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Maryna Nehrey[1,2*], Nataliia Klymenko[2], Volodymyr Kravchenko[2], Mariana Komar[3]

[1]Research Institute of Organic Agriculture (FiBL)
[2]National University of Life and Environmental Sciences of Ukraine
[3]Ivan Franko National University of Lviv
[1]Switzerland
[2,3]Ukraine
**Corresponding author*

UKRAINIAN AGRICULTURE DURING THE FULL-SCALE RUSSIAN-UKRAINIAN WAR: CONSEQUENCES, POLICY RESPONSES AND RECOVERY STRATEGIES

Purpose. *The present paper examines the impact of the full-scale Russian-Ukrainian war (RUW) on Ukraine's agricultural sector, focusing on the period from 24 February 2022 to the end of 2024. The article has three objectives: firstly, to assess the extent of losses in agriculture; secondly, to evaluate government policy measures; and thirdly, to propose strategies for post-war recovery.*

Methodology / approach. *The study uses a four-stage mixed-methods approach. The following four-step process was undertaken: (i) a systematic literature review of academic, institutional, and policy sources; (ii) statistical analysis of agricultural data from Ukrainian and international institutions; (iii) K-means clustering of regions by the level of impact of the war, economic loss and agricultural activity was conducted using R statistical software; (iv) an evaluation of Ukrainian agricultural policies issued during the RUW. This approach provides a comprehensive perspective on the impact of the RUW on Ukrainian agriculture, thereby informing policy and recovery strategies.*

Results. *The findings indicate that Ukraine's agricultural sector has been severely impacted, with key disruptions including a decline in cultivated land, the destruction of grain storage facilities, and blockades limiting export capacity. The study emphasises government measures such as financial aid programs, tax exemptions, and alternative logistics solutions to sustain agricultural operations. Despite ongoing challenges, Ukrainian farmers have demonstrated resilience, maintaining production on 80 % of available farmland. The research also outlines projections for post-war agricultural recovery, emphasising infrastructure reconstruction, sustainable land use, and alignment with EU agricultural policies.*

Originality / scientific novelty. *This study presents a comprehensive analysis of the multifaceted impact of the full-scale Russian-Ukrainian war on Ukraine's agricultural sector. Combining bibliometric analysis, statistical data review and policy evaluations, the research provides a novel framework for understanding the war's immediate and systemic effects. The study fills gaps in the existing literature by highlighting the interconnection between Ukrainian agriculture and global food security and proposing scientifically sound strategies that meet potential European Union integration standards.*

Practical value / implications. *The findings of this study are of significant practical value for policymakers, stakeholders and international organisations involved in Ukraine's agricultural recovery and development. By providing a comprehensive assessment of the war's impact, the research identifies critical areas for intervention, including infrastructure restoration, demining, logistical improvements, and financial support for farmers. The proposed recovery strategies emphasise innovation, digitalisation, and alignment with European Union standards, thus offering a*

roadmap for building a more resilient and competitive agricultural sector.

Key words: *Ukraine, agriculture, full-scale Russian-Ukrainian war, agricultural policy, post-war recovery, resilience, supply chain disruption, rural development, agricultural exports.*

1. INTRODUCTION

The full-scale Russian-Ukrainian war (RUW) has caused significant damage to the country's agricultural sector and poses a threat to global food security. However, the impact of the war on agricultural policy remains uncertain. To ensure a deep understanding of the challenges facing Ukraine's agricultural sector, we systematically review statistical data, legislative and regulatory measures, and relevant literature. Our analysis focuses on the war period from 24 February 2022 to the end of 2024. We identify the main issues arising from the RUW and the agricultural policy responses.

In addition, we outline potential trajectories for developing Ukraine's agricultural sector in the post-war period. This study is the first attempt to analyse Ukraine's agricultural policy during the war and envisages future post-war development through a comprehensive assessment of the agricultural challenges and policy frameworks during the war. RUW damaged Ukraine's agricultural and food production, disrupting trade with other nations. Its global impact was felt through increased fuel and food prices, which affected the entire global economy.

RUW has severely disrupted food production and trade in Ukraine. Targeted attacks by the Russian army on Ukrainian agriculture, such as shelling of agricultural facilities and infrastructure across Ukraine, mining and burning of agricultural land near active combat zones, a five-month blockade of Black Sea ports (and the re-imposition of the blockade as of July 2023), and the undermining of the Kakhovka Hydroelectric Dam, have severely hampered the functioning of the Ukrainian agricultural sector.

It is crucial to determine the key areas that have experienced the most significant impact, including the destruction and deterioration of fixed assets, a decline in cultivated land due to occupation, landmines, and soil contamination. Other significant challenges encompass export limitations, a decline in domestic food prices, severe disruptions to logistics networks, and shortages of essential resources such as labour, finances, and energy, which hinder the operations of agricultural producers. A comprehensive analysis and synthesis of these challenges will facilitate the identification of strategic directions for maintaining and restoring the agricultural sector both during and after the war.

However, there is still a lack of analysis of the Ukrainian agricultural sector and its challenges, as well as a lack of studies on policy adjustments during the war and the sector's post-war prospects.

Our study aims to fill these gaps by providing a comprehensive assessment of the multiple impacts of the full-scale Russian-Ukrainian war on Ukraine's agricultural sector. Focusing on the first two and half years of the war, we examine the scale, scope and dynamics of the invasion, while assessing the government's responses to mitigate

its effects. The structure of the paper is such that an overview of Ukraine's agricultural sector prior to the war is firstly provided, followed by an analysis of how the RUW has affected sector development. The article then assesses the agricultural policy pursued during the war and concludes with a detailed analysis of the results obtained, highlighting their significance for policy and future research.

2. LITERATURE REVIEW

The impact of the full-scale Russian-Ukrainian war on the world is studied from many perspectives and approaches. Much attention has been paid to the consequences for food security (Deng et al., 2022; Mottaleb et al., 2022; Arndt et al., 2023; Yatsiv et al., 2023); rising prices for global energy, fertilisers, and food (Sohag et al., 2022); changes in food imports (Lin et al., 2022) and exports (Chepeliev et al., 2022); and welfare losses on a regional or global scale, or both (Liadze et al., 2023).

Previous literature has analysed the impact of the war on global agriculture and food security, for example by (Abay et al., 2023; Behnassi & El Haiba, 2022). Some earlier studies have focused on Ukraine's agricultural sector, highlighting its role as an agricultural exporter (Banse, 2022; Kaminskyi et al., 2021; He et al., 2023; Rexhaj et al., 2023; Shubravska & Prokopenko, 2022). Several comprehensive studies provide insights into wartime agriculture (Nivievskyi & Neyter, 2024; KSE Agrocenter, 2023; Dibrova et al., 2023).

Global organisations are discussing the impact of the war on global agriculture and food security in individual regions and the world (FAO, 2022; FAO, 2023; World Bank, 2024). In addition, studies that examine the impact on Ukrainian agriculture focus mainly on the country's role as an agricultural exporter. Only a few international and Ukrainian studies consider the situation in Ukrainian agriculture holistically with an assessment of the losses from the war (Nehrey & Finger, 2024; Yaroshenko et al., 2023). Comprehensive studies are conducted by scholars of the Kyiv School of Economics (KSE Agrocenter, 2022a, 2022b; KSE Agrocenter, 2023 and other experts UCAB, 2023; UGA, 2024b; MAPF, 2024a; OECD, 2023). However, there is a lack of comprehensive analysis of the state of the Ukrainian agricultural sector, the problems caused by the full-scale war, and the ways of post-war recovery.

To summarise the literature review, a bibliographic review was conducted and scientific papers on the impact of the war, including on the agricultural sector, were analysed.

Using analytical tools such as ScopusTools and VOSViewer, the study identifies key relationships and uncovers new, underexplored aspects. A bibliometric analysis was conducted using the scientometric database Scopus, focusing on publications containing the keywords "Russia-Ukraine war". This search yielded 765 publications for the period from 2022 to 2024 as of September 2024. The distribution of these publications by field is shown in Figure 1, with more than 70 % related to social sciences, economics, econometrics and finance, business, management and accounting, agricultural and biological sciences.

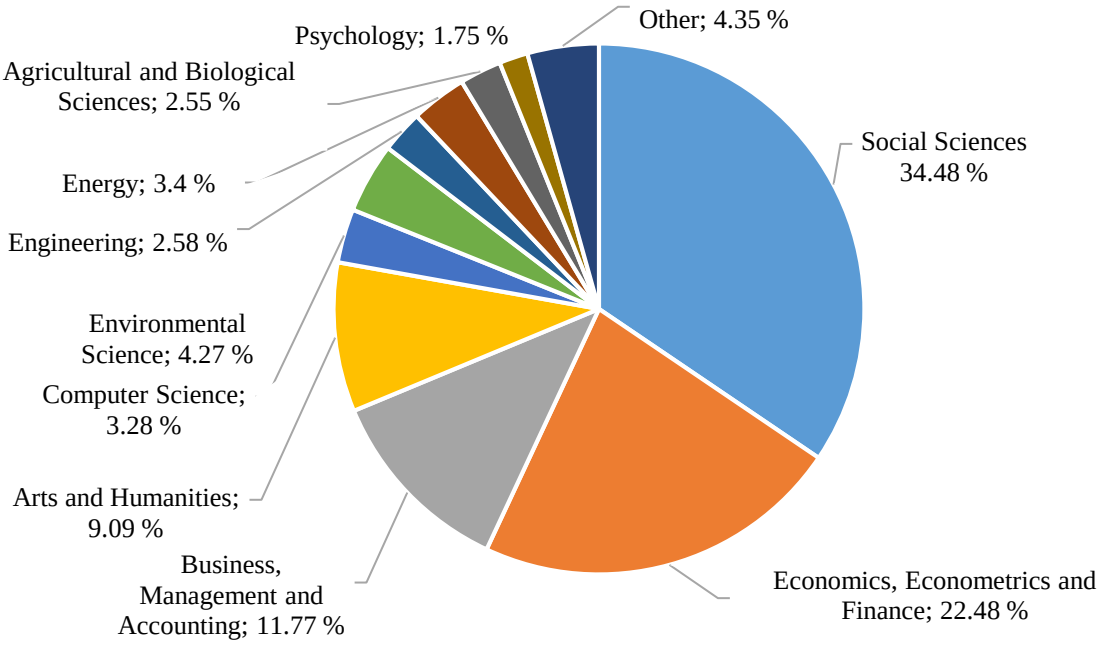


Figure 1. Structure of publications for the query "Russia-Ukraine war" from 2022 to 2024

Source: created using ScopusTools (analyse results) based on Scopus data.

The analysis of the geographical structure of research on this topic showed that the largest number of papers was published by scientists from the United States of America, India and China (Figure 2).

