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UKRAINIAN BLACK SOILS IN WAR: ASSESSING THE IMPACT OF HOSTILITIES ON VIOLATIONS OF THE GUIDELINES FOR SUSTAINABLE SOIL MANAGEMENT

Purpose. *The purpose of the article is to highlight the results of the assessment of the degree and scale of violation of the Food and Agriculture Organization of the United Nations (FAO) guidelines for sustainable soil management due to hostilities, as well as the damage and losses caused to black soils (chernozems) at the level of the territorial community due to armed aggression.*

Methodology / approach. *The study was carried out on the example of the Chkalovska territorial community (hromada) of the Chuhuiv district of the Kharkiv region (Ukraine) using the author's methodology for expert assessment of violations of the guidelines for sustainable soil management in war conditions. The following methods were used in the study: bibliometric using the VOSviewer software (to determine the status and clustering of studies on the impact of the Russian-Ukrainian war on soils and land based on the Scopus database); expert assessments (to determine the impact of hostilities on violations of the guidelines for sustainable soil management and soil quality); statistical (to process and present the results of expert assessment); calculation-analytical (to assess the damage and losses caused to soils due to Russian armed aggression); monographic and abstract-logical (to summarise the results of the study). The data was collected through an online survey of experts.*

Results. *The testing of the developed methodology made it possible for the first time to carry out an expert assessment of (i) the degree and scale of violation of the FAO guidelines for sustainable soil management due to hostilities; (ii) the strength and extent of the spreading negative impact of hostilities on soils by the following types: mechanical, physical, chemical, physico-chemical, biological, radiation and other types of impact; (iii) the strength of the negative impact of hostilities on soil productivity and their ecosystem services (provisioning, maintenance, regulatory, cultural). The losses (lost benefits) due to the degradation (deterioration) of soil quality in the pilot community due to hostilities in terms of agro-soil potentials of natural and effective fertility were determined. The damage from the reduction in the value of regulatory ecosystem services of soils due to hostilities (on the example of organic carbon sequestration in the soil) was assessed. The approximate damage from the main types of military soil degradation was estimated.*

Originality / scientific novelty. *This study is the first to offer a comprehensive expert assessment of the extent and scale of violations of the FAO guidelines for sustainable soil management caused by hostilities, as well as the damage and losses caused to soils, which deepens the understanding of the negative environmental and economic consequences of the Russian-Ukrainian war. The expert assessment method complements existing methods for assessing military soil degradation. This study contributes to a better understanding of the status, challenges and prospects for sustainable soil management in war and peace, taking into account the consequences of military soil degradation.*

Practical value / implications. *The results of the study can be used to (i) assess the extent and scale of violations of the FAO guidelines for sustainable soil management due to hostilities and to make decisions on sustainable post-war recovery; (ii) assess and predict the impact of hostilities on*

soil quality, determine damage and losses due to military degradation for further compensation; (iii) improve soil protection policies and practices in terms of sustainable management of militarily degraded soils in the agricultural sector.

Key words: *military soil degradation, soil quality, Russian-Ukrainian war, ecosystem services, damage, sustainable land management, territorial community, sustainable development, food security.*

1. INTRODUCTION

Healthy soils contribute to a wide range of ecosystem services and almost all of the United Nations (UN) Sustainable Development Goals (SDGs). However, the majority of the world's soil resources are in fair, poor or very poor condition, and their condition is getting worse in far more cases than it is improving. Overall, the problem of soil degradation has become a global one, as evidenced by the fact that 33% of soils are moderately or severely degraded due to erosion, compaction, pollution, acidification, salinisation and other components of soil degradation. Soil degradation negatively affects people's food security and livelihoods, with the majority of the 1.3–3.2 billion people affected living in poverty in developing countries [1].

For centuries, the carbon-rich and highly fertile black soils (chernozems), known as the world's food basket, have played a key role in global production of cereals, tubers, oilseeds, pastures and feed systems. The Food and Agriculture Organisation of the United Nations (FAO) recently published an international report on the global status of black soils, which is the first attempt to summarise and review the state of black soils based on the contributions of experts from all countries. It is noted that black soils are considered to be the most valuable soils for food security, which have a high organic carbon content (over 1.2%) in the upper horizon with a thickness of at least 25 cm, a cation exchange capacity of over 25 mmol/kg and a base saturation of over 50%. Despite the fact that they account for only 5.6% of the world's land area, these black soil belts feed not only the 223 million people living on them, but also millions of others in countries that import goods produced on black soil, thus significantly contributing to the development of the global economy and food security [2].

The world's attention to the state of black soil is driven by its high suitability for agriculture due to its natural fertility, high organic carbon content and soil biodiversity. In addition, black soils play an important role in mitigating and adapting to the effects of climate change. Sequestration of organic carbon in the soil is one of the most cost-effective options for climate change adaptation and mitigation. In this context, black soils are of primary importance, as they contain 8.2% of the world's soil organic carbon stocks and can provide 10.0% of the total global soil organic carbon sequestration potential [2]. However, it is globally recognised that this black treasure is under threat. Given the challenges of food insecurity, the role of soils, including black soils, is more relevant than ever. Therefore, the conservation, sustainable management and restoration of black soil is vital to addressing global challenges such as food insecurity, poverty, the climate crisis, biodiversity loss and land degradation [2].

Ukraine is one of those countries with a unique soil cover – more than 60% of its

area is covered by black soils, which are characterised by high fertility potential compared to other soils. According to the FAO, Ukraine ranks sixth in the world in terms of black soil area (34 million hectares) [2, p. 21]. Ukrainian black soil is the country's brand, a pillar of food and economic security, and people's well-being. It is the standard of soil, a natural phenomenon in terms of its morphological, physical, chemical characteristics and high fertility. Thanks to the great resource potential of its natural fertility, Ukraine is a leading global exporter of grain, sunflower and other food products. The rational use of black soil as Ukraine's national wealth, maintaining its health and fertility is key to the country's food security and the export potential of the agricultural sector. Ukraine has long been one of the leading guarantors of food security in many countries around the world thanks to its strong food exports, which in 2021 were equivalent to providing food for almost 400 million people on an international scale. The powerful potential of soil and land resources, in which Ukraine ranks first among all countries, played an important role in this and in establishing a leading position in the world in the field of agricultural trade [3–5].

The ongoing full-scale ecocidal war that the Russian Federation has unjustifiably unleashed against Ukraine has caused and continues to cause negative impacts on soil and land resources, which are Ukraine's national wealth, on global and national food and environmental security. The war unleashed by Russia is destroying Ukraine's unique black soil; the Russian Federation has turned Ukraine's fertile black soil into the most explosive-contaminated land in the world. Therefore, the efforts of scientists should be focused on assessing the damage and losses caused to soils, as well as developing and implementing sustainable management practices for militarily (war) degraded soils, including technologies and methods for sustainable post-war restoration of the fertility and health of black soil.

The importance and relevance of the problem of assessing the consequences of military soil degradation is due to the fact that the use of the results of such an assessment, as part of the concept of the economics of land degradation, will contribute to a better understanding by management entities of the value of sustainable soil fertility restoration and sustainable land management practices and the feasibility of their implementation, with a comparison of the cost of action and inaction.

The purpose of this work is to highlight the results of the assessment of the degree and scale of violation of the Food and Agriculture Organization of the United Nations (FAO) guidelines for sustainable soil management due to hostilities, as well as the damage and losses caused to black soils at the level of the territorial community due to armed aggression.

