Received: 18.04.2024. Revised: 20.10.2024. Accepted: 28.11.2024.

EKONOMIKA APK

https://doi.org/10.32317/ekon.apk/6.2024.10
Ekonomika APK, 31(6), 10-26

UDC 38.432

Assessment of the impact of the Russian-Ukrainian war on the agrarian potential in Kherson region

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► **Abstract.** The relevance of the study lies in the need to assess the impact of the russian-Ukrainian war on the agrarian potential of the Kherson region due to significant economic and ecological losses, in particular, the destruction and contamination of soils, which requires urgent monitoring of their quality and restoration of fertility to restore the agrarian sphere of the region. The assessment of the impact of the russian-Ukrainian war on the agrarian potential of the Kherson region and the determination of the prospects for its post-war recovery were chosen as the purpose of this work. The research was carried out using general scientific and special methods of studying phenomena and processes: analysis and synthesis, system analysis, method of analogy and modelling, system analysis, methods of information collection and processing. Data from the NASA FIRMS databases, Sentinel-2 satellite images, as well as images of fires from the Giovanni resource were used as an information base for the analysis. Additionally, tracking results of MODIS, VIIRS and VIIRS 2 Suomi satellites are involved. A mutual correlation of the yield of agricultural crops and the Agricultural Stress Index was carried out, which proves the absence of a serious impact of drought on the yield of agricultural crops in the Kherson region, except for the driest years. The dependence between the yield of grain and

► **Suggested Citation**: Horoshkova, L., Studinska, G., Mamchur, V., Menaker, A., & Menshov, O. (2024). Assessment of the impact of the Russian-Ukrainian war on the agrarian potential in Kherson region. *Ekonomika APK*, 31(6), 10-26. doi: 10.32317/ekon.apk/6.2024.10.

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leguminous crops and the application of fertilisers and pesticide treatment was established through the use of the mutual correlation function. A model of the influence of the application of mineral fertilisers and pesticides was built using the Cobb-Douglas econometric function, which allows predicting the optimal conditions for the introduction of agricultural production. Conclusions, proposals and practical recommendations will be useful in the development of relevant programs and measures aimed at the post-war restoration of agricultural soil and the general development of the country's agricultural production

▸ **Keywords:** agricultural production; yield; soil quality; fertilisers and pesticides; Agricultural Stress Index; mutual correlation function; Cobb-Douglas function

▸ Introduction

The consequences of hostilities and the temporary occupation of Ukrainian territories by Russian invaders are unprecedented in scale and impact on the future development of the country's economy. The deterioration of the economic and ecological state of the country, the socio-economic living conditions of the population and the demographic crisis in the conditions of a prolonged war have a further negative trend. The war has affected all spheres of life, with problems in each area reinforcing each other and requiring a comprehensive solution both in the current time and the post-war period. This necessitates an appropriate comprehensive interdisciplinary study of these consequences.

O. Menshov *et al.* (2021) found that during the years of Ukraine's independence, agricultural production played a significant role in its economy. Moreover, the share of the primary sector of the economy, to which agriculture belongs, increased to 20% during this time, which exceeds the corresponding world average by almost 4 times. From 1991 to 2024, there was a structural reversal from the industrial-agrarian economy of the pre-reform period to an agrarian-industrial one with the raw material exploitation of human, natural and economic resources by local and foreign companies (Mohylnyi, 2024). Since agricultural production plays a leading role in the national economy of Ukraine, its losses from military aggression have become the most tangible. Due to its specific features, agriculture has always been and remains the most vulnerable to social unrest, natural disasters, various extraordinary events, catastrophes, etc. The main reason for this, according to Y. Hadzalo (2023), is the nature of the main means of production of the industry – land, agricultural land, with the loss of which agricultural activity, as well as the existence of the peasant himself, becomes impossible.

The effectiveness of the development of the agricultural sector manoeuvres in a two-vector coordinate system: agricultural production and socio-economic conditions for the development of rural areas (Mamchur & Studinska, 2023). The determining factors of the efficiency of the development of agricultural production according to the first vector are, first of all, the quality of the fertile soil, the level of knowledge-intensiveness of production, its technological and technical innovation, the availability of resources (financial, energy, chemical, organic, human). Most of the listed factors are within the competence of state and local authorities and require appropriate decisions, the development of a strategy, programs for its implementation, and significant investments. The need for the development of rural areas is caused by the significant polarisation of the socio-economic living conditions of the population in rural and urban areas, which has led to the disappearance of several hundred villages over the years of independence and a shortage of workforce in agricultural production, which is exacerbated by military migration. The war destroyed the pre-war model of the Ukrainian economy, exacerbated internal contradictions and confirmed the general inefficiency, and increased the degradation of the raw material sector in the agricultural; farmers have lost incentives to produce raw materials and reduce crops (Studinska, 2023).

The minimum calculation of environmental damage for the year of the war, carried out by the Ecocide: 10 environmental consequences of russia's war against Ukraine (2023), is 441 billion dollars. The destruction of soils and their contamination is considered to be especially serious damage. In Ukraine, 30% of the entire area of the state is mined. Significant destruction of the most fertile black soil occurred in the south and east of Ukraine, including in the Kherson region. According to experts, the territories covered with craters after shelling may be unsuitable for agricultural use due to the large number of chemicals that the ammunition contained, which, after the explosion can remain in the soil for a long time and "migrate", that is, get into groundwater and plants. Products grown on land affected by the fighting may be unsafe for consumption, and almost the only way to avoid danger is to remove the land from agricultural use.

The problem of returning land plots to their normal condition is particularly acute and requires significant financial resources. Thus, according to experts, the average cost of such work is about 1,000 US dollars per hectare, including the cost of surveying, demining, reclamation, chemical (biological) contamination, etc. (Husakov, 2023). The total cost of restoration may exceed the standard monetary valuation of the land. To improve the situation, experts recommend the use of innovative agricultural technologies, such as plantation ploughing, deep melioration loosening, and crop rotation, in particular the cultivation of maize, which may be less sensitive to pollution. Microbiological preparations will help reduce toxic elements, and chemical and organic melioration will contribute to the restoration of soils. Phytoremediation is also effective for cleaning contaminated areas (How to save …, 2023).

Damaged, destroyed fertile soil requires the development of a list of measures according to a certain algorithm that can restore its natural properties. The restoration of the agricultural sector of Ukraine should begin immediately after the liberation of the territories from occupation, as the consequences of the war are extremely complex and large-scale. It is advisable to begin preparatory work on restoration before the de-occupation of the territories (remotely), with monitoring the condition of the soil and substantiating a set of measures for the reincarnation of the fertile soil. The purpose of the work is to assess the impact of the russian invasion on the agricultural potential of the Kherson region and outline the possibilities of its post-war restoration in the future.

▸Materials and methods

In the process of conducting the research, general scientific (analysis and synthesis, induction and deduction, analytical grouping) and special (abstraction, modelling, forecasting, statistical analysis, Microsoft Excel, etc.) methods of studying phenomena and processes were used. In order to determine the impact of Russian aggression on agricultural production in the Kherson region, data from NASA FIRMS databases, Sentinel-2 satellite images and the Giovanni resource were used. (Fire information for…, n.d.). For the analysis of the number of fires, data from NASA FIRMS databases were used (due to the lack of such data for 2023, additional observation data from MODIS, VIIRS and VIIRS 2 Suomi satellites were used). The study was conducted based on statistical data for the period from 2018 to 2024 (Moderate resolution imaging… n.d.; Visible infrared imaging…n.d.; VIIRS+CrIS…, n.d.). The study of the impact of droughts as a factor in the damage to agricultural areas and the reduction in crop yields was conducted using FAO data, in particular its remote sensing tools and their further analysis using the following indices. The Agricultural Stress Index (ASI) made it possible to indirectly assess and determine the percentage of agricultural land (arable land or natural pastures) within certain areas that are potentially affected by drought (Earth Observation, n.d.). The data are provided in monthly (decadal) and annual (seasonal) sections. The basis for assessing the drought risk areas is the complex data on the normalised difference index (NDVI) and temperature index (BT4), obtained from the AVHRR sensor. Through a series of transformations, the combined series of NDVI and BT4 is transformed into a vegetation health index (VHI), on the basis of which the percentage ASI for a given area is calculated. According to the FAO classification (Earth Observation, n.d.), there are 7 main gradations of ASI. FAO defines the following levels of ASI: <10%, 10-25%, 25-40%, 40-55%, 55-70%, 70-85%, >=85%. The value of the indicator at the level of <10% means that the region or area is almost not experiencing the negative impact of drought. The increase in the value of the indicator indicates an increasing impact of drought on the state of agriculture in the region.

