particular focus on their relevance to Central Asian countries. (2) To analyze national challenges that impact the sustainable management of soil resources within Central Asia. (3) To propose effective measures for mitigating negative effects on soil resources and enhancing sustainable soil management practices in the region.

The research questions addressed in the paper are as follows: (1) What are the global trends and national challenges for Central Asian countries in terms of the condition of soil resources? (2) What measures can be applied to reduce negative effects on soil resources?

To address the outlined research questions, the study employed a quantitative-qualitative approach based on the methodology of comparative and correlation analysis of the scores of the top 10 and Central Asian countries on the indicators and sub-indicators of the Global Food Security Index (GFSI) [12-15] and an expert survey.

Since the GFSI does not cover all Central Asian countries, our study focuses on Kazakhstan, Uzbekistan, and Tajikistan.

A significant premise of the study was the scientific recognition of the need to account for negative effects on soil resources to improve the efficiency of management decisions related to crop production. The article shows the potential of measures applicable to soil resource management. The results complement the methods of mitigating negative effects on soil resources proposed in the analyzed research.

The rest of the paper is organized as follows. The next section reviews scientific sources addressing the degradation of soil resources. Following this, the research methods and results are presented and discussed. At the end of the paper, we draw theoretical and practical conclusions and outline the limitations.

1.2 Background

At present, the study of soil resources follows two systems of objective indicators: characteristics of the natural properties and parameters of soils obtained as a result of studying them as natural environments [16-21] and indicators reflecting the agrobiological requirements of agricultural crops to the soil as a place to grow [22]. Within the "soil – plant" link, the agrobiological parameters and requirements for soil describe its quality [23]. These aspects determine the quality of soil from the perspective of the given crop with its features. For this reason, certain soil properties in relation to the needs of agricultural crops can be seen as the expression of their agro-ecological suitability [24]. Although the core of suitability is still made up by the same parameters and properties of soils that characterize soils themselves, the standard of goodness is defined by the requirements of crops [25].

The quality of soil resources is examined in science in two distinct ways: in the first case, the quality of soil resources is defined by the properties and parameters of soils [26]; in the second case, soil quality depends on crop yields [27]. The two directions do not appear to contradict each other that much, since they reflect different facets of the research subject relying on different categories: the first one – on the characteristics and parameters of soils, the second – on crop yield or productivity. Crop yield is influenced by several factors and anthropogenic activity plays a significant role.

We agree with Otarov et al. [28] and Virto et al. [29] in that the quality of soil resources can only be defined based on the properties and parameters of soils, e.g., humus content, the depth of the humus horizon, granulometric composition, salinity, acidity, etc., i.e., the properties and parameters that have been researched, analytically established, mapped, and quantified. Aliev et al. [30] suggested that the best soil resources are those rich in biological and biochemical converted organic matter (humus) with optimal characteristics of other properties and traits.

The level of soil resource quality is established by comparing the specified characteristics with indicators reflecting the requirements of each crop to the soil environment [31]. In this case, the best soil resources meet the agrobiological characteristics of crops in terms of quality. However, apart from the above parameters, the concept of soil resources as an objective category comprises other indicators, including the intensity of soil use, which causes soil degradation [32].

Gonzalez-Roglich et al. [33] demonstrated that persistent negative processes, both natural and anthropogenic, disturb soil functions and create the risk of soil degradation (salinization, wind and water erosion, reduction of fertility caused by soil dehumification, changes in the agrochemical composition of soil, pH, etc.). Research suggests that the leading causes of soil degradation are irrational tillage and excessive plowing [34], irrational use of fertilizers [35], ameliorative measures [36], and the introduction of unbalanced crop rotations [37]. These factors reduce the productivity of soils and reduce the quality of crop products. Baishanova and Kedelbaev [38] argued that the main risks of reduced soil fertility due to human economic activity include erosion dehumification, pollution with radionuclides, pesticides, and heavy metals, acidification, salinization, waterlogging, and swamping. According to Karlen and Rice [39], the reasons behind reduced soil fertility are: deep plowing of soils, contributing to uncontrolled development of water erosion and deflation, mineralization, and the leaching of organic matter (humus); insufficient fertilizers to maintain soil fertility; and lack of infrastructure of land reclamation systems for constant water supply.