2. LITERATURE REVIEW

The results of the study using the search strategy (TITLE (soil OR land OR "black Earth") AND TITLE-ABS-KEY ("Russian-Ukrainian war" OR "Russia-Ukraine war" OR "Russo-Ukrainian war" OR "Russian-Ukrainian conflict" OR "Russo-Ukrainian conflict" OR "Armed conflict" OR war OR conflict OR "military operation*" OR "military action*" OR "armed aggression" OR aggression OR invasion) AND TITLE-

ABS-KEY (Ukrain* AND Russia*)) showed that a total of 54 published documents were indexed in Scopus during the full-scale Russian-Ukrainian war as of the beginning of 2025. Despite the increase in the number of publications in the world in recent years on the assessment of military impact on soils and land, the level of publication activity in this area is low. This is due to various factors, but one of the main ones is the limited possibilities for conducting field research, therefore, research using remote sensing currently prevails. Scientists from Ukraine (31 papers or 57.4% of the total), China (5 papers or 9.3%) and Poland (5 papers or 9.3%) had the largest number of indexed publications in the analysed database. The analysis by organisations of the world by the number of publications indexed in Scopus on the impact of the Russian-Ukrainian war on soils and land shows that representatives of five scientific organisations published 24 papers (44.4% of the total). According to the Scopus database, the leader in the study of the analysed problem is the National Scientific Center "Institute for Soil Science and Agrochemistry Research named O. N. Sokolovsky" (Ukraine), which has 7 published papers.

It was found that the majority (75.9%) of the works were published in the form of articles; 11.1% were conference papers; 9.3% were books and book chapters, and the rest were reviews. The issue of military impact on soils and land is studied from the perspective of various sciences. The largest number of documents were published in the fields of social sciences (20.2%), environmental science (19.3%), earth and planetary sciences (13.8%), arts and humanities (8.3%), agricultural and biological sciences (6.4%), and business, management and accounting (6.4%). Overall, economic sciences accounted for 10.1% of the total number of documents indexed in Scopus. Based on the analysis of the sectoral distribution of documents, the interdisciplinary nature of research on military impact on soils and land was noted. The leader of the rating in terms of the number of publications on the studied issue is the Ukrainian scientist M. Solokha, who has four indexed works. This scientist carried out one of the first field studies of the impact of the full-scale Russian-Ukrainian war on soil cover.

Subsequently, based on the analysis of titles and abstracts of publications, we selected 32 documents [6–37] for bibliometric analysis, which relate to various aspects of the impact of the Russian-Ukrainian war on soils and land. The data from these publications were used for bibliometric analysis using the VOSviewer software. As a result of the study, a bibliometric map of the most commonly used terms in publications on the impact of the Russian-Ukrainian war on soils and land was constructed (Figure 1), which includes 22 key words used at least three times, grouped into three thematically related clusters.

The results of clustering made it possible to identify the main areas of research in each of the clusters based on the most used terms:

- cluster 1 – marked in red, includes eight words: bombing (19 times), controlled study (19), heavy metal (19), remote sensing (18), remote-sensing (18), land use (17), mapping (15), Russian Federation (15); focuses on studying and mapping the impact of the war waged by the Russian Federation, in particular bombing, on soils and land use by applying remote sensing methods, as well as assessing heavy metal pollution.

This cluster includes a group of studies on the identification of militarily degraded soils and land not cultivated due to the war using remote sensing; identification of "hot spots" of strong impact of changes in land use and soil cover; mapping and monitoring of militarily degraded soils of agricultural land [6–14];

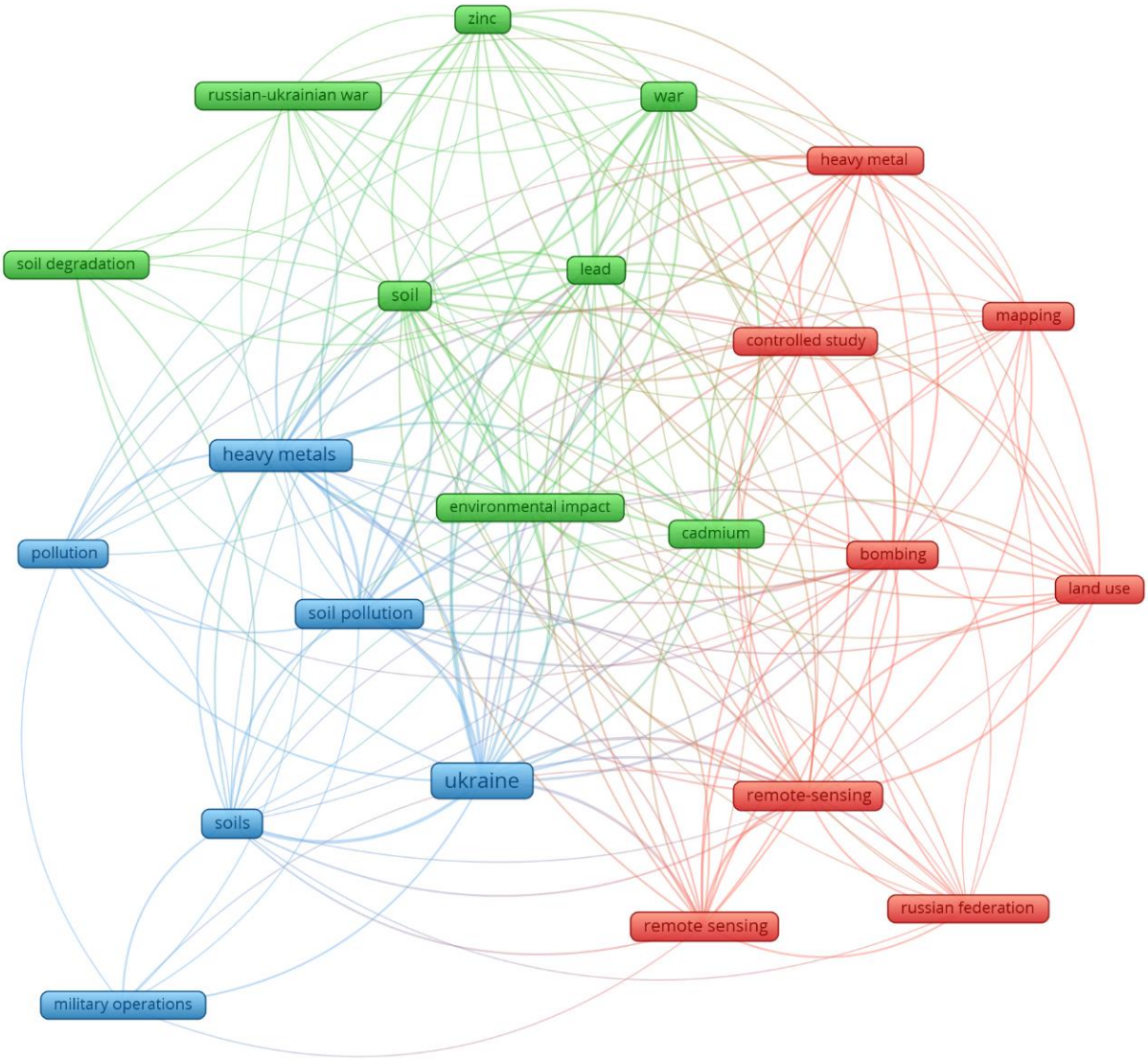

Figure 1. Bibliometric map of the most used terms in publications on the impact of the Russian-Ukrainian war on soils and land

Source: created by the author using VOSviewer based on data from the Scopus database.

- cluster 2 – marked in green, includes eight words: lead (20 times), soil (20), war (20), environmental impact (19), cadmium (18), zinc (18), Russian-Ukrainian war (14), soil degradation (11); focuses on the study of the impact of the Russian-Ukrainian war on the environment, in particular on soil degradation with an emphasis on its contamination with lead, cadmium and zinc. Analysing the impact of the Russian-Ukrainian war on the environment, scientists focused their attention on land, soil, air and water, in particular: the consequences of the war on the temperature of the earth's surface and air quality were recorded; the consequences of the Russian occupation on the soil and water resources of drained lands were assessed; the reasons for the increase in radiation levels in Chornobyl during its Russian occupation were determined; the

cumulative effect of soil damage and air pollution by explosion products were assessed; and the facts of military soil degradation (physical disturbance, soil contamination and changes in land use) were recorded [15–22];

- cluster 3 – marked in blue, includes six words: heavy metals (21 times), soil pollution (21), Ukraine (21), soils (18), pollution (14), military operations (7); focuses on the study of issues related to the contamination of Ukrainian soils, primarily with heavy metals, as a result of military operations. This cluster includes studies devoted to the comparative assessment of soil contamination in Ukraine before and after the Russian invasion; assessment of the level of contamination of agricultural and urban soils due to military actions in different regions of Ukraine; and comparison of magnetic and geochemical soil parameters to assess heavy metal contamination [23–27].