The NDVI index is a normalised relative vegetation index, on the basis of which conclusions are drawn about the development of plant biomass during the growing season. Using the NDVI index, it became possible to assess the "greenness" of the soil cover. NDVI values range from +1 to -1, with high positive values indicating dense and healthy vegetation, and low and/or negative NDVI values indicating poor vegetation conditions or sparse vegetation cover. The NDVI anomaly shows a change in the vegetation condition during a certain current period (decade, month) compared to the long-term average value. Positive changes (in % with a sign +) indicate an improvement in the vegetation condition compared to the average level, and negative (negative) values mean relatively negative changes (in % with a sign "–") was the state and conditions of vegetation.

For the purpose of analysing and identifying common trends in the change of the resulting indicator and factors influencing it, a cross-correlation function was used, which characterises the density of the connection of each element of the dynamic series of values of the dependent (resulting) y_t and explanatory x_t variables, shifted relative to each other by a time lag τ. The cross-correlation coefficient was determined by the formula (1) (Nakonechnyi, 2004):

$$r_\tau = \frac{(n-\tau)\sum_{t-1}^{n-\tau} y_t\, x_{t-\tau} - \sum_{t-1}^{n-\tau} y_t \sum_{t-1}^{n-\tau} x_{t-\tau}}{\sqrt{[(n-\tau)\sum_{t-1}^{n-\tau} y_t^2 - (\sum_{t=1}^{n-\tau} y_t)^2][(n-\tau)\sum_{t-1}^{n-\tau} x_{t-1}^2 - (\sum_{t=1}^{n-\tau} x_{t-\tau})^2]}}, \quad (1)$$

where y_t and x_t – are the elements of the vector of the dependent (resulting) and explanatory variables, respectively, shifted relative to each other by a time lag τ; n – is the number of values of the quantity r_τ.

Considering the existence of relationships between the resulting indicator and the influencing factors, it was determined to be appropriate to use the possibilities of econometric modelling using the Cobb-Douglas function and to build the corresponding regression model and check its reliability using the MS Excel tool in terms of determining the coefficients a_0, a_1 and a_2 (Nakonechnyi, 2004).

▸ Results and Discussion

Before the start of the full-scale war, the Kherson region was one of the leaders in the production of grain and sunflower, vegetables, and melon crops. In addition, it was one of the largest exporters of agricultural products in Ukraine. According to the State Statistics Service (Agriculture, forestry, and…, n.d.), about a third of the population of the Kherson region in pre-war times was traditionally employed in agriculture, forestry and fisheries as of 1 January, 2022, the situation has changed significantly. Restoring the region's former potential requires a detailed analysis of the situation and determining the directions of its restoration and further development in the post-war period.

Before the beginning of the russian aggression in the Kherson region, the agro-industrial complex (AIC) was the leading sector of the regional economy and the sphere that provided a large number of jobs and formed the export potential of the region. In the Kherson region, 2,469 AIC business entities operated, including 1,941 farms, 528 agricultural enterprises, of which 25 were agricultural production cooperatives, and 66 were agricultural service cooperatives. Agricultural land as of 01.01.2022 amounted to 1,969.5 thousand hectares, including arable land – 1,777.9 thousand hectares, 26.6 thousand hectares – perennial plantations, 10.4 thousand hectares – hayfields, 155.7 thousand hectares – pastures (Economic Statistics / Economic…, n.d.). In the arid climate, the presence of a drip irrigation system was important for the region. Of the total amount of agricultural land, 427 thousand hectares or 24% were irrigated, 43.5 thousand hectares had drip irrigation. In terms of ploughing, the territory had indicators higher than the average in Ukraine, namely 62.7%, which is higher than the average level in the country, which is 53.9%. The ploughing of agricultural land was 87.9%. As for crop production, in the structure of agricultural production, the region occupied almost 87%, but compared to 2017, it decreased by 5.2%. As for comparative estimates of the area occupied by agricultural crops, 5.1% of the area available in Ukraine was occupied by grain crops in the region, 5.3% – by sunflowers and 32.3% – by vegetables. Regarding grain and leguminous crops, in 2021 (a record year for the Kherson region), the harvest was harvested from an area of 812.8 thousand hectares, which is 5.7% of the total area in Ukraine (15,948.4 thousand hectares). The volume of the harvested crop in the Kherson region was 3,528.8 thousand tons, which is 4.1% of the total in the country (86,010.4 thousand tons). Industrial crops in the Kherson region in 2021 were harvested from an area of 636.5 thousand hectares, which is 5.9% of 536.5 thousand hectares in Ukraine. The volume of the harvested crop in the region was 5.3% of the total in Ukraine (1,208.6 thousand tons and 22,896.9 thousand tons, respectively). If we compare the indicators of irrigated land for grain and leguminous crops, then in total in Ukraine in 2021 their area amounted to 200.6 thousand hectares, of which in Kherson region – 115.8 thousand hectares (57.7%). As for the volume of harvested crops, in total in Ukraine in 2021 there were 14,316.2 thousand tons, of which 56.1% or 8,028.4 thousand tons – in Kherson region (Agriculture, forestry and…, n.d.; Economic Statistics / Economic…, n.d.).

With the beginning of the war, the situation changed dramatically, most of the region was occupied. The above analysis of the main indicators of agricultural production will help determine the impact of the war on the state of crop production in the Kherson region. Table 1 shows the dynamics of the sown areas of winter crops for grain and green fodder, and grain and leguminous crops for grain for harvest as of 1 December of the following year:

Table 1. Sown area of winter crops and green fodder in the Kherson region for the harvest on December 1 of the following year, thousand hectares

	2019	2020	2021	2022	2023	2024
Winter crops for grain and green fodder, incl.:	660,624	698,449	712,223	668,106	29,328.9	52,800
grain and leguminous crops for grain, incl.:	568,735	603,527	613,231	562,604	24,186.5	42,831
wheat	478,886	495,568	494,758	455,905	20,824.7	36,589
rye	1,493	1,659	1,990	2,238	-	-
barley	88,320	106,300	116,483	104,460	0.3285	6,232
canola	89,465	91,172	94,898	102,230	0.44328	9,700

Source: built by the authors for Agriculture, forestry and fisheries (n.d.); Economic Statistics/Economic Activity/Agriculture, Forestry, and Fishing/Agriculture (n.d.); Main Statistical Office in the Kherson Region (n.d.)

The information provided indicates noticeable negative changes due to the occupation of the Kherson region. However, the de-occupation of part of the territory, 26.4% of which was agricultural land, at the beginning of 2023 slightly improved the situation, due to which the level of reduction in sown areas was more than 50%. The situation has significantly improved by the beginning of 2024, as part of the territories will be additionally demined. Figure 1 shows the chain growth rates of sown areas of winter crops for grain and green fodder and grain and leguminous crops for grain during 2018-2025:

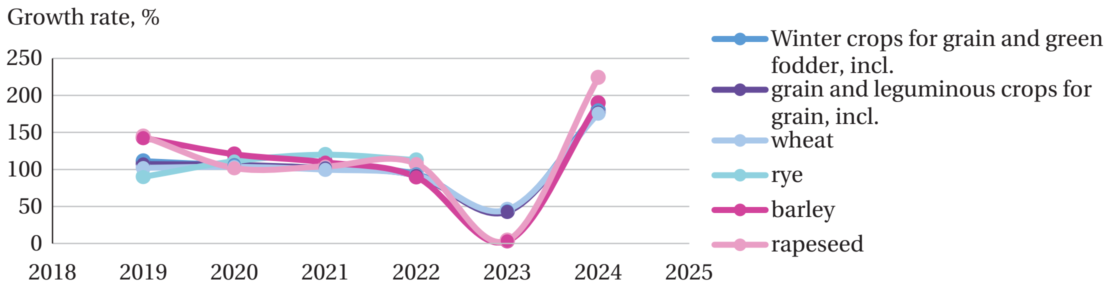

Figure 1. Chain growth rates of sown areas of winter crops for grain and green fodder and grain and leguminous crops for grain during 2018-2023, %
Source: built by the authors for Agriculture, forestry and fisheries (n.d.); Economic Statistics / Economic Activity / Agriculture, Forestry, and Fishing / Agriculture (n.d.); Main Statistical Office in the Kherson Region (n.d.)

The area of agricultural land in the territory of the de-occupied Kherson region as of the beginning of 2023 was 520 thousand hectares, of which more than 10% (56.4 thousand hectares) has already been officially demined. But farmers also carried out demining on their own; the share of such lands was also approximately 10%. The total area of demined lands is only approximately 25% of the pre-war level of agricultural land in the region. As of 01.01.2024, part of the region, which is located in a 20-kilometer zone of active hostilities, is not subject to demining; therefore, agricultural lands cannot be used. This is the territory of four communities of the Kherson district of the region: Kherson; Bilozersk; partly Stanislavsk and Darivsk.