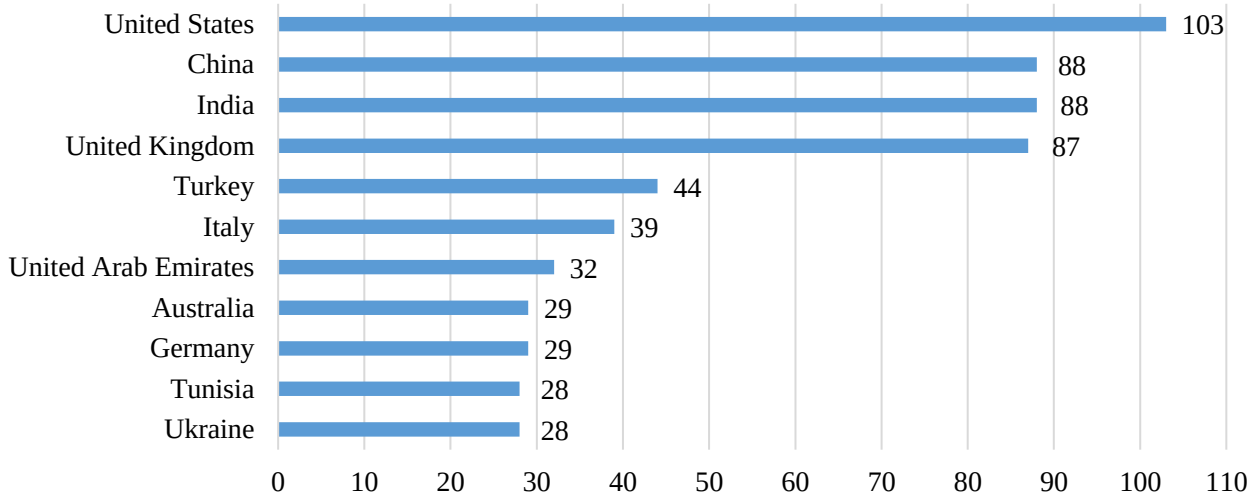


Figure 2. Geographical structure of the scientific research for the query "Russia-Ukraine war", 2022–2024

Source: created using ScopusTools (analyse results) based on Scopus data.

In the Scopus scientometric database, 28 papers were published by Ukrainian scientists during the period under study at the query of "Russia-Ukraine war". There are many more studies that reveal certain aspects of the impact of a full-scale war on Ukraine and the world as a whole.

By limiting the review of these publications to the field of Agricultural and Biological Sciences, only 12 publications were found that matched the two filters by

field and the specified keywords. This situation indicates that the proposed topic has not been sufficiently studied in the Ukrainian scientific literature and underlines the relevance of our study. Most of these papers deal with water security, the destruction of the Kakhovka Dam and its consequences (Vyshnevskyi et al., 2023; Gleick et al., 2023). Several papers are devoted to the problems of labour migration (Yaroshenko et al., 2023), changing grain export routes (Skribans et al., 2024) and disruption of supply chains (Krykavskyy et al., 2023).

The next step in the synthesis of the bibliographic data analysis was to perform a cluster analysis of the publications indexed in the scientometric database Scopus using the VOSviewer platform. After the software processing of the data, a map of scientific research was generated, illustrating the relationships between publications and citations. The clustering was based on the number of references and resources (Figure 3). The radius of the circles representing scientific resources varies depending on the number of articles in each scientific journal. The clusters into which the resources were grouped are highlighted in different colours.

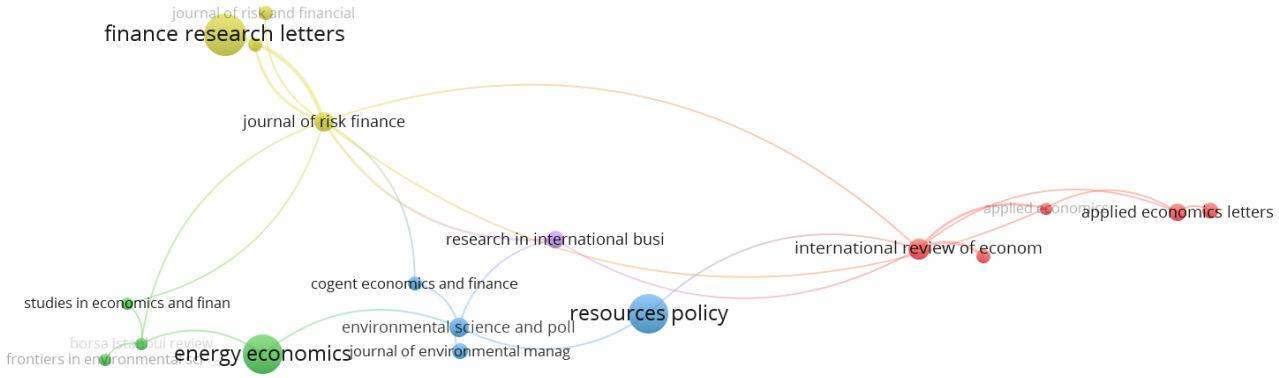


Figure 3. Map of scientific research networks

Source: authors' elaboration using VOSviewer platform based on Scopus data.

The limited branching observed in the resource map (a sample of 765 scientific publications) underlines the novelty of the research problem. In addition, the presence of nodes characterised by the publication of more than 10 articles, each with 100–400 citations within a short period, indicates a significant interest in studying the impact of war on agriculture and the economy in general.

The VOSviewer software allows generating a map of scientific research by the query "Russia-Ukraine war", which demonstrates the relationship between keywords. It can be stated that three clusters are clearly formed according to the relevant request.

In particular, the first cluster combines keywords related to production processes, export prices, and supply chains. In the second cluster, the keywords that have the greatest weight are COVID, investor, shock, volatility, model, connectedness, investment. And the third, the largest cluster in terms of the number and size of nodes, summarises keywords related to the European Union and Ukraine, security, food security, cooperation, peace, and narratives. Figure 4 shows that the identified clusters are interconnected by the concept of "war," which once again emphasises the importance of comprehensive research on the impact of war and the assessment of local and global consequences.

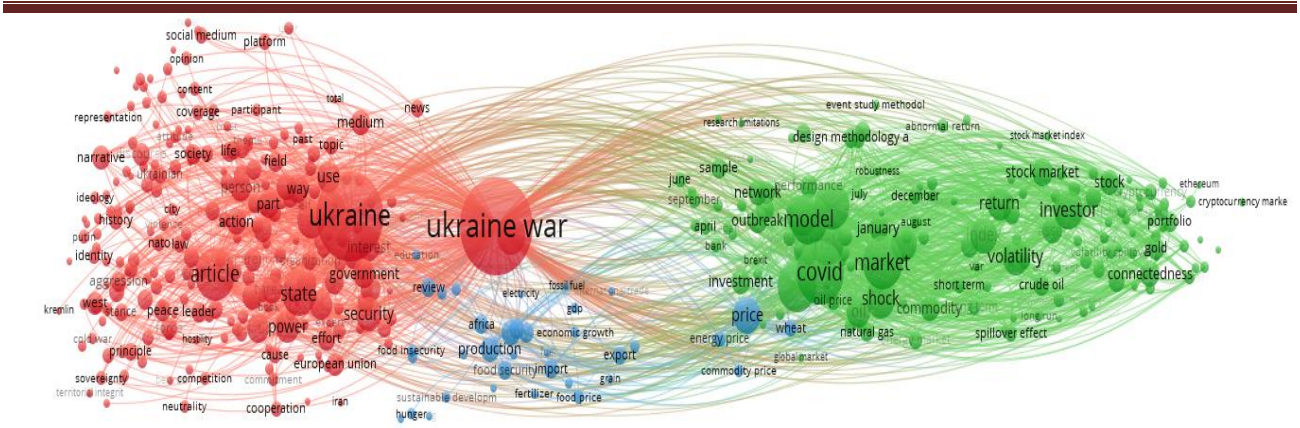


Figure 4. Map of intercluster relationships of keywords for the query "Russia-Ukraine war"

Source: authors' elaboration using VOSviewer platform based on Scopus data.

This paper seeks to address the following research questions by drawing upon a critical analysis of the existing body of research on wartime agriculture and the inconsistencies identified in prior studies:

1. What are the direct and indirect consequences of the full-scale Russian-Ukrainian war on Ukraine's agricultural sector, particularly in terms of production, logistics, and market access?

2. How have Ukrainian government policies and international interventions mitigated the impact of the war on agriculture?

3. What are the primary challenges impeding the recovery of Ukraine's agricultural sector during and after the war?

4. What strategies can be used to reconstruct Ukraine's agricultural sector in a manner that ensures long-term sustainability, enhances competitiveness, and facilitates integration into global markets?

This study examines these research questions by analysing the disruptions caused by the war, evaluating policy responses, and proposing strategic frameworks for the recovery and modernisation of Ukraine's agricultural sector.

3. METHODOLOGY

Focusing on the war period from 24 February 2022 to the end of 2024, our analysis examines the first two and half years in-depth, potentially setting the stage for future studies covering subsequent war phases and the post-war period.

The approach used in this study consists of four main stages. Initially, a comprehensive literature review was conducted, encompassing a systematic analysis of research articles, government reports, and publications from organisations including the Food and Agriculture Organization (FAO), the World Bank and the United Nations. Secondly, we conducted an in-depth analysis of statistical data from the Ukrainian State Statistics Service, the Food and Agriculture Organization, and other relevant institutions. Third, we applied K-means clustering to group Ukrainian regions based on war exposure, economic losses and agricultural activity. Data for clustering were

obtained from the State Statistics Service of Ukraine – regional agricultural production, land use and employment (State Statistics Service..., 2022b) and the World Bank – damage assessments and business losses (RDNA4, 2025). Clustering was performed using R statistical software (cluster package), providing a structured approach to understanding the heterogeneous impacts of the RUW on agriculture. By categorising regions based on war exposure, economic losses, and agricultural activity, this analysis enables a more precise evaluation of regional disparities and informs tailored recovery strategies. Finally, we examined Ukrainian agricultural policy by reviewing legislative and regulatory documents issued by the Verkhovna Rada of Ukraine, the Cabinet of Ministers of Ukraine, and the Ministry of Agrarian Policy and Food of Ukraine.

The combining of these methodological steps provided a comprehensive understanding of Ukrainian agriculture during the two and half years of the war. This included an analysis of the challenges facing the sector, the responses of farmers and the government, and an assessment of the sector's potential. Such a comprehensive assessment serves as a basis for deriving key lessons for agricultural policy formulation and potential growth trajectories within the sector for the post-war period.

4. RESULTS

4.1. Ukrainian agriculture before the full-scale Russian-Ukrainian war. Before the war, Ukrainian agriculture played a central role in the country's economy, making a substantial contribution of 10 % to GDP and accounting for 41 % of total exports. On average, approximately 2.8 million people were employed in Ukraine's agricultural sector between 2019 and 2021 (State Statistics Service..., 2022b).

The structure of Ukrainian agriculture was twofold. On the one hand, 4 million households cultivated 20.8 million hectares of land and produced 55.0 % of the gross output. On the other hand, more than 39,000 agricultural enterprises were active in Ukrainian agriculture, cultivating 20.4 million hectares of land and producing 45.0 % of the gross output (State Statistics Service..., 2022b). Among the agricultural holdings, the largest share of land (24.6 %) was cultivated by agricultural enterprises of between 1000 and 5000 hectares. Large agricultural holdings were a feature of the Ukrainian agricultural sector. In 2021 they cultivated 12.8 % (5,273,845 hectares) of the Ukrainian agricultural area. The largest agricultural holdings in Ukraine before the war were Kernel (514,000 hectares of land bank), UkrLandFarming (500,000 hectares of land bank) and MHP (362,000 hectares of land bank).

The predominant focus of Ukrainian agriculture was on crop production, accounting for 81.4 % of total output, while livestock farming constituted the remaining 18.6 % (State Statistics Service..., 2022a). The specialisation of agricultural enterprises in Ukraine was primarily focused on cultivating crops that were intended for export, including grains, pulses, sugar beets, and sunflowers. In contrast, household farms focused on the production of vegetables, fruits, and other agricultural goods for domestic consumption. Figure 5 provides a visual representation of the production trends of key agricultural commodities.