As noted by Graves et al. [40], the biggest threat is the physical and agrochemical degradation of soil cover, because soil degradation processes are directly connected with long-term humus loss, deterioration of phosphorus and potassium regime, and increase in the area of acidic soils. The main causes of these degradation processes are the decline of general farming culture and the reduced application of organic fertilizers and ameliorative means.

Liniger et al. [41] suggested that the most significant risks arise as a result of chemical soil pollution with pesticides, heavy metals, and radionuclides. The leading cause of chemical soil pollution is the irrational application of agro-technologies and the long-term use of mineral fertilizers and chemical plant protection products.

Despite their effectiveness as chemical crop protection agents, pesticides are the most dangerous factor in the chemical pollution of soils and the environment. When a pesticide is applied, only a small fraction (0.1-1.0%) reaches the target object, while the rest ends up in the soil, water, atmosphere, and agricultural products. Moving along trophic chains in the ecosystem, toxic substances lead to the reduction of biodiversity and affect irreversible processes in the structure of biocenoses, disturbing the biological equilibrium [42]. The accumulation of pesticide residues or metabolites in agricultural products and water can also have adverse effects on human health, both through direct and indirect action [43].

No less significant are the negative effects of heavy metals on the basic physical, chemical, and biological properties of soils. Amid increased anthropogenic pollution by heavy metals, the genetic features of soils and their fertility define the growth and development conditions of agricultural crops [44].

The intensity of radionuclide accumulation by plants is strongly associated with the content of radioactive substances in soil, the technogenic and agrochemical load on soil, and the agrochemical and physicochemical soil properties [45]. If the soil is polluted with radionuclides, there is a risk that the obtained products will exceed the permissible levels of pollutants.

Research also suggests that soil degradation can result from the violation of the optimal land use ratio, which occurs due to the irrational use of soil resources and disrupts ecological balance in the ratio of arable land to the total area of ecologically stabilizing lands (forests, natural forage lands, water bodies, etc.) [46]. Arable land is the most vulnerable and most intensively used category of land. Therefore, the main threats to the security of agricultural land use arise precisely in the agricultural exploitation of arable land.

Another factor in the degradation of soil resources is the unsatisfactory phytosanitary condition of crops, arising under favorable conditions due to the excessive proliferation of pests on crops (disease outbreaks, a rise in pests, increased weediness, etc.). The yield of agricultural crops is reduced, and the quality of crop products deteriorates [47].

1.3 Scientific grounds for sustainable management of soil resources

Soil degradation (including pollution) is now an essential component in the condition of agricultural land. This applies to land plots adjacent to industrial facilities (metallurgical, chemical, cement, etc.), highways and railroads, and areas where pesticides and mineral and organic fertilizers are used excessively. The negative condition of soil resources in the agricultural sector can lower crop productivity levels [48].

To prevent or minimize negative effects on soil resources and further control their consequences, it is important to develop an algorithm for soil resource management covering the entire cycle of growing crops. According to Mikhailenko and Timoshin [49], the stages of such an algorithm when growing crops include studying and listing the key factors contributing to the degradation of soil resources; defining the main measures to reduce negative effects on soil resources, including recommendations on the use of optimal measures in agricultural production to prevent and minimize these effects.

The process of soil degradation is not uniform. It depends on the natural properties and parameters of the soil cover and the harmful substances present in the soil, their toxicity, and their concentration in the soil environment. For this reason, the suitability of degraded soils must necessarily reflect the natural and acquired properties of their qualitative state. These two types of characteristics can be aggregated by mapping the boundaries of degraded lands on soil maps. This will make it possible to establish the area, the composition of agricultural soil groups, and the natural characteristics of the degraded soils, such as humus content, humus profile depth, granulometric composition, etc. [50]. Therefore, when it comes to the basic principles of determining the suitability of arable land for crop production, it becomes vital to consider certain aspects of using degraded plots of agricultural land [51].

Several researchers note that degraded (including polluted) lands are not always considered separate, independent entities, but are united under a single concept [52]. Despite being fully merged in relation to productivity characteristics, these issues need to be considered separately.

2. METHODS

2.1 Research approach

According to the outlined approach to sustainable soil resource management as a foundation for crop production efficiency, a qualitative-quantitative case study was considered the most appropriate research strategy to analyze global trends and national challenges for Central Asian countries in terms of soil resource management. The data obtained in this way are more informative and complete compared to a regular quantitative study, offer more detail, and are more helpful in collecting information to develop recommendations and in obtaining feedback from the expert pool. Nevertheless, the chosen method has limitations. For this reason, we should clarify that the key purpose of this study consists in obtaining qualitatively new knowledge on specific methods of soil resource management.