In 2023, more than 60 thousand hectares of land were sown in the Kherson region, including: grain group – 23.5 thousand hectares, 35.7 thousand hectares – industrial crops, of which 31.7 thousand hectares – sunflower. It is quite clear that such a structure of the distribution of sown areas between crops cannot be considered rational, since most of it was given to industrial crops in general and to sunflower, in particular. The reason is that farmers were unable to sow the planned areas with spring crops in time due to land clearance, and were forced to sow the land with sunflower later than the established deadlines. Let us analyse the yields of the main crops of the Kherson region in dynamics through the area of harvested crops (Table 2) and the productivity of these crops (Table 3).

Based on the data in Table 2, we will construct a diagram (Fig. 2) that visualises changes in the areas where the crop was harvested from 2018 to 2024.

Table 2. Dynamics of harvested crop areas in Kherson region, thousand hectares

	2017	2018	2019	2020	2021	2022	2023
Grain and leguminous crops, including	738.6	710,179.9	756,820	776,960	813,852	45,516	18,629
wheat	470.4	471,587.2	482,959	491,731	503,662	33,366	7,172
barley	185.8	156,803.1	193,164	196,321	209,753	9,845	5,867
maize	45.0	41,278.8	44,717	46,862	59,036	1,114	1,211
Sunflower	356.6	341.70	353,038	335,344	348,884	11,671	35,073
Rapeseed and colza (spring rapeseed)	51.1	63,308.3	87,388	89,666	95,340	11.5	3,092

Source: built by the authors for Agriculture, forestry and fisheries (n.d.); Economic Statistics / Economic Activity / Agriculture, Forestry, and Fishing / Agriculture (n.d.); Main Statistical Office in the Kherson Region (n.d.)

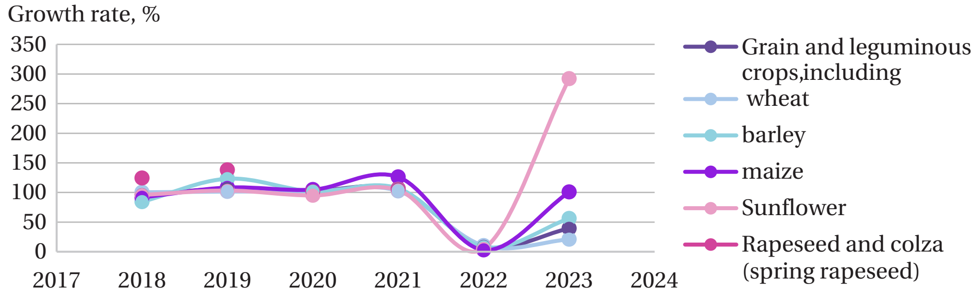

Figure 2. Chain growth rate of harvested crop areas in the Kherson region, %

Source: built by the authors for Agriculture, forestry and fisheries (n.d.); Economic Statistics / Economic Activity / Agriculture, Forestry, and Fishing / Agriculture (n.d.); Main Statistical Office in the Kherson Region (n.d.)

The reasons for the decrease in the area of most harvested crops in the Kherson region in 2023 and the increase in the area of sunflower, the chain growth rates of which are presented in Figure 2, are given above.

Based on the data in Table 3, we will construct a diagram (Fig. 3) that visualises the dynamics of changes in the gross harvest of the main crops in the Kherson region.

Table 3. Dynamics of gross harvest of main crops in Kherson region, thousand tons

	2017	2018	2019	2020	2021	2022	2023
Grain and leguminous crops, including	2,545.44	2,267.69844	2,739.7140	2,719.9474	3,528.7674	145,387.3	55,351.0
wheat	1,652.9	1,486.95973	1,640.7722	1,567.7918	2,073.3675	105,436.1	20,551.0
barley	488.41	393,712.84	629,250.6	632,753.2	813,010.9	32,427.5	16,640.7
maize	298.11	292,968.33	372,446.2	419,066.3	533,283.0	6,391.4	11,759.6
Sunflower	499.2	552,836.01	641,154.2	531,556.8	672,591.5	16,095.5	60,536.3
Winter rapeseed and colza (spring rapeseed)	128.63	148,882.61	192,308.5	197,214.9	243,994.2	21.7	4.9107

Source: built by the authors for Agriculture, forestry and fisheries (n.d.); Economic Statistics / Economic Activity / Agriculture, Forestry, and Fishing / Agriculture (n.d.); Main Statistical Office in the Kherson Region (n.d.)

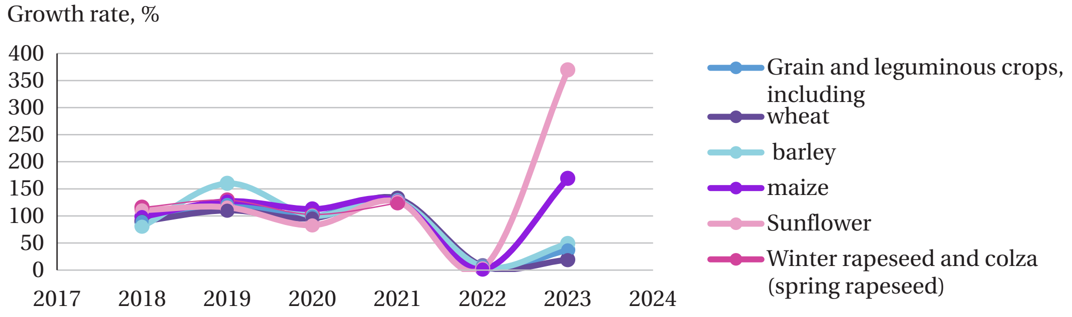

Figure 3. Chain growth rates of gross harvest of main crops in Kherson region, %
Source: built by the authors for Agriculture, forestry and fisheries (n.d.); Economic Statistics / Economic Activity / Agriculture, Forestry, and Fishing / Agriculture (n.d.); Main Statistical Office in the Kherson Region (n.d.)

The data presented in Figure 3 indicate that in 2023, only 5% of the pre-war harvest was collected in the ed-occupied right-bank part of the Kherson region. The grain harvest in the region amounted to about 55 thousand tons from 22 thousand hectares, rapeseed – 4.9 thousand tons from 2.7 thousand hectares. In 2022, due to fires caused by shelling, it was not possible to collect a significant part of the harvest. Let us analyse the yield of the main crops of the Kherson region in dynamics, the data of which are presented in Table 4.

Table 4. Yield in Kherson region, tons/hectare

	2017	2018	2019	2020	2021	2022	2023
Grain and leguminous crops, including	3.45	3.19	3.62	3.5	4.34	3.19	2.97
Wheat	3.51	3.15	3.40	3.90	4.12	3.16	2.87
Barley	2.63	2.51	3.26	3.22	3.88	3.29	2.83
Maize	6.62	7.10	8.33	8.94	9.03	5.74	9.71
Sunflower	1.41	1.62	1.82	1.59	1.93	1.38	1.73
Rapeseed and colza (spring rapeseed)	2.52	2.35	2.20	2.20	2.56	1.89	1.59

Source: built by the authors for Agriculture, forestry and fisheries (n.d.); Economic Statistics/Economic Activity/Agriculture, Forestry, and Fishing/Agriculture (n.d.); Main Statistical Office in the Kherson Region (n.d.)

The data in Table 4 indicate some fluctuations in yields in different years, but a significant decrease in yields in 2023 for wheat, barley and rapeseed. From the data in Table 4, it is noticeable that corn yield increases. We visualise the chain growth rates of crop yields in the Kherson region in dynamics in Figure 4. The data presented in Figure 4 indicate that during 2018-2023, the yield of grains and legumes in the Kherson region increased and was a record in recent years on the eve of the war in 2021. A similar trend is observed for industrial crops (sunflower and rapeseed). In the first year of the war, yields decreased significantly, which is explained by the fact that, firstly, part of the crop crops were damaged by hostilities; secondly, the rest of the crops ended up in mined areas and their processing was impossible; Thirdly, the de-occupied territory is under shelling, which also interferes with the normal conduct of agricultural work.

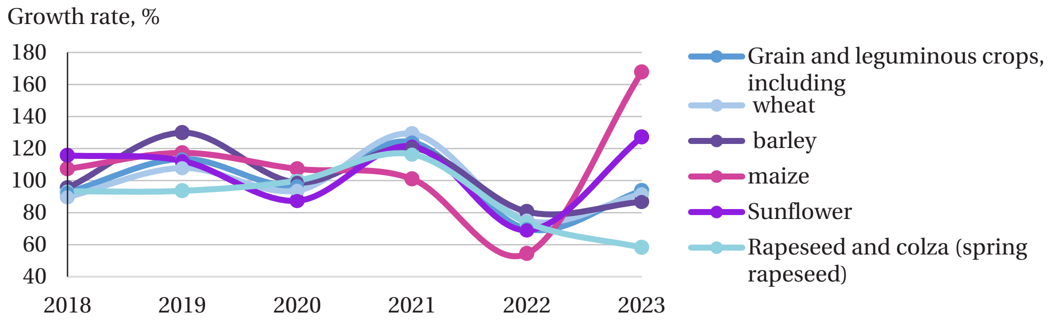

Figure 4. Chain growth rates of yields of main crops in the Kherson region, %
Source: built by the authors for Agriculture, forestry and fisheries (n.d.); Economic Statistics/Economic Activity/Agriculture, Forestry, and Fishing/Agriculture (n.d.); Main Statistical Office in the Kherson Region (n.d.)