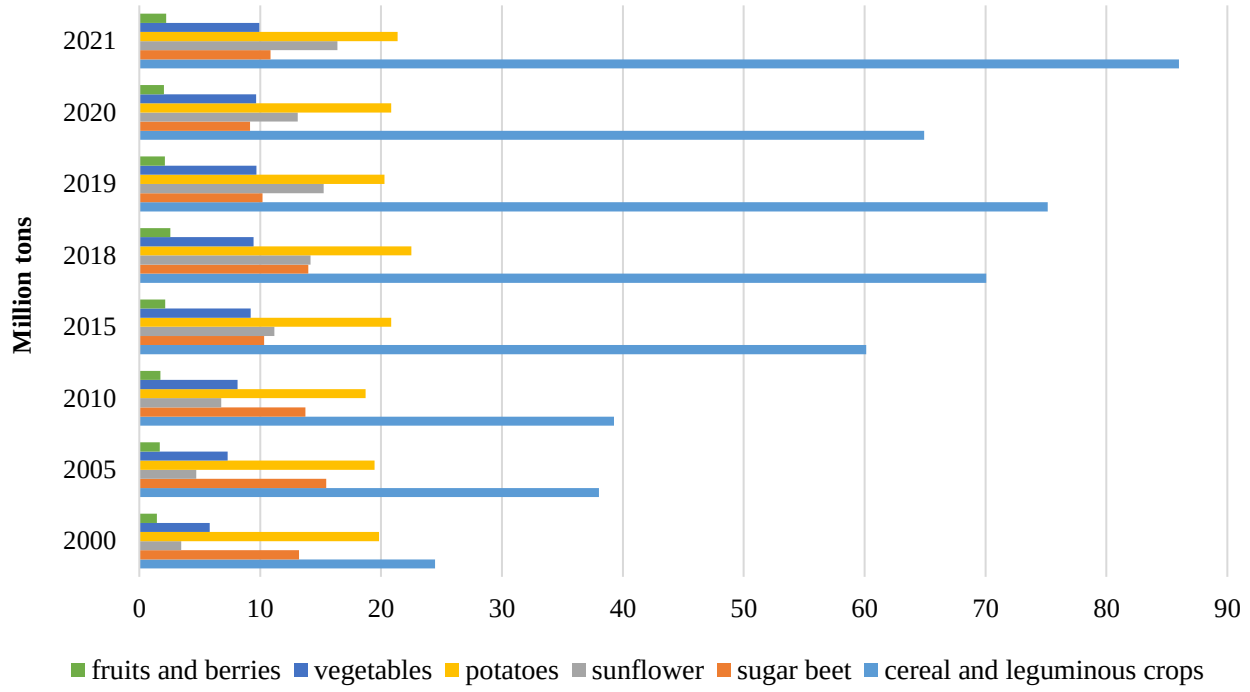


Figure 5. Production of agricultural products in 2000–2021, million tons

Source: created using data of the State Statistics Service... (2022a).

Notably, Ukrainian agriculture had achieved complete self-sufficiency in meeting the population's food needs, while enabling significant exports of agricultural commodities such as sunflower oil, wheat, barley and corn. Ukraine was the world's largest exporter of sunflower oil, accounting for 53.3 % of total exports in 2021. Ukrainian agriculture also accounted for 11.48 % of world exports of corn, 11.54 % of barley, 8.4 % of wheat and 9.6 % of rapeseed (State Statistics Service..., 2022b).

4.2. Dynamics of the full-scale RUW and its impact on the Ukrainian agricultural sector. The sequence of military and political developments, in conjunction with targeted attacks on infrastructure, gave rise to a complex and shifting set of challenges for agricultural production, logistics, and trade. In the initial phase of the invasion, from 24 February to 31 March 2022, Russian forces occupied approximately one-quarter of Ukraine's territory, including regions with significant agricultural activity such as Zaporizhzhia, Kyiv, Zhytomyr, Luhansk, Sumy, Kharkiv, Chernihiv, and Donetsk (Center for Preventive Action, 2025). This sequence of events resulted in substantial destruction of production facilities, disruption of logistical routes, and the blockade of major seaports. Consequently, agricultural exports were suspended, farmers faced acute shortages of feed and fuel, and a significant number of farms were forced to cease operations. The initial repercussions of the war included labour shortages, which resulted from mass displacement and military mobilisation. Concurrently, financial strain escalated, as access to working capital and VAT refunds became constrained. Logistics networks had to adapt quickly, often at significantly higher costs (Deininger et al., 2024; Nehrey & Finger, 2024).

Between April and August 2022, Ukrainian counteroffensives resulted in the liberation of key northern territories, including the regions of Kyiv, Chernihiv, and

Sumy (Center for Preventive Action, 2025). However, hostilities continued in the eastern regions. Although certain agricultural activities were resumed, the sector encountered significant challenges, including disrupted spring sowing, resource shortages, and the challenge of restoring deoccupied land. In order to facilitate the recovery of the agricultural sector, a series of policy measures were implemented. The European Commission's Solidarity Lanes Action Plan, initiated in May, established alternative transport corridors for agricultural exports via rail, road, and inland waterways. In July, the Black Sea Grain Initiative facilitated limited exports from Black Sea ports. In August, the State Agrarian Register was introduced with the stated aim of improving transparency and access to government support for farmers (Nehrey & Finger, 2024).

From September to December 2022, Russian attacks on energy infrastructure further strained agricultural operations (O'Hanlo et al., 2025; Center for Preventive Action, 2025). Power outages disrupted irrigation and storage, while rising prices for inputs added financial pressure. Landmines left in former combat zones hindered both harvesting and winter sowing, making some areas unsafe or inaccessible (Deininger et al., 2024).

In early 2023, between January and April, fighting intensified around Bakhmut, Vuhledar, and nearby areas, while Russia continued to attack on Ukraine's energy facilities (O'Hanlo et al., 2025). At the same time, tensions rose with neighbouring European countries, where farmers protested against the influx of Ukrainian grain (Nehrey & Finger, 2024). These protests, combined with temporary disruptions to the Grain Initiative, added new challenges. Due to occupation, mining, and reduced access to inputs, sowing areas contracted significantly. The agricultural sector operated under severe pressure amid high logistical costs, market restrictions, and limited resources.

The period from May to August 2023 was marked by Ukraine's counteroffensive and the destruction of the Kakhovka Dam in June. The dam's collapse had devastating consequences for irrigation infrastructure in southern Ukraine, reducing agricultural productivity in affected areas. The expiration of the Grain Initiative on 17 July removed a critical export channel, forcing the sector to seek costly alternatives. Concurrently, new harvests surpassed existing storage capacity, underscoring the necessity for investment in logistics and storage infrastructure (Deininger et al., 2024).

Between September and December of 2023, Ukraine's agricultural exports increasingly relied on alternative routes, including the Danube ports and land transport corridors. Nevertheless, these endeavours were undermined by Russian shelling of port infrastructure in Odesa and the Danube cluster (Uygur & Peyravi, 2025). Concurrently, several neighbouring EU countries implemented temporary bans on Ukrainian grain imports, whilst concurrently blocking transit, thereby further complicating export logistics.

By mid-2024, Russian forces persisted in their offensive operations in the frontline regions of Donetsk, Luhansk, Zaporizhzhia, and Kherson (Center for Preventive Action, 2025). A total of 20,000 hectares of land under the management of agricultural enterprises were identified as having been mined, with a further

98,000 hectares requiring clearance (Macalpine, 2025). The rate of demining activities was hindered by delays in the delivery of international aid. Notwithstanding these conditions, Ukrainian farmers were able to harvest approximately 80 % of arable land. According to the Ministry of Agrarian Policy and Food of Ukraine, as of 1 November 2024, Ukraine had harvested 66.7 million tons of grains and oilseeds from 18.6 million hectares, including 47.9 million tons of grains and 18.8 million tons of oilseeds (MAPF, 2024b). During this period, there was a modest improvement in logistics. In the aftermath of the dissolution of Polish border blockades in April, there was a notable increase in seaport activity. As of August 2023, a total of 1,600 vessels had transported 45 million tons of cargo from the ports of Greater Odesa, thereby demonstrating the sector's capacity for resilience in the face of unfavourable conditions (RDNA4, 2025).

From September to December 2024, Russia intensified its offensive operations and escalated targeted attacks on agricultural infrastructure (O'Hanlo et al., 2025). Strikes on the ports of Greater Odesa and vessels operating in the Black Sea disrupted grain exports, including shipments intended for humanitarian aid. This period was characterised by further setbacks for Ukraine's agricultural exports and a decline in production, owing to reduced cultivated areas, infrastructure damage, and persistent logistical challenges. The degree of landmine contamination was such as to reach unprecedented levels, with almost two million mines having an effect on 23 % of Ukraine's territory. This led to the rendering of substantial areas of farmland unusable and the posing of long-term threats to rural livelihoods (Uygur & Peyravi, 2025).

By the end of 2024, Ukraine had suffered losses to the value of over USD 10 billion in the agricultural sector (RDNA4, 2025). The crisis was compounded by three factors: firstly, liquidity constraints; secondly, rising input costs; and thirdly, a 41 % decline in sector capitalisation. Despite the partial compensation provided by alternative export routes for the loss of Black Sea access, these routes remained costly and constrained in terms of capacity. The ongoing deterioration of infrastructure, in conjunction with prevailing market and policy pressures, underscores the pressing need for targeted support measures to ensure the recovery, food security, and long-term resilience of Ukraine's agricultural sector.

4.3. Effects of the full-scale RUW on Ukrainian agriculture and its adaptation to wartime. The war led to changes in Ukraine's agricultural policy, with almost all traditional support programs suspended in 2022. The Cabinet of Ministers of Ukraine (CMU) redirected USD 136 million from the 2022 state budget, originally earmarked for agricultural support, to security and defence. Nevertheless, measures were introduced to support agricultural production during the war, including streamlined bureaucratic procedures, allowing the use of agricultural machinery without registration, simplified seed imports, a zero-excise tax rate, a reduction in the value-added tax (VAT) on fuel from 20.0 to 7.0 % for all uses, and temporary financial support in the form of subsidies. Agricultural producers were granted VAT exemptions on goods destroyed in the war and those used for national defence. Phytosanitary export requirements and the state registration process for pesticides and agrochemicals were simplified. The list of agrochemicals that could be imported, produced, traded and used

without registration was expanded. Under martial law, new rules on state veterinary and sanitary control were introduced, allowing the import of EU-registered feed additives for livestock production.

In 2022, Ukraine ratified an agreement with the United Kingdom to eliminate import duties and tariff quotas. As part of the Ukraine-Canada Free Trade Agreement (FTA), Canada eliminated import tariffs and restrictions on Ukrainian products for the year. In 2022, the European Council temporarily suspended customs and anti-dumping duties on certain Ukrainian products for one year.

International aid to Ukraine's agriculture, which exceeded USD 8.7 billion as of April 2023 (OECD, 2023), focused on direct damage through demining, seed supply, and equipment repair. EU assistance offered USD 96 per hectare and USD 318.5 per cow for small producers. The FAO Rapid Response provided USD115.4 million and the US AGRI initiative contributed USD 100 million. A temporary grain storage initiative provided 35,000 bins with a capacity of 7 million tons. FAO, USAID and Japan provided seed and fertiliser assistance. The FAO grant program targeted small-scale producers, and joint efforts supported farmers during the planting season.