The results of the bibliometric and theoretical analysis showed that a common research area for the three clusters is the study of soil pollution, primarily by heavy metals due to hostilities, while other manifestations of military degradation remain less studied. In addition, the topical issue of the economics of military soil degradation has received relatively little attention to date.

A separate group includes studies on the general consequences of armed aggression for land and land use, in particular: it was found that the Russian-Ukrainian war had a greater impact on land use changes than the COVID-19 pandemic; the main aspects of the war's impact on the quality and condition of land resources in Ukraine were analysed; the consequences of the war for the topographic-geodetic and land surveying sectors of Ukraine were assessed [28–30].

From the perspective of an interdisciplinary approach, scientists are trying to find out the reasons and consequences of the Russian-Ukrainian war with a special emphasis on the role of land [31–33], and are also investigating the specifics of defending Ukrainian soils using a knowledge management approach [34]. In the context of post-war reconstruction prospects, scientists substantiate ways to improve the use of agricultural land, taking into account the consequences of Russian armed aggression [35]; considering the restoration of soil fertility after demining, researchers study the suitability of land for agriculture [36]; emphasise the possibility of using the potential of black soil ecosystem services to restore the quality of war-damaged soils, in particular by growing energy crops [37].

In fact, from the first days of the full-scale war unjustifiably unleashed by Russian Federation on the territory of Ukraine, scientists of the National Scientific Center "Institute for Soil Science and Agrochemistry Research named after O. N. Sokolovsky" began research to assess the impact of military actions on the soil cover and land resources of Ukraine [1–4]. In particular, a new type of soil degradation was introduced – military (war) degradation caused by armed aggression, which includes the following types: 1) mechanical; 2) physical; 3) chemical; 4) physico-chemical; 5) biological; 6) other areas of impact on soils and land plots [3; 38]; pilot theoretical and experimental studies of the current state of the soil cover of Ukraine, which has been degraded as a result of Russian armed aggression, have been carried out [3]. This new

area of research later served as the basis for intensifying scientific discussions, developing and deepening the provisions on assessing the impact of armed aggression on soil resources [4–6; 9; 13; 20; 26; 39]. Due to the ongoing anthropogenic pressure on soils caused by Russian armed aggression, the issue of assessing the impact of hostilities on soils will remain extremely relevant for a long time, not only during martial law, but also after its end. Taking care of soils in times of war requires improving the system of soil measurement, monitoring and sustainable management, taking into account military challenges and post-war reconstruction.

However, the topical issue of sustainable soil management in wartime remains unresolved until now. A combined search in the title, abstract, and key words simultaneously for two concepts "sustainable soil management" + ("Russian-Ukrainian war" OR "Russia-Ukraine war" OR "Russo-Ukrainian war" OR "Russian-Ukrainian conflict" OR "Russo-Ukrainian conflict" OR "Armed conflict" OR war OR conflict OR "military operation*" OR "military action*" OR "armed aggression" OR aggression OR invasion) made it possible to identify only two works in the world (according to the Scopus database), none of which directly addresses sustainable soil management in wartime.

So, the issue of economic assessment of the consequences of military soil degradation in the system of sustainable land management has not yet found proper scientific justification in the analysed publications. In addition, there are grounds to state that there are significant gaps in knowledge about the degree and scale of violations of the FAO guidelines for sustainable soil management due to hostilities.

This work is a logical continuation of a series of our previous publications [3–6; 38; 39] on the issues raised. This study provides answers to the following main research questions:

1. How to assess the degree and scale of violations of the FAO guidelines on sustainable soil management at the level of territorial communities due to hostilities?
2. What is the degree and scale of violation of the FAO guidelines for sustainable soil management at the level of territorial communities due to the hostilities?
3. What damage and losses have been caused to the soils of the territorial community as a result of armed aggression?

3. METHODOLOGY

This study was carried out on the example of the Chkalovska settlement territorial community of the Chuhuyiv district of the Kharkiv region (Figure 2), which was deoccupied in September 2022. Among its soils, typical medium-humus black soils of heavy loam and light clay granulometric composition absolutely prevail, which makes them sufficiently representative for the black soils of the southern part of the Forest-Steppe.

The soil cover of the studied community is represented mainly by highly fertile black soils with a humus content of up to 5.5–5.7%, which in the pre-war period experienced minimal degradation, mainly due to erosion. The agro-soil potentials of natural (without fertilisers) and effective (with fertilisers) fertility of modal types of

black soils were 3.4–3.8 and 4.7–5.1 t/ha for winter wheat, 4.0–4.6 and 6.2–6.6 t/ha for corn for grain, and 2.4–2.7 and 3.0–3.4 t/ha for sunflower, respectively [41].

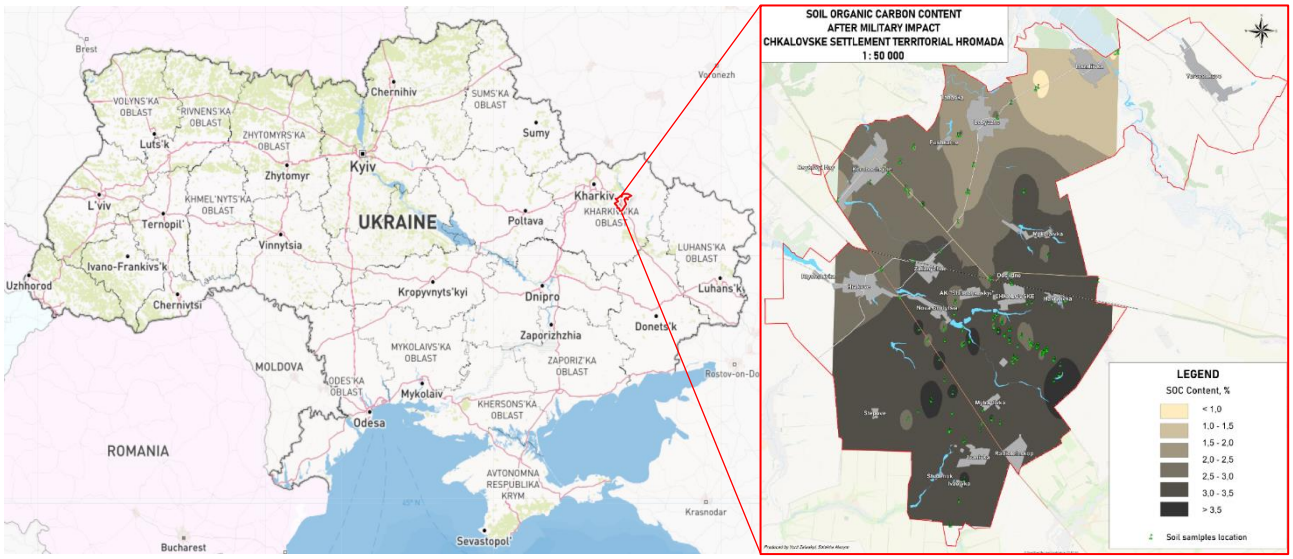

Figure 2. Location of the Chkalovska settlement territorial community on the map of Ukraine and characteristics of the soils of this community by organic carbon content after the impact of hostilities

Note. The map of organic carbon content in the soil, developed by Zalavskyi and Solokha (2024), applies only to the demined lands of the community after deoccupation. It confirms the dominance of black soils (according to the FAO methodology) in the soil cover of the community.

Source: compiled on the basis of sources [40; 13].