The decrease in yield was not so much due to weather conditions and the impossibility of irrigating farmland due to the destruction of the Kakhovka reservoir, but as a result of the negative impact of the war and the consequences of hostilities on the territory. In order to assess the impact of Russian aggression on agriculture in the Kherson region, namely its Right-Bank part (Beryslav and Kherson districts), NASA FIRMS data, Sentinel-2 satellite images, and the Giovanni resource were used, which are presented in Figure 5 as of September 2021 (before the war) and September 2023. The number of fires in the specified periods before the war and during the war increased significantly. It is quite clear that a small number of fires are observed in September, but their number became much larger during the war due to the constant shelling of territories and their consequences – the occurrence of fires. To analyse the number of fires in the specified territories, data from NASA FIRMS databases were used for the period from January 1, 2020 to December 31, 2022. Data for 2023 were not analysed due to their closed access. The analysis was carried out based on observation data from MODIS, VIIRS and VIIRS 2 Suomi satellites. The results of these observations on the number of fires in 2020-2022 are presented in Table 5:

a) b)

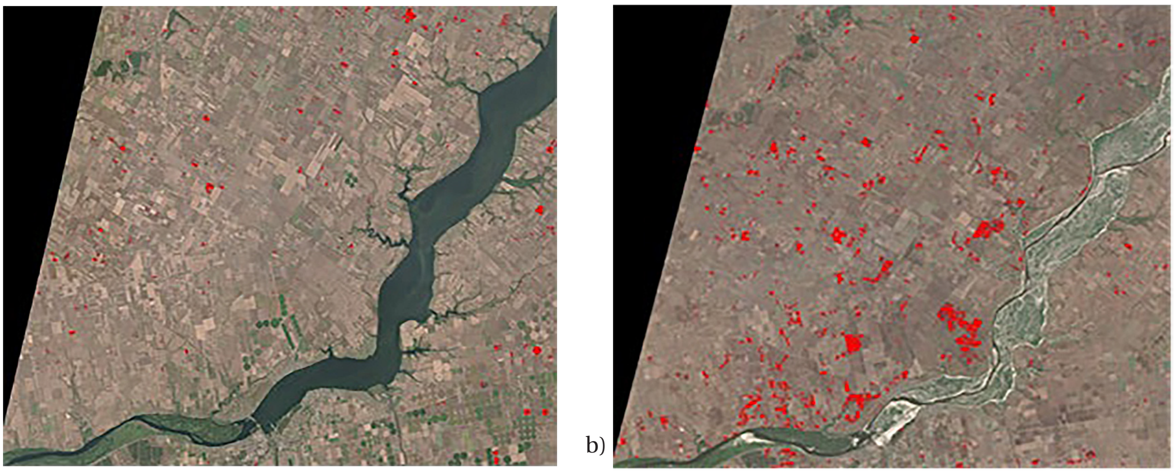

Figure 5. Sentinel-2 satellite space images for September 2021 (a) and September 2023 (b) with the Burned Area Detection filter
Source: provided by Fire information for resource management system (n.d.)

Table 5. Dynamics of the number of fires on the Right Bank of the Kherson region

	2020	2021	2022	2020	2021	2022	2020	2021	2022
		VIIRS			MODIS			VIIRS 2	
January	116	40	53	3	0	0	104	34	53
February	125	49	188	8	0	41	91	47	202
March	478	210	442	138	27	151	555	239	405
April	518	277	179	64	30	13	520	292	191
May	243	360	335	2	7	19	242	432	320
June	498	404	645	19	9	68	481	409	640
July	1,457	1,183	1,919	253	122	504	1,398	1,121	2,179
August	1,180	1,479	752	129	277	133	1,227	1,480	787
September	732	632	183	72	69	40	714	671	153
October	306	608	254	40	131	23	314	681	226
November	76	190	66	6	12	2	61	212	73
December	41	20	30	1	0	0	39	17	24

Source: built by the authors for Fire information for resource management system (n.d.)

The statistics presented in Table 5 show that the data obtained from different satellites differ, in particular, the MODIS satellite does not reflect most of the fires recorded by other satellites. An increase in the number of fires at the beginning of hostilities in February 2022, compared to 2020 and 2021, was recorded by almost 1.5 times. The next increase in the number of fires was recorded in June and July 2022, which can be explained by two reasons. First, the seasonal characteristics of agricultural production in the South of Ukraine (due to the heat). Second, the beginning of the counter-offensive operation in the South of Ukraine. In August – September 2022, the number of fires was almost 2 times lower compared to the same period in 2020-2021. This can be explained by the fact that after the end of the harvest season, stubble burning took place in agricultural fields. But given that much less grain was sown than in the pre-war years, the amount of burnt stubble, and consequently the number of fires, was much smaller. In addition, there was a general reduction in agricultural land due to the impossibility of cultivating it due to active hostilities in the Kherson region.

In order to determine the area of agricultural lands affected by fires in the Right-Bank (unoccupied) part of the Kherson region, the EO Browser tool and Sentinel-2 satellite images (for the period from January 2020 to December 2023) and the Burned Area Detection script were used. The resolution of the downloaded images was 2,500×1,189 pixels in the WGS 84 coordinate system (EPSG: 4326). Further analysis of the obtained images was carried out using the QGIS program using the Raster layer unique values report tool. The results obtained in pixels were converted into square meters, taking into account the number of square meters in one pixel, their resolution and coordinate system. The final result, namely the area of areas affected by fires, is given in Table 6.

During February 2022 and 2023, an increase in the number of areas affected by fires was recorded compared to the corresponding period in 2020 and 2021, which can be explained by the beginning of a full-scale war and the conduct of active hostilities in this territory. A complete correlation was established between the areas affected by fires in July – September 2022 and the recorded number of fires according to NASA FIRMS data. At the same time, the affected area in June 2022 is insignificant, despite the number of recorded fires, which is explained by the nature of the shelling, namely the emergence of point sources of ignition as a result of artillery shelling of russian equipment by the Defences Forces of Ukraine.

Table 6. Dynamics of the average area of fire-affected areas on the right bank of the Kherson region, km^2

	2020	2021	2022	2023
January	278,839	6,693	no data*	no data
February	0.347	6,039	1,052.576	219,986
March	428,547	1,376.97	1,417.2267	561,906
April	410.27	111,588	433,633	16.28
May	226,361	632,256	199,511	3.37
June	1,283	9,685	11,952	36,872
July	119,301	0.599	247,082	19.83
August	494,375	161,061	62,655	267,234
September	197,615	142,829	76.54	320,557
October	52,327	421,824	196.65	759.75
November	698,882	1,055.34	636,772	652,282
December	no data	no data	no data	no data

Note: * – the picture for this period is not available due to high cloud cover
Source: built by the authors for Fire information for resource management system (n.d.)

During August – October 2023, a different damage to areas compared to previous years was established, which is explained by the shelling of the Right-Bank part of the Kherson region (unoccupied) by the armed forces of the Russian Federation with artillery weapons and aerial bombs. In order to confirm the conclusions made that the main factor influencing the decrease in the efficiency of agricultural production in the region (in its controlled part) is precisely military operations, we additionally conducted studies of the impact of droughts as a factor affecting agricultural areas and reducing crop yields. For this purpose, FAO data were used, in particular its remote sensing tools and further analysis using the ASI, NDVI and NDVI anomalies indices. According to FAO data, the beginning of the season on the Right-Bank Kherson region occurs from March to April; the seasonal maximum is observed from May to June; the end of the season in most territories of the Right-Bank Kherson region occurs from July to August. Corresponding changes to the ASI index were made for the period from June 2021 to June 2024, decade by decade and presented in Table 7:

Table 7. Seasonal decadal dynamics of the ASI Index

Year	Month	Indicator ASI, %		
		The first decade	Second decade	Third decade
2021	June	<10	<10	<10
	July	<10	<10	<10
	August	<10	<10	<10
2022	March	–	–	25-40
	April	25-40	<10	10-25
	May	<10	<10	<10
	June	<10	<10	<10
	July	<10	<10	<10
	August	<10	–	–

Table 7, Continued

Year	Month	Indicator ASI, %		
		The first decade	Second decade	Third decade
2023	March	–	–	<10
	April	<10	<10	<10
	May	<10	<10	<10
	June	<10	<10	<10
	July	<10	<10	<10
	August	<10	–	–
2024	March	–	–	10-25
	April	10-25	25-40	10-25
	May	<10	<10	<10
	June	<10	<10	There are no data

Note: * the sign "–" corresponds to the meaning that the agricultural season has not started or has already ended
Source: built by the authors for Earth Observation (n.d.)