A recent study has revealed that as of February 24, 2023, the Ukrainian agricultural sector has suffered an estimated total impact of USD 40.2 billion, with losses comprising 78.0 % of this amount (Himmelfarb, 2023). The war has resulted in direct damage amounting to USD 8.72 billion, equivalent to 30.0 % of the country's pre-war agricultural capital, while the overall losses have amounted to USD 31.50 billion.

According to the World Bank, as of the end of 2024, total damage in the agriculture sector amounts to USD 11.2 billion, while losses amount to USD 72,7 billion, including the destruction of the Kakhovka Dam (World Bank, 2025). Damage includes partial or complete destruction of storage facilities, fisheries, aquaculture, perennial crops and forced grazing. In addition, it includes the destruction and theft of machinery, equipment, as well as production resources and products. Among these, damage to machinery and equipment accounts for the largest share of total losses at 57.0 %, followed by stolen inputs and products (18.0 %) and damaged storage facilities (18.0 %). Damage, losses and needs by region (in USD millions) are presented in Figure 6. The most affected regions were Luhanska, Zaporizka, Kharkivska, Khersonska and Donetska oblasts.

The total loss of Ukrainian arable land (both abandoned and seized by Russia) by 2023 is estimated at over 6 million hectares, or 18 % of Ukraine's total arable land in 2021 (Mkrtchian & Müller, 2024). The impacts of mining on the agricultural sector include crop losses, financial burdens associated with the repair or purchase of machinery, risks to worker safety, environmental degradation with soil and water contamination, increased vulnerability to invasive species, and a potential decline in investment due to unstable regional conditions.

The destruction of the Kakhovka Dam on 6 June 2023 caused extensive chaos in southern Ukraine. Estimated total damage and losses to primary agriculture amount to USD 1.18 billion, with fisheries bearing the most significant impact at USD

24.5 million (Balachandran, 2023). Additional losses include damaged crops, drowned livestock, and costs of land reclamation. The destruction of the dam has particularly affected intermittent irrigation for drought-prone agricultural land, with losses estimated at USD 909 million over the next five years.

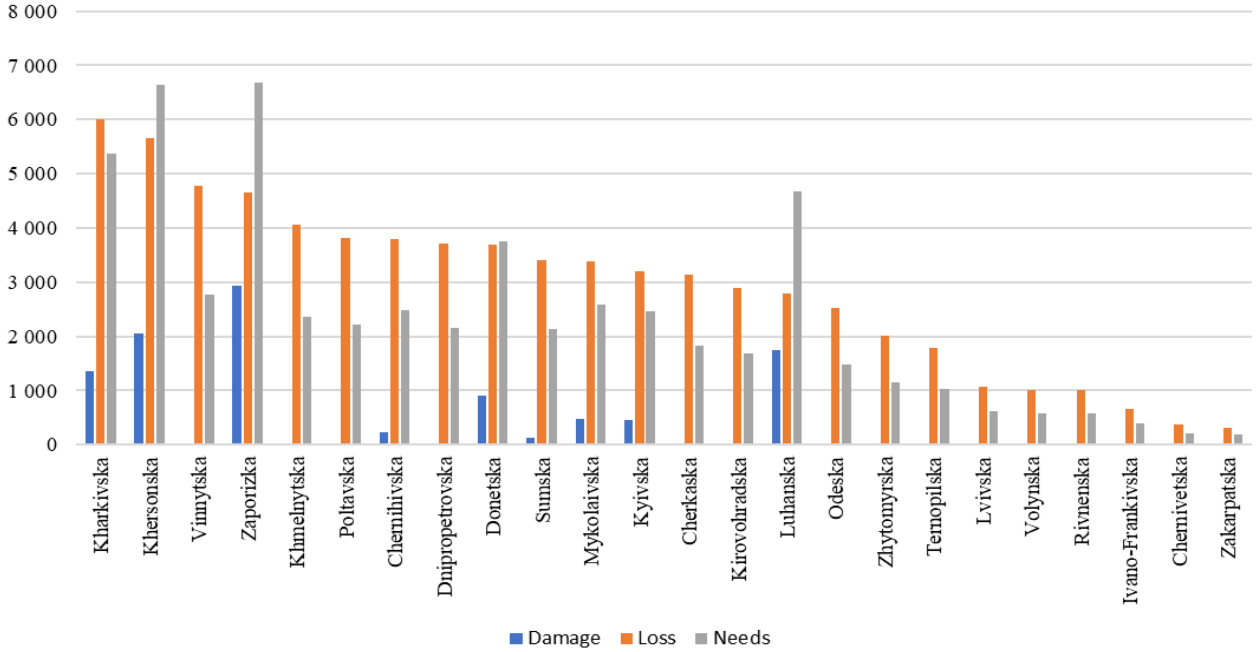


Figure 6. Regional impact assessment: agricultural damage, losses, and recovery needs as of February 2025, USD millions

Source: World Bank, RDNA4 (2025).

To raise finance, farmers have been able to use financial instruments and strategies such as the 5-7-9 % scheme and government portfolio guarantees from banks, as well as guarantees from the EBRD and IFC. In addition, farmers have used government grant schemes, eRobota grants and funding from global institutions and agencies. Non-bank financial institutions, such as leasing, finance and factoring companies and credit unions, played a key role in attracting finance. It should be noted, however, that such programs have not been available to all farmers and have not been available in all regions. According to a survey conducted by the FAO in 2022, 44.0 % of respondents acknowledged a catastrophic increase in production costs, and 25.0 % reported reducing or stopping production activities due to the war. In the first year of the war, about 90.0 % of crop producers and 60.0 % of livestock producers experienced a significant or steep decline in income (FAO, 2023). In particular, certain enterprises, especially those located in frontline regions, ceased operations, contributing to a 7.0 % bankruptcy rate among agricultural enterprises, despite government initiatives ostensibly aimed at supporting the agricultural sector throughout the RUW.

In 2022, the total capitalisation of Ukrainian agricultural holdings was EUR 66,363 million, marking a significant decrease of EUR 46,009 million (41.0 %) compared to the previous year, 2021, which recorded a total capitalisation of EUR 112,372.5 million (UkrAgroConsult, 2023). Furthermore, the fourth quarter of 2023 observed a decline in the total capitalisation of prominent Ukrainian agricultural

holdings, including MHP, Kernel, Agroton, Astarta-Kyiv, Agrodzhenerien, Milkiland, IMC, KSG Agro, Ovostar Union, Ukrproduct and Agroleague (UkrAgroConsult, 2024; Klymenko et al., 2023). According to stock exchange data and calculations by UkrAgroConsult, the total capitalisation for this period amounted to EUR 10,088.6 million, which is a decrease of EUR 1953.3 million (15.3 %) compared to the same quarter in 2022 (EUR 12,761.9 million).

In the face of the challenges of war, Ukrainian farmers showed a high degree of resilience. They continued to produce agricultural products, even in the occupied territories and "wounded" fields. In 2022, there was a significant decline in harvests of crops traditionally grown in Ukraine (Table 1). This decrease in harvest in 2022 is caused by two main factors. The first is a reduction in harvested area due to various reasons such as occupation, damage, mining, and inability to work. The second is a reduction in yields due to non-compliance with production technology. For example, due to the forced migration of large numbers of people, rising input prices, and low liquidity of agricultural producers, fertilisers and pesticides were reduced. In 2023, there was a slight increase in crop production compared to 2022, but the agricultural sector did not return to pre-war levels.

Table 1

Dynamics of areas, yields, and harvests of major crops in Ukraine in 2021–2023

Crop	Area, million hectares			Yield, tons/hectare			Harvested, million tons		
	2021	2022	2023	2021	2022	2023	2021	2022	2023
Wheat	7.1	5.0	4.7	4.53	4.05	4.79	33.0	20.2	22.0
Barley	2.5	1.7	1.5	3.82	3.47	3.93	10.1	5.8	5.8
Peas	0.2	0.1	0.2	2.36	2.28	2.59	0.6	0.3	0.4
Corn for grain	5.5	3.6	3.6	7.68	6.57	7.81	37.6	27.3	29.6
Buckwheat	0.1	0.1	0.1	1.15	1.37	1.48	0.1	0.2	0.2
Millet	0.1	0.0	0.1	2.35	2.28	2.28	0.2	0.1	0.2
Sunflower	6.6	4.8	5.0	2.46	2.17	2.39	16.9	11.1	14.2
Soya	1.3	1.5	1.8	2.64	2.43	2.65	3.5	3.7	4.9
Rapeseed	1.0	1.1	1.4	2.93	2.86	2.87	2.9	3.2	4.5
Sugar beet	0.2	0.2	0.2	47.91	50.10	47.70	10.9	9.0	0.9

Source: created using data of the MAPF (2023); State Statistics Service… (2022a).

Agricultural output experienced a significant decline during the war (Figure 7), with cereal production decreasing by 29.0 %, oilseeds by 9.0 %, and sugar beet by a relatively moderate 9.0 %. Furthermore, the livestock sector encountered reductions, with a 9.0 % decrease in meat production, a 14.0 % decline in milk output, and a 22.0 % decrease in egg production (UCAB, 2023).

The trajectory of agricultural exports during the war showed significant fluctuations across different commodities, particularly influenced by the impact of the Grain Initiative from July 2022 to July 2023. Following the expiration of the agreement, Ukrainian farmers shifted their operations to the Danube ports, resulting in a significant increase in exports to 7 million tons by December 2023. Despite the challenges, physical exports of agricultural products increased in 2023 (Figure 8).