The study was carried out using the author's methodology for expert assessment of violations of the principles of sustainable soil management in war conditions. The theoretical basis of the methodology for assessing the degree of violation of the guidelines for sustainable soil management due to hostilities is the Voluntary Guidelines for Sustainable Soil Management (VGSSM) [42], developed by the Global Soil Partnership (GSP) and approved by the FAO and adopted by its member countries. According to this document, the FAO guidelines for sustainable soil management include the following [42]:

1. Minimise soil erosion;
2. Enhance soil organic matter content;
3. Foster soil nutrient balance and cycles;
4. Prevent, minimise and mitigate soil salinisation and alkalinisation;
5. Prevent and minimise soil contamination;
6. Prevent and minimise soil acidification;
7. Preserve and enhance soil biodiversity;
8. Minimise soil sealing;
9. Prevent and minimise soil compaction;
10. Improve soil water management.

Using these principles, we recommend assessing the degree of their violation due to hostilities. Taking into account the ecological and economic foundations of the holistic concept of sustainable soil management in agriculture [43], we propose to

assess the degree of violation of each principle of sustainable soil management due to armed aggression and hostilities using the method of expert assessments on a 5-point scale, where:

1 point – very high level of violation of the principle (very significant deviations, failure to comply with the requirements due to hostilities);

2 points – high level of violation of the principle (significant deviations);

3 points – medium level of violation of the principle (noticeable deviations);

4 points – low level of violation of the principle (insignificant deviations);

5 points – very low level of violation of the principle (hostilities do not affect it).

The strength (intensity) of the impact of hostilities on soils should be assessed on a 5-point scale, where:

1 point – very low level of negative impact (hostilities have almost no impact on soils);

2 points – low level of negative impact;

3 points – medium level of negative impact;

4 points – high level of negative impact;

5 points – very high level of negative impact (hostilities have a very strong impact on soils).

The interpretation of the averaged results of the expert assessment of the degree of violation of each principle of sustainable soil management due to armed aggression and hostilities should be based on the following scale:

1.00–1.50 points – very high level of violation of the principle (very significant deviations, failure to comply the requirements due to hostilities);

1.51–2.50 points – high level of violation of the principle (significant deviations);

2.51–3.50 points – medium level of violation of the principle (noticeable deviations);

3.51–4.50 points – low level of violation of the principle (insignificant deviations);

4.51–5.00 points – very low level of violation of the principle (hostilities do not affect it).

A similar methodological approach should be used to interpret the averaged results of the expert assessment of the extent of the impact of hostilities on soils. At the same time, the directionality of the evaluated indicator (phenomenon, process) should be taken into account, i.e., a stimulator or a destimulator. For example, the interpretation of the average assessment of the strength of the impact of hostilities on soils should be carried out on the following scale: 1.00–1.50 points – very low level of negative impact (hostilities have almost no impact on soils); 1.51–2.50 points – low level of negative impact; 2.51–3.50 points – medium level of negative impact; 3.51–4.50 points – high level of negative impact; 4.51–5.00 points – very high level of negative impact (hostilities have a very strong impact on soils).

In some cases, a 3-point scale should be used in the expert assessment, then the interpretation of the averaged results is transformed into the following scale: 1.00–1.50 points – low level of impact; 1.51–2.50 points – medium level of impact;

2.51–3.00 points – high level of impact.

This study uses primary and secondary data. Primary data were collected through an online survey of experts conducted in November 2024. Secondary data were collected from academic publications, the Scopus database, and the State Statistics Service of Ukraine.

To determine the degree of violation of the FAO guidelines for sustainable soil management due to hostilities, as well as to assess the damage and losses caused to soils and land as a result of armed aggression, we conducted an expert survey of 12 competent experts. The criteria for selecting experts were: complete higher education; knowledge and/or experience in assessing the impact of hostilities on soils and land; and consent to participate in the expert study.

The minimum number of experts to conduct a rapid expert assessment is two people. The recommended minimum number of experts for a group expert assessment is 6–8 people, and the optimal number is 12–23 people [44; 45]. The group of experts we formed meets these recommendations and takes into account the time and financial constraints of the study.

To determine the status and clustering of studies on the impact of the Russian-Ukrainian war on soils and land, a bibliometric analysis was carried out using the VOSviewer software. To determine the impact of hostilities on the violation of the guidelines for sustainable soil management and soil quality, the collected expert assessments were processed using the statistical method. In particular, descriptive statistics (mean, standard deviation) were used to process and present the results of the expert assessment. The calculation-analytical method was used to assess the damage and losses caused to soils as a result of Russian armed aggression. The monographic and abstract-logical methods were used to summarise the results of the study.

4. RESULTS

This section first briefly presents the professional and qualification characteristics of the experts. It goes on to describe the results of the expert assessment of the degree and scale of violations of the FAO guidelines for sustainable soil management caused by the hostilities, as well as the assessment of damage and losses caused by the war to the black soils of the studied territorial community.

Professional and qualification characteristics of the experts. The group of experts is representative in terms of age, gender, education, work experience and experience in expert assessment. In particular, the distribution of experts by age is characterised by the following parameters: up to 30 years (inclusive) – 8.3%; 31–40 years – 41.7%; 41–50 years – 33.3%; 51–60 years – 8.3%; over 61 years – 8.3%. By gender, the same number of experts was interviewed – i.e. 50% of men and women.

In terms of education (scientific qualification), the experts are characterised by the following distribution: complete (full) higher education – 16.7%; candidate of sciences / doctor of philosophy – 50.0%; doctor of sciences – 33.3%. The involved experts have the following work experience in the subject area: up to 1 year – 8.3%;

6–10 years – 25.0%; 11–20 years – 41.7%; over 21 years – 25.0%. Regarding the the level of scientific knowledge as an expert in this area: 8.3% of experts have experience in summarising the works of domestic authors; 50.0% have experience in summarising the works of domestic and foreign authors; 8.3% have production (practical) experience; 33.3% have experience in conducting theoretical analysis and production experience.

As for the level of awareness in this area, 50% of experts have a medium level and 50% have a high level. One third of the experts have no experience of participating in expert evaluation; while the rest have such experience, in particular: little experience (up to 5 years) – 25.0% of experts; medium experience (5–10 years) – 25.0% of experts; significant experience (over 10 years) – 16.7%.

4.1. Expert assessment of the degree and scale of violations of the FAO guidelines for sustainable soil management due to hostilities. The most negative impact of hostilities is on the violation of the following FAO guidelines for sustainable soil management (Table 1): prevent and minimise soil compaction (61.7%); minimise soil erosion (60.0%); prevent and minimise soil contamination (60.0%); preserve and enhance soil biodiversity (58.3%); enhance soil organic matter content (53.3%); and foster soil nutrient balance and cycles (53.3%). These principles are characterised by a high degree of violation.

Table 1

Expert assessment of the degree of violation of the FAO guidelines for sustainable soil management due to hostilities in Chkalovska community

FAO guidelines (principles)	Mean		Standard deviation	Degree of violation
	Points	%		
Minimise soil erosion	2.00	60.0	0.739	High
Enhance soil organic matter content	2.33	53.3	0.985	High
Foster soil nutrient balance and cycles	2.33	53.3	0.888	High
Prevent, minimise and mitigate soil salinisation and alkalinisation	3.58	28.3	1.084	Low
Prevent and minimise soil contamination	2.00	60.0	1.044	High
Prevent and minimise soil acidification	3.33	33.3	0.985	Medium
Preserve and enhance soil biodiversity	2.08	58.3	1.084	High
Minimise soil sealing	3.58	28.3	1.311	Low
Prevent and minimise soil compaction	1.92	61.7	1.084	High
Improve soil water management	2.75	45.0	0.866	Medium
On average for FAO guidelines	*2.59*	*48.2*	-	*Medium*

Note. The assessment of the degree of violation due to armed aggression and hostilities of each principle of sustainable soil management was carried out on a 5-point scale.