Based on the analysis of FAO data, in particular the use of remote sensing tools and their further analysis using the average monthly anomaly index NDVI, the following results were obtained for the period from June 2021 to May 2024, which are presented in Table 8.

From the data in Table 8, it can be seen that during the study period from 2021 to 2024, the average annual ASI indicator did not exceed 10%. Accordingly, drought cannot be considered a factor of significant impact on the reduction in crop productivity on the Right Bank of the Kherson region during the study period. Let us compare the ASI indicators and the yield of grain and leguminous crops in the Kherson region during 1995-2023 (Table 9).

Table 8. Dynamics of the average monthly NDVI anomaly index

Year	Month	Average anomaly rate NDVI, %
2021	June	10-25
	July	>10
	August	<–10-0
	September	<–10
	October	<–10
	November	<–10
	December	<–25
2022	January	>10
	February	>25
	March	>25
	April	>10
	May	>10
	June	>10
	July	>10
	August	0
	September	>25
	October	>25
	November	>10
	December	>10
2023	January	>10
	February	>50
	March	>50
	April	>25
	May	>10
	June	>10
	July	>25
	August	>10
	September	<–10
	October	<–25
	November	>10
	December	<–25

Table 8, Continued

Year	Month	Average anomaly rate NDVI, %
2024	January	<–25
	February	>25
	March	>25
	April	>25
	May	>10

Source: built by the authors for Earth Observation (n.d.)

Table 9. Average annual ASI index and corresponding yields of grain and legume crops in Kherson region

Year	Indicator ASI, %	Yield, quintals /hectare	Year	Indicator ASI, %	Yield, quintals /hectare
1995	<10	24.6	2010	<10	22.1
1996	**25-40**	**15.7**	2011	<10	32.4
1997	<10	27.4	2012	**40-55**	**18.2**
1998	<10	21.2	2013	**10-25**	**22.2**
1999	<10	20.6	2014	<10	28.3
2000	<10	17.2	2015	<10	33.6
2001	<10	26.5	2016	<10	34.1
2002	<10	21.8	2017	<10	34.5
2003	**55-70**	**8.9**	2018	<10	31.9
2004	<10	26.3	2019	<10	36.2
2005	<10	22.1	2020	<10	35.0
2006	<10	22.8	2021	<10	43.4
2007	**70-85**	**16.0**	2022	<10	31.9
2008	<10	32.9	2023	<10	29.7
2009	<10	23.9	2024	The year continues	

Source: built by the authors for Agriculture, forestry and fisheries (n.d.); Earth Observation (n.d.)

The data in Table 9 demonstrate the periodic impact of drought on crop yields (data in bold). The ASI for Kherson region and its Right Bank in particular did not exceed 10% for most years and months, with minor exceptions in 1996, 2003, 2007, 2012 and 2013. For example, the 2007 drought, which led to significant losses in agriculture, corresponded to a value of 70-85% in terms of the ASI for Kherson region. Over the past 10 years, no significant impact of drought has been observed. A certain decrease in average yields was indeed observed in 2023, but the exceptions were maize and sunflower (Table 4). Therefore, there is every reason to expect positive results in terms of increasing crop yields due to the restoration of irrigation. For 2024 planned restoration of irrigation of over 3 thousand hectares of land (in three communities) through the use of the Ingulets irrigation system, which requires restoration, since enemy positions were established in its canals during the hostilities in the Right-Bank Kherson region.

The next important factor that can increase the yield of agricultural crops is the use of agro-technological measures, including the application of fertilisers. The problem of reducing soil fertility in the Kherson region arose long before the war. A negative balance of humus with a simultaneous decrease in the content of nutrients in it, significant decalcification of soils, increased acidity, a noticeable deterioration in physical and physical and chemical indicators have always been inherent in the soils of the Kherson region. In addition to this, erosion processes and deflation, which lead to the loss of humus, nitrogen, phosphorus, potassium and other substances, reduce their content in the soil, which negatively affects their balance. The effects of the war on soils have been added to these negative trends. For shelling of the territories of the Right-Bank part of the Kherson region, the russian armed forces use artillery shells, mines, shells for multiple launch rocket systems of various sizes, ballistic and cruise missiles. Regional territories are contaminated with various types of munitions, including anti-personnel and anti-tank mines (both direct-laying and remotely detonated), booby-trapped mines (based on hand grenades and grenade launcher shells), and cluster munitions. Such anthropogenic impact on soils necessitates the search for solutions and opportunities to preserve and increase the fertility of agricultural lands.

It is traditional to use mineral fertilisers and plant protection products (pesticides) at the beginning of the agricultural season. The use of pesticides is practically an integral part of modern crop growing technologies, since they are a means of combating weeds, pests and plant diseases, which helps to maintain a high yield. However, along with this, pesticides accumulate in the soil, leading to disruptions in the normal cycles of the biological circulation of substances. They suppress the biological activity of soils, destroy beneficial microorganisms. Mineral fertilisers should also be used with caution in agricultural production. Yes, indeed, their use significantly increases the yield of agricultural plants, and, taking into account the specifics of the soils of the Kherson region, their use gives positive results. But it should be remembered that an excessive number of mineral fertilisers can lead to disruption of soil processes, namely the optimal reaction of the soil solution, which will complicate the assimilation of nutrients from the soil and applied fertilisers. In this context, organic fertilisers are more useful, the result of which is the improvement of soil quality and an increase in yield. However, the effectiveness of mineral fertilisers in increasing yield is significantly higher than organic ones. In order to determine the impact of agro-technological measures on the yield of grain and leguminous crops in the Kherson region, the impact of the application of mineral, organic fertilisers and pesticides on the yield level before and during military operations was studied (Table 10):

Table 10. Fertilisers application and pesticide treatment per 1 ha in Kherson region (Grain and legume crops), kg

	2018	2019	2020	2021	2022	2023
Area under grain and leguminous crops, thousand hectares	710.1799	756.820	776.960	813.852	45.516	18.629
Area treated with mineral fertilisers, thousand hectares	327.941	353.109	394.447	419.687	38.265	11.137
Amount of applied mineral fertilisers per 1 ha, kg	105	104	168	121	94	46
Area treated with organic fertilisers, thousand hectares	16.899	11.513	16.315	42.773	There are no data	There are no data
Number of organic fertilisers applied per 1 ha, kg	3,110	6,681	2,064	1,176	There are no data	There are no data
Area treated with pesticides, thousand hectares	308.293	339.024	384.360	411.320	23.779	11.319
Number of pesticides applied per 1 ha, kg	0.767	0.870	0.744	0.951	0.534	0.491

Source: built by the authors for Agriculture, forestry and fisheries (n.d.); Economic Statistics / Economic Activity / Agriculture, Forestry, and Fishing / Agriculture (n.d.); Main Statistical Office in the Kherson Region (n.d.)

The data in Table 10 prove the fact of an increase in the areas on which fertilisers are applied and treated with pesticides. The volume of mineral and organic fertilisers applied per 1 ha increased until 2020, which was the reason for the increase in the yield of grain and legume crops in 2021. In 2021, the number of fertilisers applied per 1 ha, except for pesticides, decreased. Since the beginning of the war, the volume of fertilisers applied to the soil has decreased due to the reduction of land under cultivation, the reduction in the number of agricultural machineries for applying fertilisers, and the financial capabilities of farmers. Since fertiliser application is a traditional agro-technological measure to increase the yield of agricultural plants, an analysis of the impact of these measures on the yield of grain and legume crops over 15 years was conducted (Table 11).

Table 11. Dynamics of yield, fertiliser application and pesticide treatment per 1 ha in Kherson region

Year	Yield of grain and leguminous crops, tons per 1 hectare of harvested area	Application of mineral fertilisers, kg/ha	Application of organic fertilisers, tons/hectare	Pesticide treatment, kg/hectare
2009	2.39	35	0	н/д*
2010	2.21	43	0	н/д
2011	3.24	49	0	н/д
2012	1.82	44	0	н/д
2013	2.22	42	0	н/д
2014	2.83	40	0	н/д
2015	3.36	36	0	н/д
2016	3.41	58	0	н/д
2017	3.45	72	0	н/д
2018	3.19	105	3.110	0.767
2019	3.62	104	6.681	0.870
2020	3.50	168	2.064	0.744
2021	4.34	129	1.178	0.951
2022	3.19	95	–	0.534
2023	2.97	46	–	0.491

Note: pesticide treatment data began to be collected starting in 2018
Source: built by the authors for Agriculture, forestry and fisheries (n.d.); Economic Statistics / Economic Activity / Agriculture, Forestry, and Fishing / Agriculture (n.d.); Main Statistical Office in the Kherson Region (n.d.)