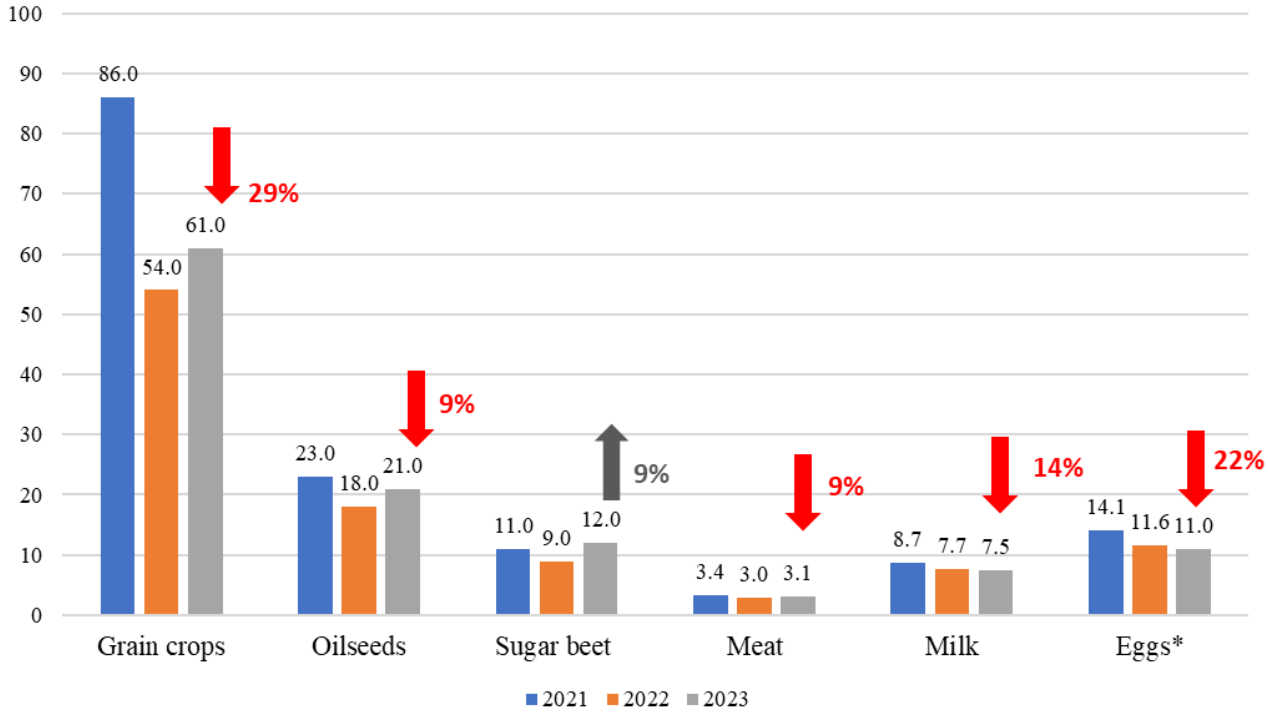
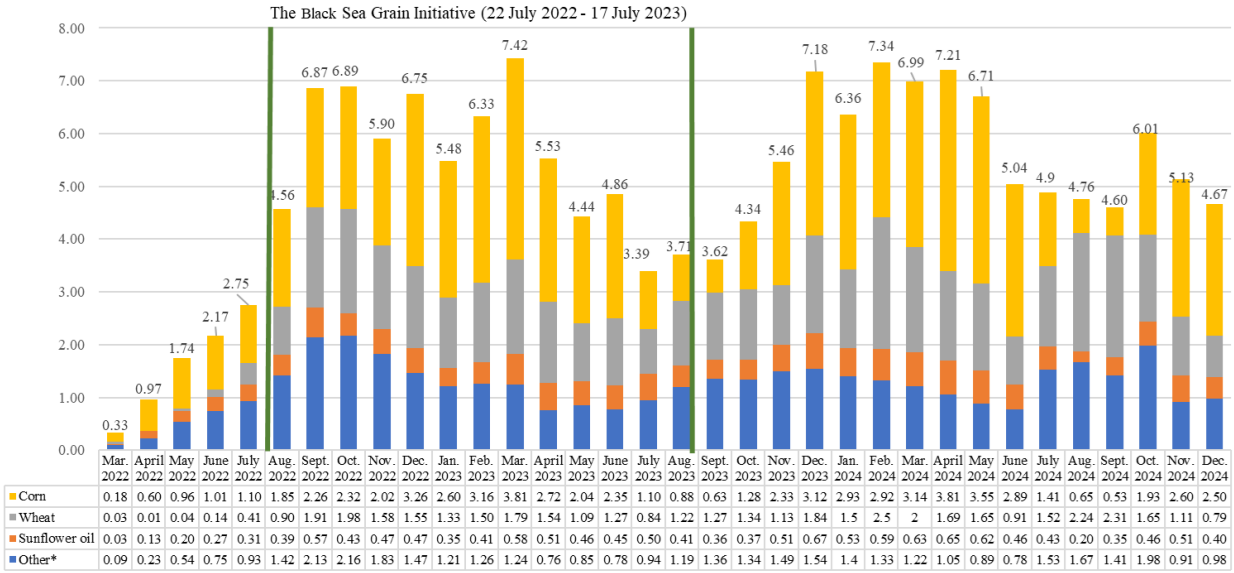


Figure 7. Dynamics of agricultural production in Ukraine in 2021–2023, million tons

Note. * Billion pcs.
Source: created using data of the UCAB (2023).



	Mar. 2022	April 2022	May 2022	June 2022	July 2022	Aug. 2022	Sept. 2022	Oct. 2022	Nov. 2022	Dec. 2022	Jan. 2023	Feb. 2023	Mar. 2023	April 2023	May 2023	June 2023	July 2023	Aug. 2023	Sept. 2023	Oct. 2023	Nov. 2023	Dec. 2023	Jan. 2024	Feb. 2024	Mar. 2024	April 2024	May 2024	June 2024	July 2024	Aug. 2024	Sept. 2024	Oct. 2024	Nov. 2024	Dec. 2024
Corn	0.18	0.60	0.96	1.01	1.10	1.85	2.26	2.32	2.02	3.26	2.60	3.16	3.81	2.72	2.04	2.35	1.10	0.88	0.63	1.28	2.33	3.12	2.93	2.92	3.14	3.81	3.55	2.89	1.41	0.65	0.53	1.93	2.60	2.50
Wheat	0.03	0.01	0.04	0.14	0.41	0.90	1.91	1.98	1.58	1.55	1.33	1.50	1.79	1.54	1.09	1.27	0.84	1.22	1.27	1.34	1.13	1.84	1.5	2.5	2	1.69	1.65	0.91	1.52	2.24	2.31	1.65	1.11	0.79
Sunflower oil	0.03	0.13	0.20	0.27	0.31	0.39	0.57	0.43	0.47	0.47	0.35	0.41	0.58	0.51	0.46	0.45	0.50	0.41	0.36	0.37	0.51	0.67	0.53	0.59	0.63	0.65	0.62	0.46	0.43	0.20	0.35	0.46	0.51	0.40
Other*	0.09	0.23	0.54	0.75	0.93	1.42	2.13	2.16	1.83	1.47	1.21	1.26	1.24	0.76	0.85	0.78	0.94	1.19	1.36	1.34	1.49	1.54	1.4	1.33	1.22	1.05	0.89	0.78	1.53	1.67	1.41	1.98	0.91	0.98

Figure 8. Ukraine's agricultural exports during wartime in 2022–2024, million tons

Note. * Oil-cake, rapeseed, soybeans, barley, sunflower seeds, sunflower seeds.
Source: created using data of the UGA (2024a).

On the other hand, export revenues amounted to USD 21.9 billion in 2023, a decrease of 8.0 % compared to 2022, mainly due to lower prices compared to the

previous year, which was characterised by the unprecedented global food prices in 2022. The export levels observed in 2022–2023 proved insufficient to cover the entire harvest period, thus increasing the risk of significant carryover stocks, particularly in the cereals sector. This financial predicament for Ukrainian farmers was exacerbated by depressed local market prices and the financial burden associated with export logistics. As a result, it became imperative to systematically explore all available options to increase export volumes and ensure that the entire harvest was fully exported before the start of the next season.

An analysis of the changes in the structure of agricultural export channels during the war (Figure 9) reveals a significant variation in exports through the Black Sea and Danube ports.

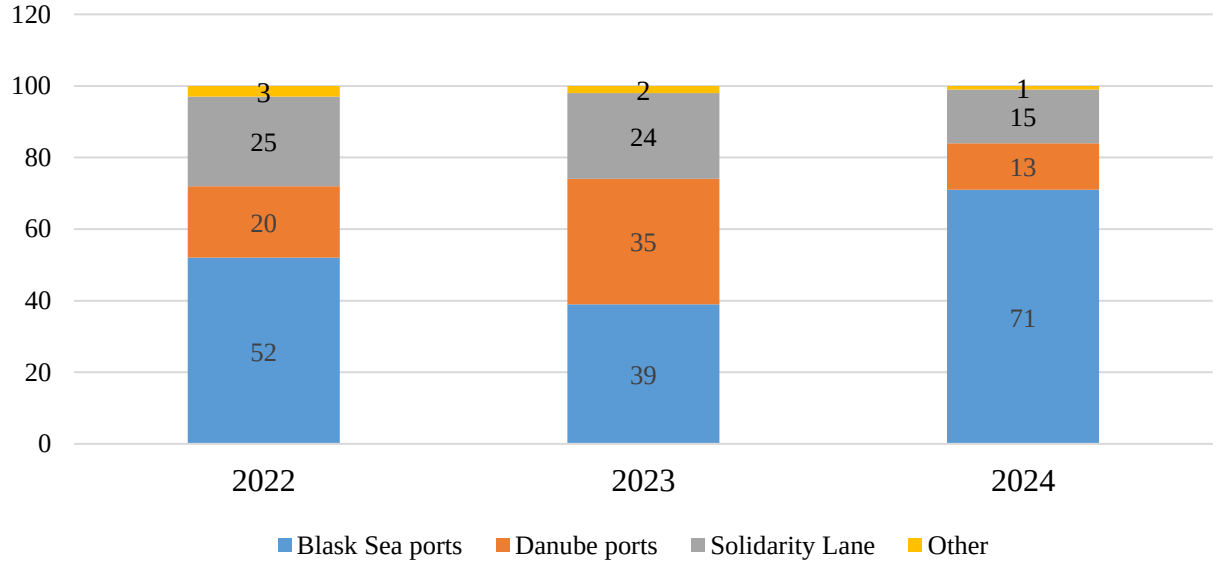


Figure 9. Logistics channels of Ukrainian agricultural exports in 2022–2024

Source: created using data of the UGA (2024a).

According to the Ministry of Agrarian Policy and Food of Ukraine, there are a reduction in the area devoted to maize and sunflower in 2024. To compensate for this, the agricultural sector increased the area under rape, soya, spring barley and wheat. These projections are based on a survey conducted by the Ministry of Agrarian Policy and Food of Ukraine, which assessed agricultural producers' plans and preparations for the 2024 spring sowing campaign (MAPF, 2024a).

In 2024, the Ukrainian farming community harvested approximately 54.7 million tons of various grains, which constitutes a decline of 8.5 % in comparison with 2023. This includes approximately 21.8 million tons of wheat, indicating a decrease of 2.0 % from the previous year, along with 25.8 million tons of corn, representing a decline of 19.4 %, and 5.3 million tons of barley, which showed an increase of 0.7 % (Figure 10).

According to the Ukrainian Grain Association, the barley harvest in 2024 was estimated at 5.6 million tons, with potential exports in the 2024/2025 marketing year projected at around 2 million tons (UGA, 2024b). However, expectations for the corn harvest were not met, as the decline resulted from a reduction in acreage. The harvest dropped to 18.3 million tons, compared to 29.6 million tons in the previous season.

Farmers also suffered losses due to low corn purchase prices, which were influenced by a decline in global prices. The sunflower harvest in 2024 totalled only 9.6 million tons, down from 14.2 million tons in 2023, with potential exports reaching up to 250 thousand tons. The rapeseed harvest in 2024 amounted to 3.5 million tons, slightly lower than the 4.3 million tons harvested in 2023. Meanwhile, soybeans were among the crops for which farmers had increased their acreage that year due to higher profitability. The soybean harvest in 2024 reached 5.7 million tons, up from 4.9 million tons in 2023, with potential exports in the 2024/2025 marketing year estimated at 4 million tons compared to 3.3 million tons in the previous season.