The limited amount of resources available to researchers, on the one hand, and the desirability of additional research on this issue, on the other hand, generated the need to publish the findings to attract interested researchers and promote discussion in the scientific community and among interested specialists in the agro-industrial complex.

2.2 Empirical context and case selection

The research was carried out in the context of increasing the efficiency of crop production in Central Asian countries through effective management of soil resources. Since not all Central Asian countries are covered by the GFSI [14], we should clarify that our study focuses on Kazakhstan, Uzbekistan, and Tajikistan. Crop production occupies a significant place in the agriculture of the considered Central Asian countries, which leads them to implement crop production development programs and diversify the crops produced with an increase in the acreage of highly profitable crops.

As stated in the report of session 43-1 of the European Commission on Agriculture [53], "driven by biophysical and socio-economic factors that are exacerbated by the impacts of climate change, degradation of land and natural resources is one of the greatest challenges faced by several countries in the region. Restoring degraded land is vital for countries to achieve multiple national and international priorities on mitigating climate change, improving livelihoods, reducing desertification, restoring ecosystems and conserving biodiversity".

According to the purpose of the study, we randomly selected web pages of agricultural enterprises related to crop production using the Google search engine. The pool of experts was selected based on the obtained sample of enterprises. The sampling criteria required the expert to have higher agricultural (agrotechnical) education and at least 10 years of experience working in an executive position at an agrarian enterprise associated with crop production.

2.3 Data collection

The data were collected between August 10, 2023 and October 10, 2023 through desk and field research.

Desk research was conducted using the GFSI. In the course of field research, as a result of searching and analyzing documents in Scopus (search terms – "sustainable soil management" + "soil degradation"; search range – all fields), we discovered 325 papers. Through an overview of articles on sustainable land resource management in the context of crop production indexed by Scopus and published in 2012-2022, we identified specific gaps in research that needed to be filled.

The field study consisted in analyzing the present situation with soil resource management by means of an expert survey. Experts were selected based on several criteria: they were required to hold a higher education degree in agriculture, soil science, or a closely related field, possess at least ten years of practical experience in executive, research, or advisory roles related to crop production or soil management, and be actively employed at agricultural enterprises, research institutions, or governmental bodies involved in land use or soil conservation. Experts were identified through a targeted search of agricultural organizations' websites and professional networks using the Google search engine. A total of 59 experts were invited to participate via email, of whom 53 agreed to take part in the survey. They were then emails with the question: "What measures can be applied to mitigate negative effects on soil resources?". The data obtained through the expert survey were used to identify measures to reduce negative effects on soil resources.

2.4 Data analysis

The study utilized the following research methods: monographic (to analyze the place of Central Asian countries in the food security ranking), economic statistics (to analyze the problem of soil degradation and the indicators of soil resources condition among Central Asian countries according to the GSFI), correlation analysis (to establish the strength of the relationship between the GFSI, its components, indicators, and the sub-indicators of soil resources condition across the world), and abstract-logical (to summarize and analyze the results of the study).

The GFSI [12] includes four components: (1) affordability, (2) availability, (3) quality and safety, and (4) sustainability and adaptation. Together, these components consider 58 food security indicators. As of 2022, the index is calculated for 113 countries. This data was used for correlation analysis, which was performed in STATISTICA.

In data analysis, we used the triangulation method to ensure the validity and reliability of empirical findings [54]. Our study involved researcher triangulation [55], whereby several researchers involved in the project participated in information processing. Following this, each theme was discussed separately, and the information agreed upon by all participants was entered into the report. Triangulation ultimately increased the reliability of survey data and the quality of information. All results were documented in the research report.

3. RESULTS

According to the 11th annual report of the GFSI (2022), in 2021, the countries of Central Asia (Kazakhstan, Uzbekistan, Tajikistan) ranked 32nd, 73rd, and 75th, respectively, out of 113 countries. Thus, food security remains relatively poor in Uzbekistan and Tajikistan, especially compared to the top 10 (Table 1).

Table 1. Top 10 countries in GFSI and the position of Central Asian countries (2022)*

Country	GFSI		Component							
			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
United Kingdom	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 is the best condition.
Source: compiled and calculated based on the 2022 Global Food Security Index [12].