Source: author's calculations.

The medium degree of violation is characteristic of the following principles: improve soil water management (45.0%); prevent and minimise soil acidification (33.3%). At the same time, hostilities have the least negative impact on violations of the following principles: prevent, minimise and mitigate soil salinisation and

alkalinisation (28.3%); minimise soil sealing (28.3%). In other words, the latter two principles were adhered to by 71.7% on average. In general, the FAO guidelines for sustainable soil management were violated by an average of 48.2% due to the hostilities, which indicates a medium level of violation (with noticeable deviations).

It was found that most of the FAO principles for sustainable soil management (7 out of 10) are violated mainly at the level of individual enterprises (medium scale), while three principles are violated mainly locally, i.e. at the level of individual fields (Table 2).

Table 2

Expert assessment of the scale of violation of the FAO guidelines for sustainable soil management due to hostilities in Chkalovska community

FAO guidelines (principles)	Mean		Standard deviation	Scale of violation
	Points	%		
Minimise soil erosion	1.83	61.0	0.718	Medium
Enhance soil organic matter content	1.58	52.7	0.669	Medium
Foster soil nutrient balance and cycles	1.67	55.7	0.651	Medium
Prevent, minimise and mitigate soil salinisation and alkalinisation	1.42	47.3	0.515	Local
Prevent and minimise soil contamination	1.75	58.3	0.754	Medium
Prevent and minimise soil acidification	1.58	52.7	0.669	Medium
Preserve and enhance soil biodiversity	1.92	64.0	0.669	Medium
Minimise soil sealing	1.42	47.3	0.515	Local
Prevent and minimise soil compaction	1.83	61.0	0.577	Medium
Improve soil water management	1.42	47.3	0.515	Local
On average for FAO guidelines	*1.64*	*54.7*	-	*Medium*

Note. The assessment of the scale of violation of each principle of sustainable soil management due to armed aggression and hostilities was carried out on a 3-point scale, where: 1 point – local scale (level of individual fields) of violation of the principle; 2 points – medium scale (level of individual enterprises) of violation of the principle; 3 points – large scale (level of the community as a whole) of violation of the principle.

Source: author's calculations.

Thus, the largest scale of violations caused by hostilities is characteristic of the following FAO guidelines for sustainable soil management: preserve and enhance soil biodiversity (1.92 points or 64.0%); minimise soil erosion (1.83 points or 61.0%); prevent and minimise soil compaction (1.83 points or 61.0%). On average, the FAO guidelines for sustainable soil management are violated mainly on a medium scale.

In terms of the strength (intensity) of the negative impact of hostilities on soils, the following types of impact are characteristic of a high level (Table 3): mechanical impact (4.33 points), physical impact (3.83 points), other types of impact, including land contamination (3.75 points) and chemical impact (3.67 points). The medium level of strength of the negative impact of hostilities on soils is characteristic of biological (3.50 points) and physico-chemical impact (2.75 points), while radiation impact at the time of the study was characterised by low intensity (1.75 points).

Table 3

Expert assessment of the strength (intensity) of the negative impact of hostilities on soils in Chkalovska community

Type of impact on soils	Mean		Standard deviation	Strength (intensity) of impact
	Points	%		
Mechanical impact (reduction of profile depth; reduction of humus content; formation of craters, trenches, pits; formation of embankments; anthropogenic skeletonisation; activation of erosion processes, landslides; mechanical disturbances of the morphological structure of the soil profile; mixing of genetic horizons)	4.33	86.6	0.778	High
Physical impact (deterioration of physical properties of soils; persistent changes in granulometric composition; persistent changes in aggregate composition (destructuring))	3.83	76.6	0.835	High
Chemical impact (pollution with toxic inorganic substances and organic compounds; trophic depletion of soil due to reduction of nutrients; salinisation)	3.67	73.4	0.985	High
Physico-chemical impact (acidification, alkalisation; salinisation)	2.75	55.0	0.965	Medium
Biological impact (reduction (narrowing) of soil biodiversity; reduction of soil biological activity; deterioration of sanitary condition; soil toxicity)	3.50	70.0	0.905	Medium
Radiation impact (deterioration of soil radiation status due to contamination with artificial radionuclides)	1.75	35.0	1.215	Low
Other types of impact (land contamination, etc.)	3.75	75.0	1.288	High
On average for all types of impact on soils	*3.36*	*67.2*	-	*Medium*

Note. The assessment of the strength of the impact of hostilities on soils was assessed on a 5-point scale.

Source: author's calculations.

In general, for all types of impact, the average strength (intensity) of the negative impact of hostilities on soils was 3.36 points, which corresponds to the medium level. The strength of the impact correlates to some extent with the degree of its spread in the fields of the studied territorial community (Table 4). Thus, the highest degree of spread of the negative impact of hostilities on the soil of a particular field is characteristic of mechanical impact (3.17 points), land contamination and other types of impact (2.83 points), physical and chemical impact (2.75 points each). A low degree of spread is characteristic of biological (2.50 points) and physico-chemical impacts (2.17 points), and the degree of spread for radiation impacts was assessed as very low.

To summarise, we calculated a consolidated indicator of the danger of different types of impact on soils as the product of the average assessment of the strength of the negative impact and the average degree of spread of this impact. It has been established that the most negative (harmful) types of military impact are the following: mechanical (13.73 points), land contamination and other types of impact (10.61 points), physical

(10.53 points) and chemical (10.09 points). The lowest score is characteristic of radiation impact.

Table 4

Expert assessment of the degree of spread of the negative impact of hostilities on the soils of a separate field in Chkalovska community

Type of impact on soils	Mean		Standard deviation	Degree of spread
	Points	%		
Mechanical impact	3.17	63.4	1.030	Medium
Physical impact	2.75	55.0	1.055	Medium
Chemical impact	2.75	55.0	1.215	Medium
Physico-chemical impact	2.17	43.4	1.193	Low
Biological impact	2.50	50.0	0.905	Low
Radiation impact	1.50	30.0	0.798	Very low
Other types of impact	2.83	56.6	1.337	Medium
On average for all types of impact on soils	*2.52*	*50.4*	-	*Medium*

Note. The degree of spread of the impact of hostilities on the soil of a particular field was assessed on a 5-point scale, where: 1 point – very low degree of spread (no or almost no degradation – up to 10% of the field area); 2 points – low degree of spread (degradation is weakly expressed – 10–25% of the field area); 3 points – medium degree of spread (degradation is moderately expressed – 25.1–50% of the field area); 4 points – high degree of spread (degradation is strongly expressed – 50.1–75% of the field area); 5 points – very high degree of spread (degradation is catastrophic – more than 75% of the field area).

Source: author's calculations.

4.2. Assessment of damage and losses caused to soils as a result of armed aggression. The results of the assessment of the strength (intensity) of the impact of hostilities on soil ecosystem services (Table 5) show that the greatest severity of the negative impact is characteristic of provisioning services (3.75 points), which qualifies as a high degree of impact on the relevant scale. For other groups of soil ecosystem services, the average strength of the negative impact of hostilities on these services was determined, namely: cultural (3.33 points), supporting/maintenance (3.00 points), and regulatory/regulating (2.92 points). In general, the hostilities have a medium intensity of negative impact on the soil ecosystem services (3.25 points). The transformation of the scores into the average relative loss of soil ecosystem services showed that the average level of loss is 32.4%, varying by service group in the following range: from 37.4% for provisioning services to 23.4% for regulatory services.