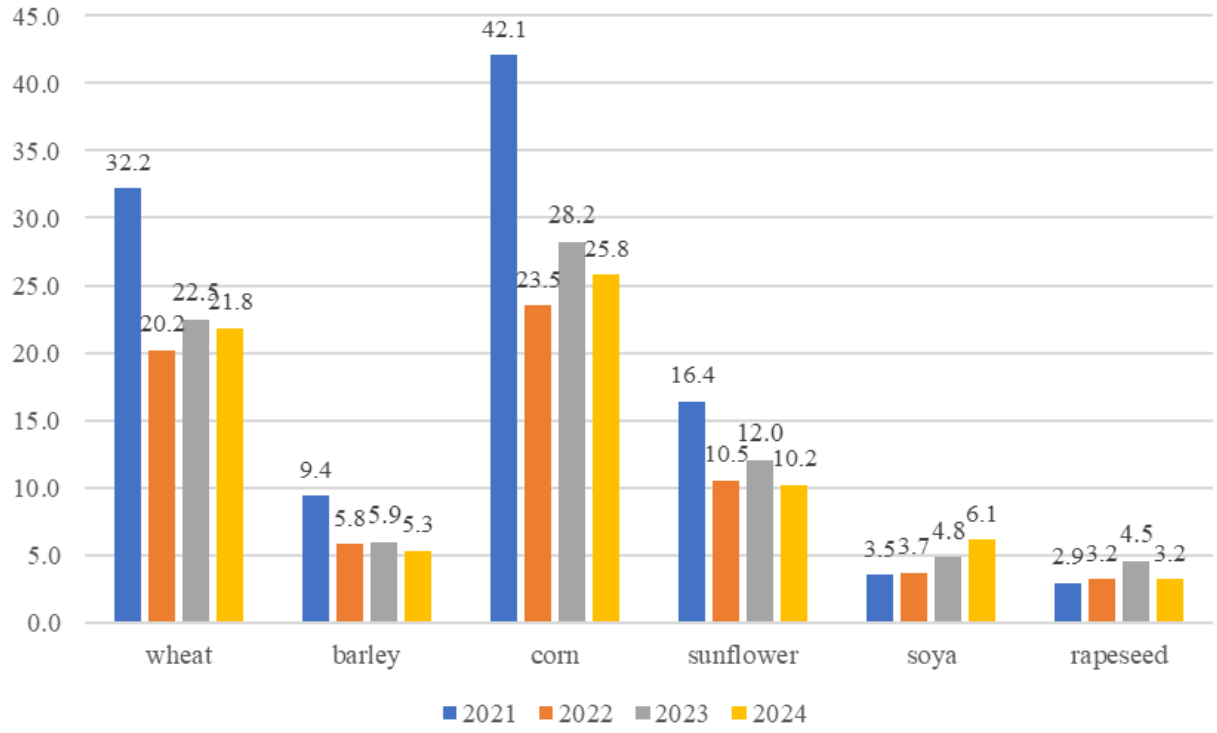


Figure 10. Grain and oilseeds harvest in 2021–2024, million tons

Source: created using data of the MAPF (2024a; 2024b); UGA (2024b); State Statistics Service… (2022a).

According to the National Scientific Centre "Institute of Agrarian Economics", oilseeds were the most profitable crops in 2024 (AgroPortal, 2025). Rapeseed, in particular, had a profitability rate of up to 60.0 %, soybeans up to 40.0 %, and sunflower up to 30.0 %. This was largely driven by a significant increase in prices for these crops. For example, the price of sunflower rose by nearly 158.0 % from January to October. Compared to 2023, the considerable improvement in profitability was attributed to the resumption of export activity and lower logistics costs. Regarding grain crops, the profitability of wheat increased to 17.0 %, and barley to 25.0 % compared to 2023. However, corn, due to a significant yield decline of nearly 18.0 %, saw its profitability cut in half to just 11.0 % (AgroPortal, 2025).

The main factors contributing to the increase in profitability compared to previous periods are the establishment of a dedicated export sea route, higher prices for cereals and oilseeds despite the fall in world prices, and lower logistics costs.

A significant decline in agricultural profitability has led to farmers' lower incomes and wages for millions of Ukrainians employed in the agricultural sector. As a result, a 20.0 % reduction in cultivated area and a 10.0 % reduction in livestock is projected to lead to an 18.0 % reduction in direct employment in the sector. This will affect the food security and livelihoods of some 3.4 million people. The indirect impact is even more significant, as the decline in agricultural profitability reduces the demand for labour and further lowers the wages of agricultural workers (OCHA, 2024).

In the pursuit of sustaining agricultural production and exports, the Ukrainian government initiated several policy measures, including the establishment of financial aid programs, the provision of tax exemptions, the streamlining of trade regulations, and the exploration of alternative logistics routes. In addition, international partners contributed substantial aid, encompassing demining activities, the rehabilitation of infrastructure, and the liberalisation of trade. While these measures have contributed to the alleviation of certain challenges, funding gaps and logistical constraints persist, underscoring the necessity for sustained international support to facilitate long-term recovery.

4.4. Clustering approach for analysing war impact on Ukrainian regions. The clustering analysis was conducted using a dataset comprising multiple variables related to agricultural production, war exposure, and economic damages. The key indicators used for clustering included:

- sown areas of agricultural crops (2021 and 2023) to measure agricultural continuity;
- land exposed to war (%), indicating direct war impact;
- estimated cost for humanitarian mine action, representing the extent of demining needs;
- suspected contaminated area (km²) as an indicator of land usability post-war;
- housing and infrastructure damage (USD million) was used as a measure of economic losses, and commerce and industry losses (USD million) were used to reflect the overall economic disruption.

Each region was represented as a data point with these variables, and the dataset was normalised to ensure uniformity in scale before applying K-means clustering.

The K-means clustering method was selected for its capacity to organise data into meaningful groups based on similarities across multiple dimensions. The process involved the following steps. Initially, the optimal number of clusters (K) was determined using the Elbow Method. This method indicated that four clusters provided an optimal balance between intra-cluster similarity and inter-cluster distinction. Then, the initial cluster centroids were assigned randomly, and the process was iterated until convergence. Finally, the Euclidean distances between each region and the centroids were calculated to group similar regions together. The centroids were then updated iteratively until minimal variation in cluster assignments was observed.

The analysis resulted in the identification of four distinct clusters, each characterised by specific attributes (Table 2). To assess the statistical reliability of the clustering results, three commonly used validity indices were calculated: the Silhouette

coefficient (0.367), the Davies-Bouldin index (0.776), and the Calinski-Harabasz index (15.85). Together, these metrics confirm the statistical reliability and internal consistency of the clustering structure used in the study.

Table 2

Clustering results of Ukrainian regions based on war exposure, agricultural activity, and economic losses

Cluster characteristics	Cluster numbers			
	1	2	3	4
Regions included	Cherkaska, Chernihivska, Dnipropetrovska, Khmelnytska, Kirovohradska, Mykolaivska, Odeska, Poltavska, Sumska, Vinnytska, Zhytomyrska	Donetska, Kharkivska, Khersonska, Luhanska, Zaporizka	Chernivetska, Ivano-Frankivska, Lvivska, Rivnenska, Ternopilska, Volynska, Zakarpatska	Kyivska
War exposure, %	16	76	0	37
Suspected contaminated area, km²	3,803	21,046	0	8,817
Agricultural land, thsd ha, 2021	1,520	1,391	527	1,220
Agricultural land, thsd ha, 2023	1,445	498	525	1,180
Agricultural activity	Slight decline but remains functional	Drastic decline due to occupation and destruction	Stable with minimal disruptions	Relatively stable but faces logistical challenges
Economic losses, USD billion	6.4	12.4	1.6	87.0
Transport damage, USD billion	2.3	7.3	0.9	15.1
Commerce & industry losses, USD billion	6.4	12.4	1.6	87.0
Recovery needs	Financial aid, logistical support, farmer subsidies	Urgent demining, infrastructure rebuilding, extensive recovery aid	Policies ensuring continued stability and integration into broader economic frameworks	Targeted economic revitalisation, infrastructure investment, financial recovery measures

Source: authors' elaboration based on the State Statistics Service... (2022b) and RDNA4 (2025) data.

Cluster 1 includes 11 moderately affected regions with about 16.0 % war exposure, where agricultural activity has declined slightly but remains functional. Economic losses are significant but not devastating. Rehabilitation priorities for this group include financial assistance, logistical support and targeted subsidies to stabilise agricultural activities.

Cluster 2 includes Donetska, Kharkivska, Khersonska, Luhanska and Zaporizka oblasts – the regions most affected by the war, with approximately 76.0 % of the area

affected. These areas suffered widespread destruction of infrastructure and farmland, resulting in a sharp decline in agricultural production. Recovery here requires urgent demining, large-scale land reclamation and major infrastructure reconstruction, supported by substantial financial and humanitarian assistance.

Cluster 3 consists of 7 western regions that were largely unaffected by war. Their agricultural systems continue to function normally and economic damage is minimal. Efforts in these regions should focus on maintaining resilience, increasing productivity and further integrating into national and international supply chains to support wider recovery.

Cluster 4 includes only Kyivska oblast, which represents a special case. Despite moderate war exposure (37.0 %), it has suffered disproportionately high economic losses due to damage to critical infrastructure and business sectors. While agricultural production remains relatively stable, the region faces serious logistical obstacles. Recovery efforts should focus on infrastructure rehabilitation, economic revitalisation and financial support to affected businesses and agricultural workers.

4.5. Challenges and recovery strategies for Ukraine's post-war agricultural sector. Despite the prevailing uncertainty, the war has highlighted the resilience, unity and ingenuity of Ukraine's agricultural sector. This underscores its remarkable resilience and ability to persevere and adapt in the face of difficult circumstances.

In light of the substantial damage and losses incurred by agricultural producers in Ukraine, the restoration of the sector's potential necessitates considerable resources. In terms of categorisation, these needs can be divided into two distinct groups: reconstruction needs and restoration need. The reconstruction needs should encompass the replacement of destroyed and damaged assets, while the recovery needs should address the challenges faced by the agricultural sector, including increasing resilience, producing value-added products, and facilitating EU accession processes.

The total recovery and reconstruction needs in the public sector are estimated at USD 56.3 billion over 10 years (Table 3), including USD 435 million in 2024.

Table 3

Total recovery and reconstruction need (USD million) as of December 31, 2024

Category	Type of activities/investments	Total needs (2025–2035)
Reconstruction needs	Support for reconstruction	10,470.6
Recovery needs	Support for immediate agriculture production recovery	6,142.0
	Support for sustainable recovery of agriculture	35,821.0
	Support for agricultural public institutions and programs	3,020.0
Total needs met		872.8
Total		56,326.4

Source: RDNA4 (2025).

In order to ensure the recovery of the agricultural sector, stimulate overall economic recovery, serve as a reliable source of income for farmers, and provide food for the Ukrainian population, several key investments must be made. These include addressing liquidity constraints, investing in resilience to disasters and climate change,

developing integrated food-energy systems, and strengthening public agricultural institutions to effectively support recovery, reconstruction and EU accession. The near doubling of total recovery and reconstruction needs between RDNA2 and RDNA3 – an increase of 89.0 % – reflects the increase in total damage and losses over the same period.

The main focus of recovery and reconstruction in 2024, taking into account the implementation and absorption capacity of the government, includes the following measures (RDNA4, 2025):

- providing direct support to farmers through public programmes that have been successful in previous years. This support combines grants and inputs for small farms, interest subsidies for agricultural production loans and matching investment grants for horticultural production;

- mine clearance.

Donors have already pledged to allocate USD 488 million – 112 % of the amount needed for 2024 – for the recovery of Ukrainian agriculture (Table 4).