Comparing the GFSI scores of Kazakhstan, Uzbekistan, and Tajikistan with the top 10 countries, we can see considerable reserves for improvement. Specifically, the 2021 GFSI score of Uzbekistan is 22.6 points lower than the average among the top 10 countries and 4.7 points lower than the average across all 113 countries. The 2021 score of Tajikistan is 23.2 points lower than the top 10 average and 5.5 points lower than the world average.

Considering the specific components, the least secure area for Uzbekistan and Tajikistan is the affordability of food, in which they rank 85th and 82nd, respectively. The situation with respect to sustainability and adaptation is also rather negative; in absolute terms, this indicator is the lowest among the four for Tajikistan (53.1 points).

Out of the Central Asian countries, Kazakhstan is the only one showing indicators above the world average. However, even Kazakhstan's sustainability and adaptation score exceeds the global average by only 1.3 points and is 6.1 points below the top 10, suggesting that this area also needs improvement.

In view of our research objectives, we focus specifically on the 4th component of GFSI, which covers the country's resilience to natural resource risks and how it adapts to these risks and everything that affects food security in terms of crop production efficiency. The "resilience and adaptation" component was first introduced in the GFSI in 2017 as an adjustment factor and became a separate category in 2020. As of 2022, this component contains six indicators, one of them being "soil resources", which includes 2 sub-indicators referring to soil condition and crop production (Table 2).

Among the top 10 countries in the 2022 GFSI, the highest soil resources score is demonstrated by Norway (85.1 points) and the lowest – by Portugal (59.2 points). Central Asian countries (Kazakhstan, Uzbekistan, Tajikistan) received 53.1, 53.6, and 46.0 points, respectively. These scores are 8-15 points lower than the global average and 19-26 points lower than the top 10, which suggests that this aspect could be significantly improved. On a global scale, the worst indicator turns out to be the content of organic matter in soil with only 29.1 points out of 100. However, while global soil degradation amounts to 69.6 points, the Central Asian countries scored only 41.7 points (Kazakhstan) and 53.6 points (Uzbekistan). The most severe situation with soil degradation is observed in Tajikistan, where, according to GFSI estimates, 100% of land is degraded.

Thus, the biggest weakness of soil resources in Central Asian countries is soil degradation.

The pairwise correlation analysis (Table 3) shows statistically significant correlations between GFSI, its components, and the indicator and sub-indicators of soil resources.

Direct moderate correlations are found between the indicator of soil resources and the GFSI (r = 0.434) and its components – affordability (r = 0.377) and availability (r = 0.312), the quality and safety of products (r=0.342), and sustainability and adaptation (r=0.461). The GFSI shows a moderate direct correlation with the sub-indicators of soil degradation (r = 0.368) and soil organic content (r = 0.355). The soil resource indicator correlates stronger with the sub-indicator of soil degradation (r=0.713). Thus, soil degradation has the greatest impact on the indicator of soil resources.

Table 2. Indicator and sub-indicators of soil resources status of the top 10 and Central Asian countries according to GFSI (2021)

Country	Soil Resources, Points*	Including	
		Soil Degradation	Soil Organic 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
United Kingdom	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 is the best condition.
Source: compiled and calculated based on the 2022 Global Food Security Index [12].

Table 3. Pairwise correlation matrix for GFSI, its components, and the indicator and sub-indicators of soil resources in 113 countries of the world (2021)

Indicator	y	x1	x2	x 3	x 4	x5	x6	x7
GFSI (y)	*1.000*							
Affordability (x1)	*0.837*	*1.000*						
Availability (x2)	*0.832*	*0.735*	*1.000*					
Quality and Safety (x3)	*0.876*	*0.767*	*0.672*	*1.000*				
Sustainability and Adaptation (x4)	*0.709*	*0.522*	*0.541*	*0.584*	*1.000*			
Including: soil resources (x5)	*0.434*	*0.377*	*0.312*	*0.342*	*0.461*	*1.000*		
Of these: soil degradation (x6)	*0.368*	*0.271*	*0.118*	*0.204*	*0.311*	*0.713*	*1.000*	
Soil organic content (x7)	*0.355*	*0.309*	*0.317*	*0.287*	*0.358*	*0.486*	0.074	*1.000*

Note: characteristics that are statistically significant at the level of 0.05 are italicized.
Source: our own calculations based on the 2022 Global Food Security Index [12].