Table 5

Expert assessment of the strength of the negative impact of hostilities on soil ecosystem services in Chkalovska community

Type of soil ecosystem service	Mean		Standard deviation	Strength (intensity) of impact
	Points	%		
1	2	3	4	5
Provisioning (e.g., provision of crops (food and biomass); provision of water, fibre, timber and fuel)	3.75	75.0	0.754	High
Supporting/maintenance (e.g., habitat for living organisms; source of medicines and genetic resources)	3.00	60.0	1.044	Medium

Continuation of Table 5

1	2	3	4	5
Regulatory/regulating (e.g., sequestration of organic carbon; source of nutrients; regulation of climate conditions; water purification) accumulation (sequestration) of organic carbon; source of nutrients; regulation of climate conditions; water purification)	2.92	58.4	1.084	Medium
Cultural (e.g., cultural heritage, acquisition of new knowledge, values and experiences)	3.33	66.6	0.888	Medium
Overall (on average) soil ecosystem services	*3.25*	*65.0*	-	*Medium*

Note. The assessment of the strength of the impact of hostilities on soil ecosystem services was carried out on a 5-point scale, where: 1 point – very low level of negative impact (hostilities have almost no impact on soil ecosystem services; losses of up to 10%); 2 points – low level of negative impact (losses of 10–25%); 3 points – medium level of negative impact (soils have partially lost the ability to provide relevant services; losses of 25.1–50%); 4 points – high level of negative impact (losses of 50.1–75%); 5 points – very high level of negative impact (hostilities have a very strong impact on soil ecosystem services, i.e., soils have actually lost the ability to provide relevant services; losses of more than 75%).

Source: author's calculations.

The results of the expert assessment of damage and losses caused to soil resources due to hostilities indicate high damage and losses – 3.92 points (Table 6). The average expert assessment of damage and losses to soil resources of the studied community caused by hostilities was close to the average assessment of the extent of the impact of hostilities on soil productivity (3.75 points), which to some extent confirms the notion of their relationship.

Table 6

Expert assessment of damage and losses caused to soil resources due to hostilities, and the strength of the impact of these actions on soil productivity in Chkalovska community

Indicator	Mean		Standard deviation	Degree of damage / strength of impact
	Points	%		
Assessment of damage and losses caused to the soil resources of the community due to hostilities	3.92	78.4	0.669	High
Assessment of the strength of the impact of hostilities on soil productivity	3.75	75.0	0.866	High

Notes. 1. The assessment of damage and losses caused to the soil resources of the community due to hostilities was carried out on a 5-point scale, where: 1 point – damage and losses are virtually absent or very low; 2 points – low damage and losses; 3 points – medium damage and losses; 4 points – high damage and losses; 5 points – very high damage and losses.

2. The strength of the impact of hostilities on soil productivity was assessed on a 5-point scale, where: 1 point – very low level of negative impact (hostilities have almost no impact on soil productivity); 2 points – low level of negative impact (productivity reduction up to 10%); 3 points – medium level of negative impact (productivity reduction by 11–30%); 4 points – high level of negative impact (productivity reduction by 31–50%); 5 points – very high level of negative impact (hostilities have a very strong impact on productivity reduction – more than 50%).

Source: author's calculations.

As a result of transforming the score assessment of the impact of hostilities on soil productivity into the average relative value of the loss of this productivity, it was found that the average level of loss (reduction) of productivity due to hostilities is 29.2%. Using this relative indicator, as well as the average yield indicators of major crops under natural and effective fertility [41], the value of yield loss (reduction) (Table 7) and the amount of losses per unit of land area (Table 8) were determined.

It has been established that, according to the agro-soil potentials of natural fertility, losses (due to hostilities) in the yield of winter wheat range from 0.76–1.05 t/ha; winter barley – 0.67–0.99 t/ha; spring barley – 0.64–0.88 t/ha; corn for grain – 0.82–1.23 t/ha; sunflower – 0.53–0.76 t/ha. Yield losses in terms of agro-soil potentials of effective fertility are as follows: winter wheat – 1.11–1.43 t/ha; winter barley – 1.11–1.46 t/ha; spring barley – 0.96–1.34 t/ha; corn for grain – 1.11–1.87 t/ha; sunflower – 0.67–0.93 t/ha. Based on these yield losses, the losses of landowners and/or land users in the form of lost benefits/income due to the degradation (deterioration) of soil quality were determined (Table 8).

Table 7

Calculation of losses (reduction) of soil quality of the Chkalovska community due to hostilities according to agro-soil potentials of natural (1) and effective (2) fertility

Soils	Crop yield losses, t/ha									
	winter wheat (after fallow)		winter barley		spring barley		corn for grain		sunflower	
	1	2	1	2	1	2	1	2	1	2
Typical heavy loamy and light clay black soils	1.05	1.43	0.99	1.46	0.88	1.34	1.23	1.87	0.76	0.93
Typical heavy loamy and light clay black soils secondary-slightly saline	0.96	1.37	0.93	1.40	0.79	1.23	1.11	1.69	0.61	0.82
Typical heavy loamy and light clay black soils residually secondary-slightly saline	0.99	1.40	0.96	1.43	0.82	1.28	1.17	1.75	0.67	0.88
Typical heavy loamy and light clay black soils weakly xeromorphic (slightly leached)	0.91	1.26	0.85	1.31	0.79	1.17	1.08	1.64	0.67	0.82
Typical heavy loamy and light clay black soils medium xeromorphic (medium leached)	0.76	1.11	0.67	1.11	0.64	0.96	0.82	1.11	0.53	0.67

Source: author's calculations.

The amount of these losses varies depending on the type of soil and crop in a wide range: from 126 USD/ha (spring barley at natural fertility) to 431 USD/ha (sunflower at effective fertility). The average amount of losses at natural fertility is for: winter wheat – 198 USD/ha; winter barley – 172 USD/ha; spring barley – 153 USD/ha; corn

for grain – 222 USD/ha; sunflower – 299 USD/ha. In fact, these indicators indicate losses from the decline of one of the main provisioning ecosystem services – the provision of crops (food). At effective fertility, the indicators of losses are higher, while maintaining a similar ratio between crops as at natural fertility.

Table 8

Calculation of losses (lost benefits/income) due to the degradation (deterioration) of soil quality of the Chkalovska community caused by hostilities in terms of agro-soil potentials of natural (1) and effective (2) fertility

Soils	Losses due to reduction in crop yields, USD/ha									
	winter wheat (after fallow)		winter barley		spring barley		corn for grain		sunflower	
	1	2	1	2	1	2	1	2	1	2
Typical heavy loamy and light clay black soils	223	303	194	285	171	263	252	384	350	431
Typical heavy loamy and light clay black soils secondary-slightly saline	204	291	183	274	154	240	228	348	283	377
Typical heavy loamy and light clay black soils residually secondary-slightly saline	210	297	188	280	160	251	240	360	309	404
Typical heavy loamy and light clay black soils weakly xeromorphic (slightly leached)	192	266	166	257	154	228	222	336	309	377
Typical heavy loamy and light clay black soils medium xeromorphic (medium leached)	161	235	131	217	126	188	168	228	242	309
Average value	*198*	*278*	*172*	*263*	*153*	*234*	*222*	*331*	*299*	*379*

Notes. Calculated at prices as of November 2024: 3rd class wheat – 8500 UAH/t, barley – 7850 UAH/t, corn – 8250 UAH/t, sunflower – 18500 UAH/t. The average annual exchange rate of hryvnia to the dollar in 2024 was: 1 USD = 40.15 UAH.

Source: author's calculations.

The damage from the loss of soil ecosystem services due to hostilities was assessed using the example of one of the most important of these services, the sequestration of organic carbon in the soil (Table 9), the stocks of which were determined based on pre-war data [41]. The losses of this service were taken at the average level of losses (23.4%) for regulatory ecosystem services.

The results of the calculations show that the amount of the loss due to reduction of the value of organic carbon stocks in the arable layer of soil ranges from 581–834 USD/ha at a carbon price of 30 USD/t and in the range of 969–1390 USD/ha at a carbon price of 50 USD/t. The average amount of damage for the analysed soil group due to carbon loss ranges from 748 to 1247 USD/ha depending on the carbon price.