Table 4

Actual donor support, USD million

Types of activities/investments	2023	2024	2025	Total
Support for immediate agriculture production recovery	273.8	448.2	134.9	856.9
Interest rate compensation (5-7-9 credit program)	180.0	250.0	70.0	500.0
Partial credit guarantee for agriculture	21.8	6.8	0.8	29.4
Additional liquidity for agricultural financing	3.5	3.5	3.5	10.5
Grants for production by small farms	-	173.2	50.0	223.2
Inputs and cash transfers for small farms	51.6	11.2	8.3	71.1
Storage bags and other storage equipment distributed to farms	2.3	2.3	2.3	7.0
Procurement of equipment	14.5	1.2	-	15.7
Support for longer-term recovery of the agriculture sector	46.7	21.9	15.8	76.0
Development of storage infrastructure	4.7	4.7	14.7	44.0
Investment grants for value chains	3.2	6.4	6.0	15.6
Investment grants for horticulture	30.0	2.0	2.0	34.0
Support for water use associations and restoration of irrigation systems	10.7	10.7	5.0	26.4
Financing of medium to long-term investments	2.8	2.8	2.8	8.4
Support for agricultural public institutions, including for acceleration	22.1	18.3	14.2	39.5
Support for MAPF (including State Agrarian Registry maintenance)	3.2	4.3	3.3	10.8
Support for food safety	2.1	1.2	1.2	4.5
Support for agricultural research and education institutions	5.2	5.2	4.7	15.1
Support for policy dialogue and strengthening of the technical capacity of Ukrainian institutions	11.6	7.6	5.1	24.2
Total	342.6	488.3	164.9	972.4

Source: RDNA3 (2024).

In the short term, several critical measures require urgent attention, including ensuring the availability of resources, improving logistical efficiency and expanding

access to global markets. Post-war agricultural recovery is a complex and multifaceted process that requires clear short- and long-term strategies and coordinated efforts. The stages of this process are outlined below:

1. Immediate response (6 months):

1.1. The initial phase of the response will be focused on assessing the damage and securing the necessary funding to facilitate the restoration process. This will entail a comprehensive assessment of crop losses, soil degradation, and damage to agricultural infrastructure and equipment. The objective is to obtain financial assistance from international donors, development banks, and government agencies to support the rapid recovery efforts. To this end, an emergency response task force will be established to coordinate aid distribution and recovery operations.

1.2. Demining agricultural land. In collaboration with international organisations, a strategy will be implemented to deploy demining experts and specialised equipment for the clearance of farmland. Conduct large-scale awareness campaigns to educate local farmers and rural populations about mine risks and safe zones.

1.3. Providing emergency support to farmers. Distributing essential humanitarian aid, including food, medical supplies, and temporary shelter for displaced farming communities. Providing agricultural inputs such as seeds, fertilisers, pesticides, and fuel to kick-start production in unaffected areas. Establishing emergency credit lines for small and medium-sized farms to stabilise operations.

2. Short-term measures (6 months – 2 years):

2.1. Restoration of agricultural infrastructure. The following measures should be given priority:

- roads, railways, and bridges should be repaired and rebuilt in order to restore supply chains;
- irrigation and drainage systems should be reconstructed and modernised to enhance water efficiency and prevent soil degradation;
- grain storage facilities and silos should be rebuilt to secure harvests and prevent post-harvest losses.

2.2. Upgrading agricultural equipment and inputs. The provision of financial assistance, in the form of grants or low-interest loans, is to be made for the purpose of purchasing modern farming equipment. To improve access to advanced technology, partnerships are to be established with international agricultural machinery manufacturers. To reduce reliance on imports, encouragement is to be given to the domestic production of fertilisers, pesticides and agricultural machinery.

2.3. Market access and trade expansion. The diversification of export destinations is to be encouraged, with the aim of reducing dependency on traditional markets. This is to be achieved by the development of new trade agreements. The strengthening of branding and marketing initiatives is to enhance the global competitiveness of Ukrainian agricultural products. The improvement of customs procedures and logistics is also called for to streamline agricultural exports.

3. Medium-term strategies (2–5 years):

3.1. Investing in innovation and modernisation. The promotion of precision

agriculture should be facilitated by the implementation of digital technologies such as sensors, AI, and drones for the purpose of efficient farm management. The expansion of automation in farming processes, incorporating smart irrigation and robotic harvesting systems, is also recommended. Furthermore, the development of agri-tech start-ups and research initiatives should be fostered to drive innovation.

3.2. Education and workforce development. The establishment of agricultural training centres is imperative to provide farmers with the necessary skills and knowledge to use modern techniques and sustainable practices. The provision of scholarships, internship programmes, and financial incentives is recommended to attract young professionals into the agricultural sector. The promotion of knowledge exchange and collaboration with EU agricultural institutions is advised to align with best practices.

3.3. Enhancing environmental sustainability. The promotion of regenerative agriculture and organic farming is recommended to improve soil health and reduce chemical dependency. The implementation of national afforestation programmes and water conservation initiatives is advised to counteract the impacts of climate change. The development of carbon credit programs is recommended to incentivise farmers to adopt sustainable farming practices.

3.4. Developing agricultural insurance and risk management systems. The establishment of state-backed agricultural insurance programmes is imperative to safeguard farmers against prospective risks. The development of early-warning systems for climate-related disasters and pest outbreaks is crucial. The reinforcement of financial mechanisms, such as hedging strategies and forward contracts, is essential to stabilise commodity prices.

4. Long-term vision (5+ years):

4.1. Strengthening cooperative models and rural development. The establishment of farmer cooperatives should be encouraged to facilitate shared access to machinery, storage, and market opportunities. Furthermore, the expansion of government programmes to support cooperative growth and financial stability is recommended. The improvement of living conditions in rural areas can be achieved through the development of schools, hospitals, and housing infrastructure.

4.2. Developing a national agricultural strategy. The alignment of Ukraine's agricultural policies with the European Common Agricultural Policy is imperative to ensure seamless integration into the EU market. The implementation of long-term climate adaptation plans, encompassing the development of drought-resistant crop varieties and water management strategies, is crucial for ensuring food security in the face of climate change. The strengthening of land tenure security and the regulation of the land market are pivotal in attracting foreign investment in the agricultural sector.

4.3. Boosting agro-processing and value-added production. The investment in food processing infrastructure is proposed as a means of effecting a shift from the export of raw commodities to the export of value-added agricultural products. The development of domestic agro-industrial zones is suggested as a means of increasing the local production of food, beverages, and biofuels. The encouragement of foreign

direct investment in agro-processing is proposed as a means of enhancing competitiveness.

4.4. Improving digital infrastructure and connectivity. The expansion of broadband internet access in rural areas is imperative for the support of smart farming and e-commerce for agricultural products. The promotion of digital marketplaces and e-trading platforms is necessary for the establishment of direct connections between farmers and buyers. The enhancement of data-driven decision-making through the integration of big data analytics into agricultural planning is essential for the optimisation of resource utilisation and the enhancement of agricultural efficiency.

Ukraine's post-war agricultural recovery plans cover a number of key areas and strategies aimed at ensuring sustainable development and increasing the efficiency of agricultural production. The main aspects of these areas are illustrated in Figure 11.

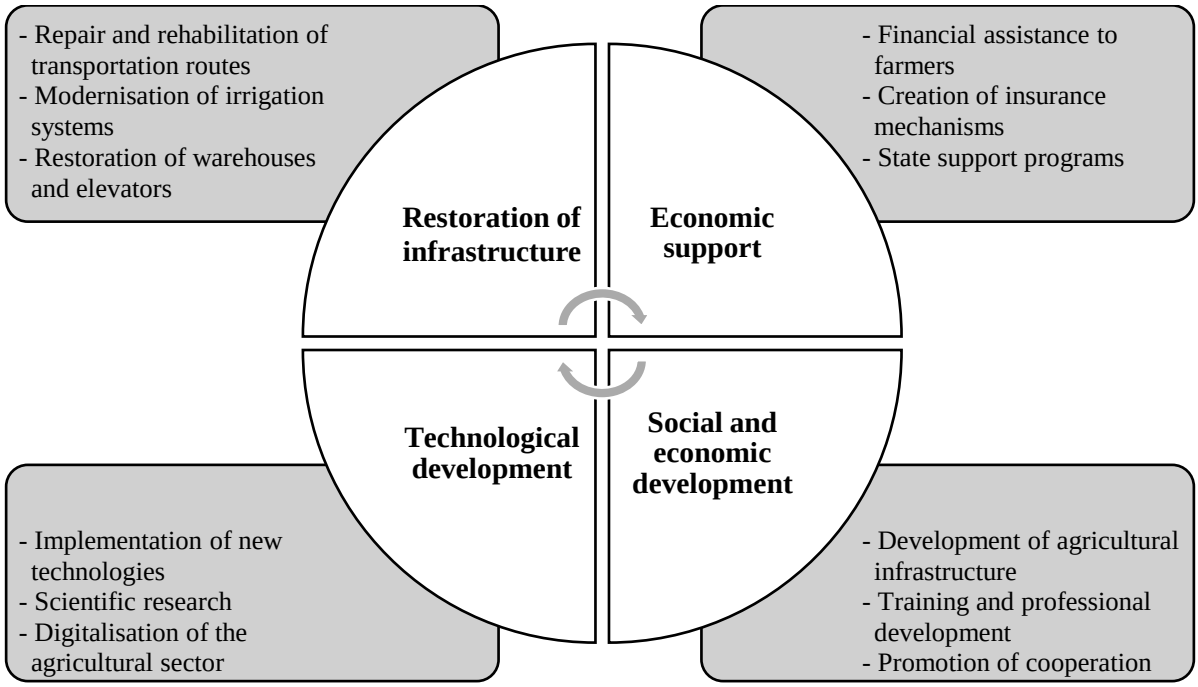


Figure 11. Directions for the recovery of Ukraine's agricultural sector after the war

Source: authors' development.

The successful implementation of these recovery plans necessitates a holistic strategy that engages multiple stakeholders, including government authorities, private enterprises, international organisations, and local communities. A concerted effort among these actors will expedite the agricultural sector's rehabilitation and encourage its long-term viability.

The key drivers of post-war growth include the following elements:

- human capital: this includes attracting and recruiting new workers by creating favourable conditions for their participation in agriculture. Supporting agricultural education and scientific research is also crucial;

- strengthening small and medium-sized enterprises (SMEs): SMEs are essential for ensuring Ukraine's food security, supporting regional supply chains, promoting rural development and preserving biodiversity;

- agricultural integration with the European Union: given Ukraine's candidacy for EU membership, there are significant opportunities to expand trade relations and enhance economic cooperation;

- prioritising environmental and sustainable development: Ukraine's agricultural sector has considerable potential for the establishment of organic farms and the production of organic products. Proactive adaptation to climate change is essential;

- support research, innovation and technological development: digitalisation is emerging as a critical factor in the sector's growth trajectory. Leveraging Ukraine's well-developed IT sector can facilitate collaboration between the IT industry and agriculture, fostering innovation and technological advancement.

In analysing the challenges and opportunities facing Ukraine's agricultural sector, it is imperative to adopt a multifaceted approach that prioritises both the immediate recovery of key infrastructure and the establishment of long-term development goals. A pivotal aspect of this strategy pertains to the restoration of grain storage facilities, irrigation systems, and transport networks, with the objective of enhancing logistics and production efficiency. Additionally, large-scale demining and land rehabilitation initiatives are deemed essential, as these measures will facilitate the safe return of farmers to cultivated areas, thereby contributing to the restoration of agricultural output.

Technological modernisation will play a pivotal role in strengthening the sector, with an increased focus on precision agriculture, digitalisation, and smart farming solutions to optimise productivity and resource management. Expanding market access beyond traditional partners is also essential, with efforts directed at strengthening trade relationships with the European Union and diversifying exports to new global markets. Ensuring the resilience of small and medium-sized farms is another priority, as these producers are vital to the sector's recovery. To this end, measures must be taken to facilitate access to affordable credit, specialised training, and cooperative networks, thereby enhancing the competitiveness of these enterprises in an evolving agricultural landscape. Finally, it is imperative to integrate sustainability and climate adaptation into recovery strategies to ensure the sector's future viability. This can be achieved through the promotion of organic farming, the introduction of carbon credit programmes, and the implementation of sustainable land management practices, which will enhance environmental resilience and long-term productivity. These strategic measures, when implemented, will enable Ukraine to rebuild a modern, globally competitive, and environmentally sustainable agricultural system, positioning it as a key player in international markets.