In connection with the need to overcome the negative aspects of soil resources in Central Asian countries, the experts were asked about measures to manage the condition of soil resources. Proceeding from the expert survey, we compiled a list of measures to mitigate the negative effects on the soil resources of Central Asian countries for crop production (Figure 1).

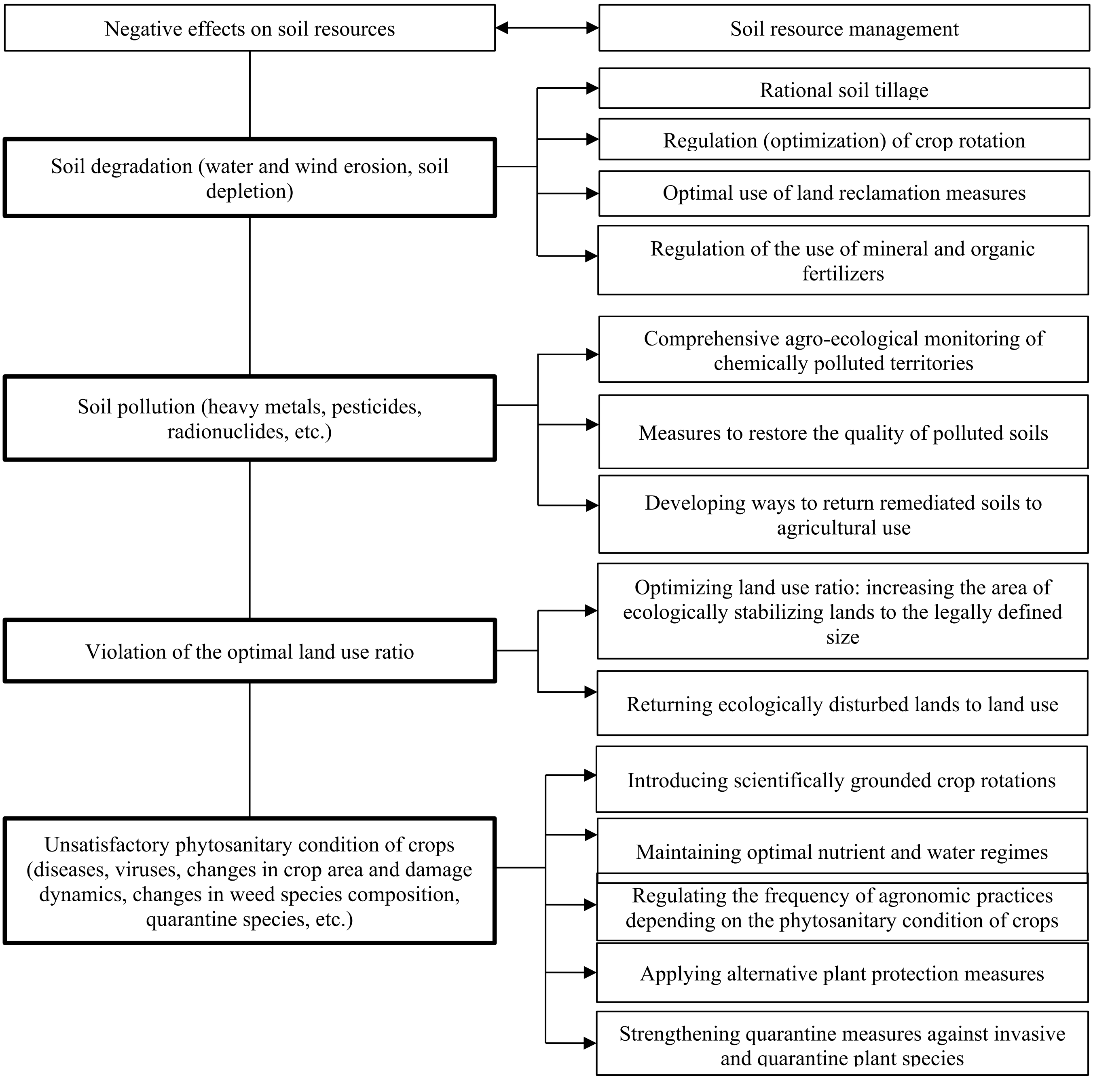

Figure 1. Measures to mitigate negative effects on soil resources
Note: compiled based on the expert survey

4. DISCUSSION

The results obtained through the expert survey deserve special attention. The correlations in this study imply that it is essential to properly understand the relationship between soil resource management and food security in Central Asian countries. The observed correlation between soil degradation and food security, confirmed by numerous studies [56, 57], suggests that the declining quality of soil resources is a significant limiting factor in agricultural productivity. The correlation between soil organic content and soil resources/crop yield highlights the need to implement conservation strategies to sustain long-term food production in Central Asian countries. The low scores on the soil degradation indicators indicate that targeted interventions are required to counter soil degradation and improve soil fertility.