Table 9

Economic assessment of damage from the reduction in the value of regulatory ecosystem services of soils (on the example of soil organic carbon sequestration) due to hostilities

Soils	The value of organic carbon stocks in the arable layer of the soil (30 cm), USD/ha		Losses of organic carbon stocks in the arable layer of the soil (30 cm), USD/ha	
	1	2	1	2
Typical light clay black soils	3456	5760	809	1348
Typical heavy loamy and light clay black soils secondary-slightly saline	3564	5940	834	1390
Typical light clay secondary-slightly saline black soils	3564	5940	834	1390
Typical heavy loamy and light clay black soils weakly xeromorphic (slightly leached)	2916	4860	682	1137
Typical light clay residual secondary-slightly saline black soils	2484	4140	581	969
Average value	*3197*	*5328*	*748*	*1247*

Note. Calculated using carbon prices: 1 – 30 USD/t; 2 – 50 USD/t.
Source: author's calculations.

At the final stage, the estimated damage from the main types of military soil degradation was determined, which amounts to 108.4 million UAH, which is equivalent to 2.699 million USD (Table 10).

Table 10

Calculation of estimated damage from the main types of military soil degradation in Chkalovska community

Name of impact	Type of impact on soil cover	Area, ha / quantity, m^3	Damage, UAH/ha	Total damage	
				thousand UAH	thousand USD
Military roads	Mechanical (soil compaction)	23.28 ha	2520	58.7	1.5
Plant burning	Biological (burning)	109.0 ha	26437	2881.6	71.8
Aircraft and artillery craters	Mechanical (turning up soil layers)	40362 m^3	2024*	81692.7	2034.7
Anti-tank ditches; strongholds/trenches		11730 m^3	2024*	23741.5	591.3
Total		*132.28 ha; 52092 m^3*	-	*108374.5*	*2699.3*

Note. * Calculated on the basis of reclamation costs – 2024 UAH/m^3 [3].
Source: author's calculations.

The calculations of the amount of damage and losses caused to the soils of the studied community show that they vary significantly by type of military degradation – from several hundred to several thousand dollars per hectare (taking into account the simultaneous manifestation of several types of degradation on the same land plot). It should be noted that these results of the calculation of damage and losses are

preliminary and need to be clarified in the future, taking into account demining and surveying the entire territory of the community under study. With each passing day of the ecocidal war, the scale of the damage and the amount of losses are increasing.

5. DISCUSSION

The formation of a system of sustainable soil and land management, as well as the assessment of its efficiency, is directly related to the assessment of the scale of the consequences of existing degradation processes, including those caused by the war. This study fills in the gaps identified by the bibliometric and theoretical analysis, and contributes to a better understanding of the status, challenges and prospects for sustainable soil management in the context of the Russian-Ukrainian war by assessing the degree and scale of violations of the FAO guidelines for sustainable soil management due to hostilities, as well as the economic consequences of military soil degradation.

The study confirms that Russia's full-scale armed aggression has led to a large-scale and multifaceted violation of FAO's guidelines for sustainable soil management, especially in regions dominated by highly fertile black soils. These violations are manifested through mechanical, physical, chemical, physico-chemical, biological and other types of military soil degradation, posing significant threats to long-term food and environmental security and the possibility of agricultural recovery.

The military degradation of Ukrainian soils caused by the war unleashed by Russia has significant negative consequences not only for national but also for global food and environmental security. For example, according to our preliminary expert assessments, the estimated annual loss of gross grain production due to military soil degradation and temporary occupation of land is 10–15 million tons, which is equivalent to providing this type of food for 77–115 million people (based on FAO data on average annual grain consumption of 130 kg per person [46]). At the same time, even without taking into account the temporarily occupied territories, the soil cover of Ukraine can provide more than 40 million tons of grain in terms of the agro-soil potential of natural soil fertility (without fertilisers), which indicates a significant contribution to global food security [4, p. 35].

Soil contamination due to the Russian-Ukrainian war, as documented in a number of studies [15–17; 23–27], confirms the negative impact on environmental safety and human health. At the FAO level, it is recognised that pollution knows no borders: pollutants spread across terrestrial and aquatic ecosystems, and many of them are distributed worldwide through atmospheric transport. In addition, they are redistributed in the global economy through food and production chains [47].

Sustainable management of black soils contributes to the achievement of the Sustainable Development Goals, in particular SDG 1 (No poverty), SDG 2 (Zero hunger), SDG 13 (Climate action), SDG 15 (Life on land) and SDG 17 (Partnerships for the goals). This is also in line with the four key pillars of FAO Strategic Framework 2022–2031: better production, better nutrition, better environment and better lives, leaving no one behind [2]. At the same time, our research, together with the results of

other studies [7–30], shows that the Russian war against Ukraine is focused on preventing sustainable soil management and, accordingly, the achievement of the SDGs and the implementation of the FAO Strategic Framework.

The main threats to soil health are erosion, loss of organic matter, poor nutrient balance, salinity and alkalinity, pollution, acidification, loss of biodiversity, compaction, sealing and poor water management [1]. Our study complements these threats with an expert assessment of their significance in the context of a prolonged full-scale war. In particular, based on the example of the pilot community, it was found that the top priorities include soil compaction, erosion, pollution, reduced soil biodiversity, changes in soil organic matter content, and disruption of soil nutrient balance and cycles.

Due to land use change from natural grasslands to cropping systems, unsustainable management practices and excessive use of agrochemicals, most black soils have lost half of their soil organic carbon stocks and suffer from moderate to severe erosion processes, as well as nutrient imbalances, acidification, compaction and loss of soil biodiversity [2]. Military conflicts also cause the degradation of black soils, polluting them with various sources of pollutants and significantly reducing their biodiversity [2, p. 9], but so far they have been considered mainly as secondary factors. The Russian-Ukrainian war has probably had a greater negative impact on black soil and land use changes than the above non-military factors.

More than 15 million hectares of Ukrainian land are under the influence of hostilities, where soil degradation and soil cover destruction are widespread. The armed aggression of the Russian Federation has caused damage to various soil types over large areas in the combat zone. In terms of area, the most affected soil type is black soil. At different times, more than 5 million hectares of black soils were in the combat zone, which led to their military degradation of varying intensity and direction – physical, physico-chemical, mechanical, chemical, biological [4, p. 41].

There is an opinion that the Russian-Ukrainian war is "a battle for a border land" [32], as well as for natural resources in general. In addition, there is an assumption that the occupation of the territories of southern Ukraine (including the northern Azov Sea, the Black Sea and Crimea), which are promising for agricultural production, is one of the goals of Russia's armed aggression against Ukraine [33].

The scale of the negative impact of the Russian-Ukrainian war on soil and land resources indicates the need to recognise military soil degradation at the international level as a serious threat to soil health; this degradation affects the (in)ability of soil to provide ecosystem services, including the production of safe and sufficient food, which threatens global food security.

The findings confirm a new category of risks for black soil (the ongoing Russian-Ukrainian war) and show the vulnerability of the most fertile soils during the war. This should increase global attention to black soils as a strategic resource, and form the basis for international cooperation, in particular in terms of (i) holding the Russian aggressor accountable for the destruction of Ukrainian black soils, including through compensation for damages, and (ii) developing and implementing policies to protect

and restore these soils in the context of war and post-war reconstruction. To this end, it is recommended that these issues be included in the global agreement on sustainable management (conservation, protection and restoration) of black soils [2], which is to be developed at the FAO level.

The proposed and tested methodology of expert assessment and situational analysis of the degree of violation of the FAO guidelines for sustainable soil management due to hostilities is a significant addition to the arsenal of methods that should be used for a comprehensive assessment of the impact of armed aggression on the state of black soils [3–6; 38]. The expediency and validity of using the method of expert assessments, in particular scoring, to determine the damage caused to the environment by military actions is also evidenced by the results of studies by other scientists [48], who propose this approach for the environment in general. This approach, with certain modifications, may also be useful for such a component of the environment as soil resources.