Organic fertilisers began to be used only in 2018 in fairly small amounts. Increasing their application volumes simultaneously with a corresponding increase in the volume of mineral fertilisers can be considered measures that may have a positive impact on the yield of grain and leguminous crops in the future. There is reason to believe that a significant increase in the volume of mineral fertiliser application to 168 kg/hectare in 2020 and 129 kg/hectare in 2021 led to a record harvest in 2021. In addition, in 2019-2020, the application of organic fertilisers was simultaneously increased, and in 2021, the volume of pesticide treatment was also increased.

Based on the data presented in Table 10, an analysis was conducted of the presence of common trends in the yield of grain and legume crops and the application of mineral, organic fertilisers and pesticide treatment using the mutual correlation function (1).

Accordingly, three models were constructed: in the first, the resulting variable is the yield of grain and legume crops, and the influencing factor is the amount of mineral fertiliser application (kg/hectare); in the second model, the resulting variable is the yield of grain and legume crops, the influencing factor is the application of organic fertilisers (tons/hectare); in the third model, the resulting variable is the yield of grain and legume crops, the influencing factor is pesticide treatment (kg/hectare).

For the first model, the correlation coefficient was 1.0, which indicates a significant impact of mineral fertiliser application on yield. In the second model, the maximum value of the correlation coefficient reached 0.5912, but there were negative values, which indicate a low level of correlation. As for the third model, the maximum value of the correlation coefficient was 0.7256, which indicates a closer relationship than in the previous model. The results obtained correspond to the situation described above regarding the specifics of the impact of fertilisers and pesticide treatment on the level of yield. In the Kherson region, the influential factor is precisely mineral fertilisers and pesticide treatment, not organic fertilisers. To some extent, this can be explained by the specifics of the region's soils, but there are grounds for risks regarding excessive application of mineral fertilisers against the background of underestimation of the potential of organic fertilisers and the presence of fewer possible negative consequences from their use.

Taking into account the existence of interrelationships, econometric modelling was carried out using the Cobb-Douglas function and a regression model was constructed, in which the resulting indicator is crop yield, and the influencing factors are the amounts of mineral fertiliser application and pesticide treatment. To determine the coefficients a_0, a_1 and a_2 were used MS Excel. As a result, we obtained the following data: coefficient values $a_2 = 1.0496399$, $a_1 = 1.002898$, $a_0 = 5.7316155$; standard errors of these coefficients 0.0275036; 0.0167969 i 0.1418608 accordingly; coefficient of determination $R^2 = 0.708326$; F-criterion value = 4.04166.

Received the model: $\ln Y = 5.731616 + 1.002898 \ln K + 1.049639 \ln L$. So, the Cobb-Douglas function has the form:

$$Y = 308.46722 \times K^{1.002898} \times L^{1.049639}, \qquad (1)$$

where K – amounts of mineral fertilisers applied (in g/hectare); L – amounts of pesticides applied (in g/hectare); y – yield of grain and legume crops (kg/hectare).

The tabular value for the t-criterion = 0.277 (at α = 0, 20), that is, only one experimental value: 2.9967; more than the tabular value, the others are 0.1854 and 2.1433. Therefore, there are grounds for concluding that the correlation coefficients regarding the density of the relationship between the dependent and explanatory variables in the proposed model are, but incomplete. Let's consider another version of the model and build a regression model in which is taken into account only the effect of mineral fertiliser application on yield. Let's build and consider a model of the form:

$$\ln Y = \ln a_0 + a_1 \ln K. \qquad (2)$$

To determine the coefficients a_0 and a_1 it will be used the capabilities of MS Excel. As a result, we will obtain the following data: coefficients $a_1 = 1.0913$, $a_0 = 2.3598$; standard errors of these coefficients are 0.0291; 0.1215, respectively; coefficient of determination R2 = 0.4228; value of F-criterion = 9.5229; significance 0.008676. So, there is a model: $\ln Y = 2.3598 + 1.0913 \ln K$. Moving on to the Cobb-Douglas function, it is: $Y = 10.5891 \times K^{1,0913}$.

Let's assess the significance of the proposed model. $F_{table} = 6.94$ at a significance level of α = 0,05 (probability 0.95, for degrees of freedom m – 1 = 2 – 1 = 1 and n – m = 15 – 2 = 13). Thus, $F_{fact}(9.5229) > F_{table}(9.07)$, which means that the corresponding econometric model is statistically significant, i.e. the hypothesis that the quantitative assessment of the relationship between the dependent variable (yield) and the explanatory variable (mineral fertilisers) in the model is significant with a probability of 0.95 is confirmed.

Let's check the significance of the correlation coefficient. The tabular value for the t-criterion = 3.012 (at α = 0, 95), the experimental values: 5.4902; 3.0861 are greater than the tabular value, which allows us to conclude that the correlation coefficients, which characterise the density of the relationship between the dependent (yield of grain and legume crops) and the explanatory variable (volume of mineral fertiliser application) in the proposed model, are reliable with a probability of 0.95. Thus, the proposed Cobb-Douglas function in this case is correct and the model is significant and can be used to model an effective system of sustainable land use.

As a result of the war, there was a noticeable decrease in profits from grain export operations. Thus, the total profit from exports in 2022 was only 13.8% of the same Figure for 2021. In 2023, the situation deteriorated further: the total profit from exports was only 5.2% of the corresponding Figure for 2021. This indicates that the war is hindering the realisation of the region's agricultural potential for export. (Agriculture, forestry and …, n.d.).

Pre-war statistical data of the Kherson region indicate that the total area of agricultural land with fertile lands was 1,968.4 thousand hectares, including 1,770 thousand hectares of arable land. According to the Kherson Regional State Administration, 1,396 hectares of agricultural land are located on the left-bank (occupied) part of the region. On the territory where 515 thousand hectares, or 36.9% of the land area, are cultivated. That is, 881 thousand hectares of land, or 63.1%, are not cultivated due to the war (Economic Statistics / Economic…, n.d.). According to the information of the occupiers, the quality of the grain stolen by them is only 40% of the standards for food wheat, which can be the result of both agro-technological measures and the use of grain varieties resistant to arid climate. In 2022, the enemy exported all the grain stored in elevators from the occupied territories. The problems of spring sowing did not concern him. Therefore, one could only count on the harvest of winter varieties. Spring sowing practically did not take place, or the remains of low-quality grain were sown. In June 2023, after the destruction of the Kakhovka reservoir, the water of which was actively used in the irrigation system of the left-bank Kherson region, the problems of flooding of agricultural lands and the impossibility of irrigating the lands were added. As a result, part of the lands was not cultivated, which created additional consequences that will need to be overcome after the de-occupation of the Left-Bank Kherson region.

As part of improving the situation in the Right-Bank Kherson region, measures to support farmers have already been approved, and a number of relevant programs are planned for 2024. In particular, agricultural producers from de-occupied and war-affected territories who cultivate up to 120 hectares will be able to receive eight thousand UAH in non-refundable aid for each hectare. Farmers who keep from three to 100 cows will receive seven thousand UAH for each animal, and those who raise up to 500 sheep and goats will also be entitled to appropriate financial support (State support programs…, 2024). Such measures will help increase the productivity of agricultural production. Restoring the pre-war level of agricultural production and productivity is a more complex task that will require a significant amount of investment. Farmers can count on partial compensation for losses, the amount of which is still being calculated today.

Given Ukraine's strategic goal of becoming a member of the European Union, it is essential to take into account the aspect of its sustainable development in the issues of economic recovery from the consequences of the russian-Ukrainian war. Especially since Ukraine has officially supported a number of international decisions on sustainable development, such as the "Agenda for the 21st Century" (Agenda for the…, 1992). In this regard, the study by I. Alieksieienko *et al.* (2023) on the sustainable development of territories in the post-war period deserves attention, in which Ukrainian scientists substantiated the need to transform the conceptual principles of sustainable development of territories in the period of post-war ecological restoration of states. Using the example of post-war ecological restoration in Bosnia and Herzegovina, researchers have proven that sustainable development goals are effective vectors for improving the state of the environment during the period of post-war ecological restoration. A study of the European and Japanese experience of restoration after military conflicts made it possible to propose acceptable approaches to the reconstruction of Ukraine. The survey helped to determine the start dates and priorities for the restoration of these territories. Based on these data, a concept of sustainable development of territories was formulated, represented by its post-war cognitive model. We fully share the need to take into account the goals of sustainable development in the post-war restoration of Ukraine, including the fertile layer of agricultural land, since Ukraine joined the world community in achieving these goals in 2017 (Martynovych *et al.,* 2023).