An implication presented by these findings underscores the need to implement soil management practices backed by scientific data. The results indicate that countries with better soil conditions and management practices tend to achieve higher food security rankings. Therefore, adopting soil management measures can improve soil health and food production efficiency.

Soil degradation risk management is critical to prevent the deterioration of soil properties due to natural or anthropogenic factors. The loss of potential and effective soil fertility can be reduced using measures such as:

Rational soil tillage, consistent with propositions to use modern innovative anti-erosion methods and technological measures to counteract the rapid deterioration of the top fertile layer of soil [4];

Regulation (optimization) of crop rotation, which agrees with the results of Podkolzin et al. [20] indicating that proper crop rotation helps to supply the soil with nutrients, protects soils from erosion, contributes to the effectiveness of fertilizer application, prevents the spread of weeds, pests, and pathogens, and creates an optimal balance of nutrients in the soil and increases yields;

Optimal implementation of land reclamation measures, including drainage, irrigation, and the use of gypsum and lime as soil amendments, which help improve and maintain soil fertility [32];

Regulating the application of mineral and organic fertilizers to ensure optimal balance of basic soil nutrients (NPK), humus content, microelements, pH, and reactions of the soil environment. A critical assessment of the proposed measures reveals several underlying challenges in their implementation in Central Asia. A study by Qin et al. [58] reveals that for these measures to be successful, there is a need for proper funding in agricultural research. The lack of modern equipment, chemical reagents, experimental equipment, and an increasing import load of seeds can be attributed to the fact that the agricultural sector of Central Asia makes up only 1.4% of its GDP. In response to the need for irrigation measures, proper drainage and anti-seepage systems must be implemented.

Another critical factor is the socio-economic structure of rural communities. Implementing soil management measures with high technological ceilings, such as precision agriculture or agroecological monitoring, will be challenging due to low technological literacy and limited extension services. Consequently, successful implementation would require a comprehensive capacity-building approach, including farmer education programs, government support, and international cooperation.

Abdivaitov et al.'s [59] assessmented of the crop rotation system in Uzbekistan shows some underlying problems [59]. It emphasizes the need for optimized land allocations and more diverse crop rotations, in addition to wheat and cotton, which are predominantly cultivated in the country. Their study suggests that implementing GIS (geographic information system) systems will significantly improve resource allocations and identify soils that are lacking.

Politically, for these measures to be efficient in Central Asian countries, Dankova et al. [60] suggested that it is advisable to differentiate water resource planning and irrigation management to endeavour full commitment to sustainable agriculture. Policy reviews will also be needed in river basin management, land allocation, support for agricultural innovations, relaxed restrictions on imports and exports, and public-private partnerships.

Furthermore, climate change plays a significant role in soil degradation in the region, necessitating adaptive strategies that account for increasing aridity and extreme weather events. While the proposed measures address soil degradation under current conditions, they must also integrate climate resilience frameworks to ensure long-term effectiveness. Wang et al. [61] suggested additional measures, such as adjusting crop production to optimally use the production environment. In addition to the use of organic fertilizers, drought-resistant varieties should be promoted.

The key objectives in determining the methods to manage the risks of chemical soil pollution include:

- Comprehensive agro-ecological monitoring of territories polluted with pesticide residues, heavy metals, and radionuclides;
- Identifying potential sources of pollution and the extent of chemical soil degradation;
- Ecotoxicological assessment of local sources of soil pollution;
- Implementation of methods to remediate polluted areas and return them to agricultural use.

Despite the great variety of environmental pollutants, most scientific developments focus on pesticide load on soil [35, 39, 43]. Special attention is paid to developing scientific grounds for the remediation of agricultural soils polluted with pesticide residues. Researchers propose environmentally safe methods of cleaning soils based on remediation (chemical remediation, phytoremediation), the restoration of polluted areas, and their return to agricultural use.