The methodology for expert assessment of violations of FAO guidelines for sustainable soil management may be useful in the context of supplementing, adapting and updating the FAO Protocol for the assessment of sustainable soil management [49], taking into account military impacts and post-war challenges. The results of the assessment of the state of management of the black soils support the implementation of the VGSSM [42] and can be used to update the knowledge base and facilitate the inclusion of the issue of soil management in war conditions in soil reports. At the same time, the recorded degree and scale of violations of the FAO guidelines for sustainable soil management due to the Russian-Ukrainian war indicate the need for international support to restore the quality and health of affected soils and reduce risks.

This study provides important information about the degree and scale of the violation of FAO guidelines for sustainable soil management due to the hostilities, as well as the damage and losses caused to black soils at the level of the territorial community. Therefore, these results should serve as a basis for decision-making by the Chkalovska territorial community on sustainable management, restoration and conservation of black soils. At the same time, this does not reduce the significance and possibility of using the results beyond the community.

The economic assessment of the consequences of military soil degradation can be considered the first stage of the formation of a sustainable land management system; the next stages should include the development and planning of measures to restore fertility and health of black soils, organisation, motivation and control of actions for their implementation on the ground. Our results and generalised conclusions are consistent with and complement previous studies [9; 13; 39; 41] and may be useful in developing cost-effective innovative methods of sustainable management of militarily degraded soils to accelerate the restoration of their fertility and reduce the risk to the environment and human health.

In many countries around the world, there has been a recent increase in activity regarding policies and/or initiatives to protect and improve soil health. At the same time, local initiatives are likely to work better than those applied in large regions; one-

size-fits-all approaches are less effective [1]. Our case study on the example of a particular community is consistent with this statement and emphasises the need for local community leadership in initiatives to assess the impact of the Russian-Ukrainian war on soils, as well as to formulate and implement policies for sustainable post-war restoration of soil health and other natural resources.

The results of our study are a contribution to the implementation at the local and territorial levels of the global agenda and global goals set by FAO and its Global Soil Partnership, which, in pursuit of the conservation and sustainable management of black soils, have established the International Network of Black Soils [2]. In particular, this study contributes to a better understanding of the threats of black soil degradation due to the ongoing Russian-Ukrainian war; emphasises the priority of black soils in global soil policy as a strategic resource not only for Ukraine but also for global food security; and creates additional arguments for including expanded information on military soil degradation in Ukraine in the second FAO report on the comprehensive assessment of the status of the world's soils in 2025 [2]. The results of the study are in line with the objectives of the International Network of Black Soils, in particular in terms of assessing the condition, current productivity and problems of black soils, identifying and to some extent filling the gap in research on the impact of war on black soils. In addition, the findings contribute to the knowledge base on the degree and scale of the violation of the FAO guidelines for sustainable soil management due to hostilities; this issue can serve as a subject for discussion and exchange of experience among the countries participating in the International Network of Black Soils to help address the challenges associated with the conservation, restoration and sustainable management of war-affected black soils.

6. CONCLUSIONS

This work is the first study to offer a comprehensive expert assessment of the degree and scale of violations of the FAO guidelines for sustainable soil management caused by hostilities, as well as the damage and losses caused to black soils, which deepens the understanding of the negative environmental and economic consequences of the Russian-Ukrainian war. The tested expert assessment methodology complements existing methods for assessing military soil degradation; its practical application in combination with other methods will contribute to a more comprehensive assessment of the impact of armed aggression on the state of soils and their management.

The assessment of the degree and scale of violations of the FAO guidelines for sustainable soil management in the pilot area due to hostilities showed a high degree of violation of the following principles: prevent and minimise soil compaction (61.7%); minimise soil erosion (60.0%); prevent and minimise soil contamination (60.0%); preserve and enhance soil biodiversity (58.3%); enhance soil organic matter content (53.3%); and foster soil nutrient balance and cycles (53.3%). The largest scale of disturbance due to the hostilities is typical for the following FAO guidelines for sustainable soil management: preserve and enhance soil biodiversity; minimise soil

erosion; prevent and minimise soil compaction. According to a comprehensive assessment of the strength and extent of spread, the most negative (harmful) types of military impact are: mechanical (13.73 points), land contamination (10.61 points), physical (10.53 points) and chemical (10.09 points).

A high degree of negative impact of hostilities is typical for provisioning services (3.75 points). For other groups of soil ecosystem services, the average intensity of the negative impact of hostilities was established: cultural (3.33 points), supporting (3.00 points), and regulatory (2.92 points). The average level of loss of ecosystem services is 32.4%, varying by group from 37.4% for provisioning services to 23.4% for regulatory services. The average level of loss (reduction) of soil productivity due to hostilities is 29.2%.

The estimated amount of losses (lost benefits) due to the degradation (deterioration) of soil quality in the pilot community caused by the hostilities in terms of agro-soil potentials of natural and effective fertility ranges from 126 USD/ha (spring barley at natural fertility) to 431 USD/ha (sunflower at effective fertility). The average amount of damage for the analysed soil group due to carbon loss ranges from 748 to 1247 USD/ha depending on the carbon price. Estimated damage from the main types of military soil degradation ranges from several hundred to several thousand dollars per hectare.

The obtained results of the calculations, although not final, contribute to a better understanding of the state, challenges and prospects for sustainable soil management in war and peace, taking into account the consequences of military soil degradation. The main findings of the study can be used to: (i) assessing the degree and scale of violations of the FAO guidelines for sustainable soil management caused by hostilities and making decisions on sustainable post-war recovery; (ii) assessing and forecasting the impact of hostilities on soil quality, determining damage and losses due to military degradation for further compensation by the aggressor; (iii) improving soil protection policies and practices in terms of sustainable management of militarily degraded soils in the agricultural sector.

7. LIMITATIONS AND FUTURE RESEARCH

Despite the important findings, this study and the possibilities of practical application of the results are characterised by certain limitations:

(1) the limitation of the research methodology is that the use of the expert assessment method is associated with a certain subjectivity of the assessment results. Therefore, in the future, if possible, it would be worthwhile to involve more experts in the study, in particular from different categories of stakeholders (including representatives of the authorities, non-governmental organisations and business). In addition, combining the method of expert assessments with field and laboratory research will ensure a comprehensive assessment of the consequences of the war on soils and land;

(2) the geographical limitation is that the study was conducted on the example of a specific territorial community, which does not allow for a full representative

assessment of the situation throughout the entire territory of Ukraine affected by the war. In addition, we studied military soil degradation of agricultural land, so the results can only be used for sustainable management of agricultural soils, while other lands require separate research;

(3) limitations on data availability are primarily due to security factors. Due to the ongoing hostilities, access to many areas is limited or impossible, which affects the completeness and accuracy of the information collected. The results of the damage and loss assessment need to be clarified in the future, taking into account demining and surveying the entire territory of the studied community;

(4) time limitations are that this study covers only the current (short-term) impact of the war and does not take into account the long-term consequences that may manifest themselves years after the end of hostilities. Therefore, future research should attempt to assess (model) the long-term impact of war on military soil degradation and land use change.

The identified limitations of this study do not reduce the value of the results obtained and the possibility of their practical use in the sustainable management of war-affected soils, but open up opportunities for future research. Important areas for future research include the following: expanding the scope of the study to assess the degree and extent of violations of the FAO guidelines for sustainable soil management caused by hostilities, damage and losses at different levels of management (agricultural enterprises, territorial communities, administrative districts, regions and the country as a whole); developing an optimal set of indicators of the condition of soils affected by various types of military impact (mechanical, physical, chemical, physico-chemical, biological, radiation and other types of impact) that are easy and inexpensive to measure and correlate well with soil functions and ecosystem services; development and production testing of differentiated technologies and measures for post-war restoration of soil quality and health, as well as a set of practices for sustainable management of militarily degraded soils; monitoring of militarily degraded soils to assess the dynamics of changes in the state of these soils, monitor the achievement of goals for a neutral level of soil degradation, and determine the efficiency of various technologies and measures for post-war restoration of soil fertility and health.

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