5. DISCUSSION

This study offers a detailed examination of how the RUW has influenced Ukraine's agricultural sector, while also considering its implications within the broader global agricultural and economic landscape. Key findings include the profound disruptions caused by the war, policy responses to mitigate these challenges, and strategies for post-war recovery.

The RUW has had a considerable impact on Ukraine's agricultural sector, accentuating pre-existing vulnerabilities and introducing new challenges. The immediate economic ramifications encompass substantial infrastructure damage, soil contamination, livestock losses and a decline in cultivated land. These issues are further compounded by disruptions to supply chains, export restrictions and escalating production costs. The disruptions to Ukraine's grain export routes and the broader implications for global food security, as highlighted by Teixeira da Silva et al. (2023), Balmann (2024), and Nehrey & Finger (2024), underscore the need for a comprehensive analysis of the impact of RUW on agriculture. Our findings align with global analyses of war-impacted economies, which often highlight agriculture's disproportionate vulnerability due to its reliance on stable infrastructure and governance.

Antonenko et al. (2024) conducted a study on the impact of the war on wheat biomass, providing critical insights into the degradation of Ukraine's agricultural productivity due to the war. Their findings further reinforce the significant losses in yield potential, aligning with our results on declining cultivated land and disrupted supply chains. Our findings on the challenges of post-war agricultural recovery complements the work by Nasibov et al. (2024), who examine how the war affected Ukrainian fields, particularly in terms of soil contamination and land usability.

Davydenko et al. (2022) conducted a comparative analysis of the Ukrainian taxation system with regard to European practices, emphasising the challenges and opportunities inherent in the integration of sustainability-driven fiscal policies into national economic structures. Their findings suggest that aligning Ukraine's environmental taxation with EU standards could improve financial sustainability and foster environmentally friendly agricultural practices (Davydenko et al., 2022). In response to the prevailing challenges, Ukraine's government has initiated a series of crucial measures, including tax reductions, export diversification, and subsidies, with the aim of mitigating the immediate disruptions. While these measures were undoubtedly effective in the short term, they also underscored the fiscal strain and the need for long-term solutions. These solutions included demining, rebuilding infrastructure, and aligning with EU standards for market access. The emphasis on policy responses is in alignment with the findings of Litvinov et al. (2024), which highlights labour shortages and regional disparities in agricultural operations. The importance of international cooperation and financial assistance is emphasised by both studies. However, the present study goes beyond these previous analyses by exploring innovations such as digitalisation and the potential of the IT sector to modernise agriculture.

The full-scale RUW has led to increased interconnectedness between energy and agricultural markets. Vo & Tran (2024) emphasise how uncertainty resulting from the war amplifies volatility spillovers between these markets, highlighting the global systemic risks of geopolitical instability. While the study referenced adopts a financial market perspective, the present analysis centres on the local impacts of these disruptions on Ukrainian agriculture. The findings of both studies underscore the

necessity for the implementation of coordinated global and domestic policies to stabilise markets and enhance resilience.

In their study, Zelisko et al. (2024) explore the potential of digitalisation, artificial intelligence (AI), and economic security to enhance agricultural business processes in Ukraine. Our findings on the necessity of technology-driven recovery strategies, underlining the importance of digitalisation as a pivotal factor in fostering resilience, are consistent with their research. This viewpoint is of particular significance, as digital solutions have the capacity to address labour shortages, optimise resource allocation, and enhance overall agricultural efficiency.

Shkuropadska et al. (2024) provide a complementary perspective through their quantitative assessment of Ukraine's food resilience, which they rate as "sufficient" despite wartime challenges. Our qualitative insights into infrastructural robustness, production resilience, and policy adaptation are consistent with their findings. The importance of integrated recovery strategies that address immediate needs and lay the foundation for long-term sustainability is emphasised by both studies.

The results of the clustering analysis indicate the requirement for a range of policy approaches that are adapted to the specific needs of each region. Regions within Cluster 1 require financial assistance, logistical support, and farmer subsidies in order to maintain agricultural output at satisfactory levels. Cluster 2 demands urgent humanitarian intervention, extensive land restoration, and large-scale infrastructure reconstruction in order to address the immediate challenges posed by the situation. Cluster 3 should focus on maintaining agricultural stability and leveraging its production capacity for national and international markets, whilst Cluster 4 requires targeted economic recovery initiatives, business revitalisation programs, and strategic financial support to rebuild key economic sectors.

Our clustering results complement and develop previous research conducted using econometric methods. In particular, Zomchak & Starchevska (2022) applied a logistic regression model to analyse the macroeconomic determinants of Ukraine's economic growth, thus providing further context regarding the economic environment within which agricultural disruptions were occurring. Additionally, Zomchak (2023) used a structural econometric model to examine sustainable development in Ukraine, which served to reinforce the argument that agricultural recovery must be embedded within a broader framework of social, economic and environmental sustainability.

The proposed recovery framework prioritises investments in innovation, digitalisation, and sustainable practices, aligning with global trends and the need for resilience in the face of climate change and market fluctuations. The recovery process is further influenced by the emergence of small and medium-sized enterprises and organic farming, which are identified as critical drivers of recovery. These findings reflect the growing global emphasis on inclusive and environmentally sustainable agricultural practices.

The financial resilience of Ukraine's agricultural sector is closely linked to regional economic potential and resource distribution. Davydenko et al. (2020) assess key financial components across different regions, identifying disparities that influence

agricultural investment and productivity. The findings of this research highlight the necessity for targeted financial interventions to enhance the resilience of regional agricultural economies (Davydenko et al., 2020). The consequences of the full-scale RUW for Ukraine's agricultural sector are such that they extend beyond national borders, influencing global food security. As a major global exporter of grain, any interruption in Ukraine's agricultural output has profound ramifications for international markets. This study, in conjunction with the findings of Teixeira da Silva et al. (2023), underscores the pivotal role of international collaboration and the implementation of robust policy measures in mitigating the war's deleterious effects on the agricultural sector and global food supply chains.

6. CONCLUSIONS

The full-scale Russian-Ukrainian war has resulted in considerable losses in the agricultural sector, thereby exerting a substantial impact on global food security. This study, which analyses the period from 24 February 2022 to the end of 2024, assesses the agricultural damages caused by the Russian invasion. The principal challenges arising from the war have been identified as shortages of essential resources, disruptions to supply chains resulting from port blockades, destruction of grain stocks, soil contamination, and a decline in local market activity. To support the agricultural industry, the Ukrainian government has introduced a range of initiatives, including special state programs offering low-interest loans, assistance for processing enterprises, incentives for horticultural development, and investments in greenhouse farming. In addition, alternative export logistics routes have been established in response to port closures, and tax exemptions have been implemented, along with modifications to land payment policies for state and municipal-owned properties during martial law. International organisations, foreign governments, and private sector stakeholders have directed their assistance towards addressing direct war-related damages to Ukraine's agricultural sector. As of December 2023, losses were estimated to exceed USD 10.3 billion. Key recovery efforts have focused on demining agricultural land, supplying seeds, and funding the restoration and expansion of production facilities.

K-means clustering was a valuable analytical tool in differentiating the impacts of war on Ukraine's agricultural sector. The identification of four distinct clusters enabled more precise and effective policy responses, tailored to each region's specific challenges and recovery needs.

Immediate action is needed to ensure the availability of resources, improve the efficiency of logistics and expand access to global markets. Post-war government priorities should shift towards human capital, smallholder empowerment, global market integration, sustainable practices and technological advancement, which will require supportive policies.

Despite the substantial scale of Ukraine's agricultural sector, many parts of it remain underdeveloped due to a predominant focus on the export of low-value-added raw agricultural commodities. The integration of Ukraine into the EU single market

and alignment with EU legislation are critical prerequisites for enhancing the resilience and investment attractiveness of these sectors. Such integration would foster greater sustainability and value-added production within Ukrainian agriculture, reducing its reliance on export-oriented monocultures. Moreover, the economic advantages of EU accession could serve as a pivotal mechanism for financing the restoration and modernisation of Ukraine's agricultural sector.

This study contributes to addressing fundamental research questions by assessing the direct and indirect consequences of the war on Ukraine's agriculture, the effectiveness of government and international responses, the main obstacles to recovery, and the necessary strategies for long-term sustainability. The strategic priorities for the reform and development of Ukraine's agri-food sector, as outlined in national policy frameworks, emphasise the following core areas:

- the establishment of an inclusive policy framework for agricultural and rural development is imperative, encompassing institutional capacity-building;
- ensuring food security entails addressing the population's needs for safe and nutritious food. Enhancing the sustainability and competitiveness of agricultural producers is crucial;
- promoting efficient land use through land reform and large-scale demining initiatives is essential;
- the development of climate-resilient agriculture is to be achieved by the implementation of adaptation strategies to mitigate the impacts of climate change;
- the modernisation of the agricultural sector is to be pursued through increased investment in processing, innovation, digitalisation, and knowledge exchange;
- the fostering of rural development is to be achieved by the improvement of infrastructure, services, and economic opportunities in rural areas.

Our study provides a basic understanding of the impact of the war on Ukrainian agriculture, response strategies and post-war development. Further research should track subsequent phases of the war, new challenges and policy changes for a comprehensive understanding and effective policy formulation. Rebuilding Ukraine's agricultural sector in the context of economic change and potential EU integration requires reliable policies based on evidence of technical capacity, human and financial resources and technological progress.

7. LIMITATIONS AND FUTURE RESEARCH

This study provides an analysis of the RUW's impact on Ukraine's agricultural sector, highlighting policy responses and recovery strategies. However, it is important to acknowledge and address several limitations in future research.

The temporal scope of the study encompasses immediate and short-term impacts; however, it may not fully account for evolving challenges and opportunities as the war progresses. Moreover, while this analysis provides a national-level overview, it does not delve deeply into regional disparities. These disparities, including variations in agricultural damages, labour availability, and recovery capacities across Ukraine, remain under-explored.

The study relies primarily on secondary data sources, including government reports and publications from international organisations, which limits the integration of real-time field surveys or primary data. The role of external dependencies, including international aid and geopolitical factors, is acknowledged but not extensively modelled, leaving room for further exploration of their long-term impacts on agricultural recovery and integration with global markets.

Future research should extend the temporal scope to assess medium- and long-term impacts, including post-war reconstruction efforts and the potential effects of integration with the European Union. Detailed regional analyses are required to identify the specific challenges and opportunities within Ukraine's diverse agricultural zones. Furthermore, exploring the broader economic implications of such disruptions, including their effects on rural livelihoods, supply chains, and environmental sustainability, could provide a deeper understanding of the sector's challenges.

Furthermore, examining the global interconnections of Ukraine's agricultural disruptions with food security, trade, and energy markets would offer valuable policy insights for international stakeholders. Finally, the development and simulation of alternative policy scenarios, such as demining initiatives, fiscal support measures, and infrastructure investments, could inform evidence-based decision-making.

By addressing these limitations and expanding the research focus, future studies can build on this foundation to offer a more comprehensive understanding of Ukraine's agricultural recovery and its reintegration into the global economy.

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