In the context of sustainable development of the world economy, it is useful to study the well-known models of landscape restoration ecology, carried out by J. Aronson *et al.* (2017), who argue that in the presence of large-scale damage, it is important to consider both ecological restoration and ecological rehabilitation only as two different components in the "family" of restoration measures that should be deployed, including changed agricultural management practices to ensure continued human activity and more environmentally safe and sustainable land use. Scientists presented a new model for planning, monitoring and evaluation, expansion and application of restoration measures in new areas, which contributed to the formation of the author's approach to the study. O. Tur (2022) identi

The destruction of agricultural soils during the war is one of the current issues being studied by Ukrainian scientists, since the myth of significant reserves of the best black soil in the world has been debunked. Ukrainian black soil has been destroyed over the past century by extensive agricultural practices, crop rotation violations, and during the war by mechanical, physical, and chemical influences. Thus, in samples taken in areas of combat operations, the content of heavy metals exceeded background values by 15-30 times. Just one shelling by the Grad multiple launch rocket system makes it impossible to conduct agricultural activities for about five years (Mohylnyi, 2024). The fundamentality of the study and the validity of the conclusions of O. Mohylnyi (2024) proved the severity of the existing problem of the loss of the quality of the fertile layer of agricultural land, including from the military aggression of the russian federation, which became the leitmotif of this work.

As a result of the shelling with "Grads", the soil is deformed in all directions of the shock wave, and as a result of the burning, explosion and detonation of ammunition, various by-products are formed, most of which are toxic and dangerous, including, in particular, heavy metals. Under such conditions, the primary accumulation of pollutants occurs in the soil with subsequent redistribution both in the soil itself and their transfer to other environments – surface and groundwater, vegetation and living organisms (Presentation at the…, 2023). The authors logically focused on finding effective measures to control the technogenic load on soils and propose eco-technological optimisation of the control and restoration of soil fertility of agricultural lands during the period of high risk of their rehabilitation through the use of bee pollen produced by bees from white marigold pollen as a bioindicator for monitoring the content of toxicants in soils as a source of soil fertility restoration (Presentation at the…, 2023). Soil microbiocenosis as a functional component that determines the reduction process, humus formation, intensification of enzymatic activity, soil respiration, and contributes to an increase in the quantitative composition of amino acids has become the subject of research by scientists at the Institute of Agroecology and Environmental Management of the National Academy of Agrarian Sciences of Ukraine (Presentation at the…, 2023). A valuable contribution of the study was the focus of scientists' attention on the need to diversify control measures and restore soil fertility, which contributed to the definition and detailing of mathematical methods for assessing the impact of the russian-Ukrainian war in a particular region.

The issue of methods for monitoring damaged agricultural soils affected by the war is also in the focus of Ukrainian and foreign scientists. In particular, researchers at the Scientific Centre for Aerospace Research of the National Academy of Sciences of Ukraine have proposed a method for mapping minefields using centimetre resolution images from a helicopter-type unmanned aerial vehicle (UAV) equipped with a multispectral camera and a thermal infrared camera. The new remote method for obtaining minefield maps involves the following procedures: mission planning and aerial photography, aerial photo processing, digital image mosaic production, smoothing and pixel-by-pixel classification, decision-making and documentation (Popov *et al.,* 2022). Remote sensing of land plots for identifying war-affected territories is also proposed by independent researcher A. Shmurak (Presentation at the…, 2023). The ability to remotely monitor affected agricultural land plots helped to select the correct information sources for further analysis.

Considerable attention is paid by scientists to the analysis of existing methods for assessing damage from chemical soil pollution. In particular, a group of Ukrainian researchers calculated the amount of damage from soil pollution in accordance with the Methodology proposed by the Ministry of Environmental Protection and Natural Resources of Ukraine dated 04.04.2022 No. 167 (Order of the Ministry No. 167…, 2022). According to the calculations, the amount of damage to 1 ha of arable land contaminated with petroleum products will be 506 thousand UAH/ha in 2023, while the norm for the Kyiv region as of December 18, 2023 is 2,362 thousand UAH/ha, which is 4.66 times more. That is, in the proposed Methodology of the Ministry of Environmental Protection of Ukraine, the final results of the amount of damage are underestimated (Tretyak *et al.,* 2024). Such conclusions are of great importance for calculating the total environmental, and economic damage from the war in terms of assessing the amount of reparations that will be presented by the russian federation after the Victory. The authors propose an approach based on the theory of the replacement value of assessing the damage caused to land resources that suffered as a result of military actions in the territories of regions, and for territorial communities. In the authors' opinion, the task of scientifically substantiated development, and adoption of relevant regulatory, and methodological documents remains relevant (Tretyak *et al.,* 2024).

An important issue for the restoration of war-affected soils is the search for effective, and cheap methods for their study, in particular, a team of Ukrainian scientists proposed a magnetic method for assessing processes in the soil, and minimising risks associated with improper farming, which was practically applied on a plot of agricultural land in the Kharkiv region (Menshov *et al.,* 2023). Another method – field, agronullometric analysis is used to study soil quality by scientists of the National Scientific Centre "Institute of Soil Science and Agro chemistry named after O.N. Sokolovsky" – I. Plisko *et al.* (2023). The use of various methods for soil assessment confirmed the need for interdisciplinary research that can optimise monitoring results, and determine future methods for managing agricultural territories.

T. Hanson (2018) analyses the relationship between armed conflict, and biodiversity, and considers it using the time frame of the ecology of war, which defines war as an ongoing process of three overlapping stages: preparation, war (armed conflict), and post-war activities. The researcher draws attention to the need to raise awareness of the conservation of biodiversity in military lands, the potential of scientific, and conservation activities to mitigate the negative impact on biodiversity in combat zones, as well as the importance of the post-war period for incorporating biodiversity priorities into reconstruction and recovery efforts, which correlates with our position on the current, and post-war recovery of war-affected territories. The importance of this issue is emphasised by another group of scientists (Hryhorczuk *et al.*, 2024), who draw attention to the fact that in addition to the huge human losses, Russia's war against Ukraine has a devastating impact on the natural, and anthropogenic environment, and a just peace requires their reconstruction, and restoration, which stimulates research into the environmental consequences of the war in order to take more effective measures to protect the environment. The conclusions of the scientists emphasised the importance of maintaining the biodiversity of the natural environment, and formed confidence in the need for permanent monitoring in rural areas that were occupied, suffered from shelling, or are under occupation (Tkachenko, 2024).

Valuable for this study is the ability to compare its results with similar ones. Such work is the dissertation study by G. Gibson (2012), in which the author assessed changes in cultivated agricultural areas in Iraq using satellite remote sensing during, and as a result of the war. The author's conclusions regarding the reasons for the reduction in the area sown for grain crops during, and after the war are interesting. Unlike the impact of the russian-Ukrainian war on agricultural lands, in Iran the reduction in the area sown did not occur due to the contamination of the fertile layer or its destruction, but due to purely political motives, and levers. Thus, in the author's opinion, economic sanctions against the country affected the reduction in the area sown, and agricultural production more than military actions.

Reclamation as an artificial restoration of soil fertility, and vegetation cover after man-made disturbance of the fertile layer, which includes the consequences of war, is considered by scientists as one of the first, and primitive, and therefore debatable, methods of restoring soil quality. Thus, L. Campbell *et al.* (2019) consider it possible to apply passive reclamation to the ecosystem of estuaries, which are degraded due to anthropogenic development, which leads to a decrease in the suitability of the habitat for biological communities. A team of Spanish scientists: J.D. Peco *et al.* (2021) emphasise that traditional reclamation methods are expensive, labour-intensive, and therefore cannot be used on a large scale. However, over the past 20 years (from 2000 to 2021), plant technologies, according to the authors; have gained recognition as an environmentally friendly alternative. Plants can be used for phytoextraction, Phyto stabilisation, and Phyto evaporation. The authors consider it necessary to use these Phytoremediation methods for the restoration of contaminated soils, paying special attention to the selection of appropriate plants in each specific case. The conclusions of the scientists are valuable for the management of rural areas, as they exclude the reclamation of land, the volumes of which in the affected areas are quite large, and offer a list of alternative restoration methods that may be appropriate in the conditions of restoration of Ukrainian lands.

The institutional aspect of the problem of current and post-war restoration of war-affected territories is also of great importance, which is why a number of scientists pay attention to it. In particular, R. Tytykalo *et al.* (2022), studying the environment of Ukraine destroyed as a result of military actions, came to a logical conclusion about the important role of local governments in the most operational, and differentiated response to all problems arising in the affected territories, since the problem of environmental restoration is complex, and therefore requires coordination of the efforts of all community entities, and their active participation in this important matter. At the same time, the authors emphasise that an important aspect is the establishment of properly coordinated interaction between state authorities, and local governments, taking into account the principle of subsidiarity. The integration of interdisciplinary efforts of scientists, practicing farmers, state administration bodies, and local governments will help to detail the problem even during the war, determine a list of priority actions for the liberated territories, and optimise processes for the future.