Thus, based on the results of scientific research, the following measures were proposed to manage the risks of soil pollution by pesticides to improve the ecological condition of soil resources:

- Using the methods of chemical remediation of soils contaminated with persistent organic pollutants with the help of chemical ameliorants;
- Restoring the quality of polluted soils using phytoremediation methods using cultivated and wild plant species;
- Developing ways to return remediated soil to agricultural use.

Directions for the continued use of remediated soils in agriculture should be established given the following factors: general ecological situation; the need to clean the soil on sites polluted with pesticide residues, including organochlorine pesticides; the specifics of the site (its unique characteristics) in need of cleaning; the starting concentration of pollutants, the volume of contaminated soil; migration of pesticides through the soil profile and the possibility of pollutants leaching into groundwater; long-term effectiveness and stability of soil treatment; practical and economic efficiency of treatment technologies; prospects for further use of remediated soils in agriculture (for construction, planting forest protection belts, growing agricultural products, for recreational purposes, etc.); the impact of treatment methods on the environment and human health [26].

Degraded technogenically polluted soils require significant capital investments for their remediation and return to agricultural use. For this reason, if such measures are unfeasible, these lands are most often withdrawn from land use.

Violation of the optimal land use ratio. The importance of managing the described ecological risk lies in rational land use, which secures the optimal proportion of arable land to the total area of ecologically stabilizing lands to achieve ecological equilibrium.

Literary sources suggest that the optimal ratio of land (primarily arable land to ecologically stabilizing land) is 50:50 (%). However, Virto et al. [29] noted that there are no universal regulations on the ratio of different types of agricultural land (arable land and perennial plantations, hayfields, pastures, and lands under field protection belts). This fact is explained by the differentiation of natural conditions for natural-agricultural provinces. The researchers argue for the need to revise current land use ratios in unstable areas to ensure resilience to deflation and water erosion hazards.

The prerequisite for ensuring the ecological safety of agricultural land use is the structural balance of agro-landscapes, where the main requirements include increasing the share of ecologically stabilizing lands in the structure of agricultural land.

To prevent (or reduce) the negative consequences of the violation of the optimal land ratio, the following recommendations should be followed: increasing the area of ecologically stabilizing lands, particularly by increasing the area of field protection plantations and field margins (forest belts, edges, field roads, hedges, etc.); returning ecologically disturbed lands to land use.

The measures proposed to reduce the negative consequences of the unsatisfactory phytosanitary condition of crops include: introducing scientifically grounded crop rotations; maintaining optimal nutrient and water regimes; regulating the frequency of agronomic practices depending on the phytosanitary condition of crops; using alternative (including biological) means of plant protection that increase plant resistance to diseases and adverse weather conditions; strengthening quarantine measures to combat invasive and quarantine plant species, etc.

Sustainable management of soil resources related to soil pollution, degradation, violation of the optimal land ratio, and unsatisfactory crop condition should rely on environmental, economic, and socio-medical analyses and legal mechanisms. This will make it possible to assess the extent of negative consequences and propose measures to prevent them, improving the quality of soil resources.

Thus, the goal of sustainable management of soil resources should be to protect land from depletion, degradation, and pollution, reproduce and improve soil fertility, and preserve the functions of soil cover and landscape and biological diversity.

5. CONCLUSIONS

The article answers the following research questions: (1) What are the global trends and national challenges for Central Asian countries with respect to the condition of soil resources? (2) What measures can be applied to reduce negative effects on soil resources?

The study identified global trends, national challenges, and prospects for sustainable soil management as a basis for crop production efficiency, which will help to fill some gaps in this segment of scientific substantiation. The key global trend is precisely reflected in the thesis "Sustainable Land Use: Food Security Starts with the Soil", which points to the need to intensify efforts in sustainable soil management.

The comparative analysis of the GFSI indicators of Central Asian countries and the top 10 confirms that there is significant room for improvement, but the opportunities to achieve it are limited. The weak points of soil resources in Central Asian countries are the low content of organic matter in the soil and soil degradation, which is one of the most important problems and challenges faced by Central Asian countries.

The paper proposes priority measures to reduce negative effects on soil resources and crop production in Central Asian countries. The key measures deal with soil pollution and degradation, violation of the optimal land use ratio, and the unsatisfactory phytosanitary condition of crops.

Despite its theoretical and practical contribution, our study is partially limited to the analysis of one region and does not allow for generalizations. For this reason, we recognize the need for parallel studies on this problem. The generalized results of several studies, including other countries and regions, will provide a generalized model for the sustainable management of the condition of soil resources.

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