Conclusions

Before the start of the full-scale russian-Ukrainian war, the Kherson region was among the leaders in the production of grain, legumes, and sunflowers. The war caused a reduction in the cultivated area by more than 50%. The irrational structure of the cultivated area is also a result of the war – sunflower occupies the majority of the sown area of the Kherson region. Significant crop losses in the unoccupied territory occurred due to fires caused by shelling. The conduct of hostilities in the controlled territories of the Kherson region affected the reduction of wheat and barley yields, while the yield of maize significantly increased due to the use of the optimal structure of applied organic, inorganic fertilisers and pesticides.

Studies of the impact of droughts on crop production in the Kherson region using ASI, NDVI, and NDVI anomalies show that droughts are not a critical factor affecting crop productivity. Restoring irrigation of territories through the use of the Ingulets irrigation system will improve the situation. Analysis of the impact of agro-technological measures on the level of crop yields proves that the application of mineral fertilisers and pesticide treatment has a significant impact on the yield of grain and leguminous crops in the region, while the importance of the use of organic fertilisers' remains underestimated. The use of an econometric model based on the Cobb-Douglas function will facilitate management decisions regarding fertiliser application and pesticide treatment, and will contribute to increasing yields while minimising the risks of negative consequences from their use. A scientific approach to land use becomes particularly important in wartime, when the traditional negative factors that reduce the quality of the fertile soil layer are combined with the impact of substances that enter the soil as a result of shelling.

The practical benefit of the work lies in the possibility of applying an integrated approach to monitoring and assessing the quality of agricultural land not only in war-affected areas, but also for permanent monitoring of land quality to make optimal management decisions regarding its effective use. Since the study is regional in nature, the proposed method can be adapted and applied to other areas in future studies. Further work may focus on expanding the geography of research, introducing new soil quality indicators, and improving the monitoring system to increase the efficiency of land management in the face of climate and economic change.

Acknowledgements

None.

Conflict of interest

The authors of this study declare no conflict of interest.

References

[1] Agenda for the XXI century. (1992). Retrieved from http://surl.li/krzwnj.
[2] Agriculture, forestry and fisheries. (n.d.). Retrieved from http://surl.li/asypgc.
[3] Alieksieienko, I., Koltun, V., Grynchuk, N., Vakulenko, V., & Kohut, O. (2023). Sustainable development of territories during the period of post-war environmental restoration. *WSEAS Transactions on Environment and Development*, 19(31), 350-360. doi: 10.37394/232015.2023.19.31.
[4] Aronson, J., Blignaut, J.N., & Aronson, T.B. (2017). Conceptual frameworks and references for landscape-scale restoration: Reflecting back and looking forward. *Annals of the Missouri Botanical Garden*, 102(2), 188-200. doi: 10.3417/2017003.
[5] Campbell, L., Sizmur, T., Juanes, F., & Gerwing, T.G. (2019). Passive reclamation of soft-sediment ecosystems on the North Coast of British Columbia, Canada. *Journal of Sea Research*, 155, article number 101796. doi: 10.1016/j.seares.2019.101796.
[6] Earth Observation. (n.d.). Retrieved from: http://surl.li/lrcrma.
[7] Ecocide: 10 environmental consequences of Russia's war against Ukraine. (2023). Retrieved from https://rubryka.com/article/naslidky-viiny-dlia-dovkillia/.
[8] Economic Statistics / Economic Activity / Agriculture, Forestry, and Fishing / Agriculture. (n.d.). Retrieved from http://surl.li/zdzvuj.
[9] Fire information for resource management system. (n.d.). Retrieved from https://firms.modaps.eosdis.nasa.gov/.
[10] Gibson, G.R. (2012). *War and agriculture: Three decades of agricultural land use and land cover change in Iraq.* (Doctoral dissertation, Virginia Tech, Blacksburg, USA).
[11] Hadzalo, Y. (2023). *Domestic agriculture in modern conditions: Challenges and ways to overcome.* Kyiv: Agrarna Nauka. doi: 10.31073/978-966-540-600-6.
[12] Hanson, T. (2018). Biodiversity conservation and armed conflict: A warfare ecology perspective. *Annals of the New York Academy of Sciences*, 1429(1), 50-65. doi: 10.1111/nyas.13689.
[13] How to save soils from the consequences of war? (2023). Retrieved from http://surl.li/bumami.

[14] Hryhorczuk, D., Levy, B.S., Prodanchuk, M., Kravchuk, O., Bubalo, N., Hryhorczuk, A., & Erickson, T.B. (2024). The environmental health impacts of Russia's war on Ukraine. *Journal of Occupational Medicine and Toxicology*, 19(1), article number 1. doi: 10.1186/s12995-023-00398-y.
[15] Husakov, V. (2023). *Only 36.9% of agricultural land is used in the occupied part of Kherson region.* Retrieved from http://surl.li/afpalz.
[16] Main Statistical Office in the Kherson Region. (n.d.). Retrieved from http://surl.li/amppjb.
[17] Mamchur, V., & Studinska, G. (2023). Innovative development of the agrarian sphere under the conditions of the implementation of the national system of sustainability. *Economy and Society,* 56. doi: 10.32782/2524-0072/2023-56-144.
[18] Martynovych, N., Boichenko, E., & Dielini, M. (2023). Rebuilding of Ukraine after war: Special restoration regimes and stimulation of sustainable development of territories. *International Review for Spatial Planning and Sustainable Development,* 11(4), 54-70. doi: 10.14246/irspsd.11.4_54.
[19] Menshov, O., Kruglov, O., Vyshva, S., Ivanik, O., Horoshkova, L., & Tonkha, O. (2023). Geophysical methods in geohazards assessment for precision agriculture: Case study from Ukraine. *European Association of Geoscientists & Engineers, 84th EAGE Annual Conference & Exhibition*, 2023, 1-5. doi: 10.3997/2214-4609.2023101221.
[20] Menshov, O., Kruglov, O., Vyzhva, S., Horoshkova, L., Pereira, P., Pastushenko, T., & Dindaroglu, T. (2021). Landscape position effects on magnetic properties of soils in the agricultural land Pechenigy, Ukraine. *Earth Systems and Environment,* 5(3), 739-750. doi: 10.1007/s41748-021-00240-7.
[21] Moderate resolution imaging spectroradiometer. (n.d.). Retrieved from https://modis.gsfc.nasa.gov/about/.
[22] Mohylnyi, O. (2024). *Agricultural sector of Ukraine: The raw material trap. Part II.* Kyiv: NNC "IAE".
[23] Nakonechnyi, S., Tereshchenko, T., & Romaniuk, T. (2004). *Econometrics: Textbook (3rd ed., revised and updated).* Kyiv: KNEU.
[24] Order of the Ministry of Environmental Protection and Natural Resources of Ukraine No. 167 "On Approval of the Methodology for Determining the Amount of Damage Caused by Land, Soils Due to Emergencies and/or Armed Aggression and Hostilities During Martial Law". (2022, April). Retrieved from https://zakon.rada.gov.ua/laws/show/z0406-22#Text.
[25] Peco, J.D., Higueras, P., Campos, J.A., Esbrí, J. M., Moreno, M.M., Battaglia-Brunet, F., & Sandalio, L.M. (2021). Abandoned mine lands reclamation by plant remediation technologies. *Sustainability,* 13(12), article number 6555. doi: 10.3390/su13126555.
[26] Plisko, I., Romanchuk, K., & Krylach, S. (2023). Mechanical and physical degradation of arable soils as a result of military operations in Ukraine. *Bulletin of Agricultural Science,* 101(10). doi: 10.31073/agrovisnyk202310-01.
[27] Popov, M., Stankevich, S., Mosov, S., Titarenko, O., Dugin, S., Golubov, S., & Andreiev, A. (2022). Method for minefields mapping by imagery from unmanned aerial vehicle. *Advances in Military Technology,* 17(2), 211-229. doi: 10.3849/aimt.01722.
[28] Presentation at the international scientific and practical conference on sustainable restoration of agricultural landscapes after military actions. (2023). Retrieved from http://surl.li/hedija.
[29] State support programs for agricultural producers in 2024. (2024). Retrieved from https://dia.dp.gov.ua/programi-derzhavno%D1%97-pidtrimki-agrari%D1%97v-shho-diyut-u-2024-roci/.
[30] Studinska, G. (2023). The influence of innovations in the agrarian sphere on changes in the sectoral structure of the national economy. *Market Relations Development in Ukraine*, 97(10(289)), 25-34. doi: 10.5281/zenodo.10403189.
[31] Tkachenko, S. (2024). Post-war economic recovery in Ukraine: Problems, risks and ways. *Economies' Horizons*, 2-3(28), 4-13. doi: 10.31499/2616-5236.2(28).2024.300402.
[32] Tretiak, A., Tretiak, V., Priadka, T., Kapinos, N., Hunko, L., Tretiak, R., & Tretiak, N. (2024). Protection of lands in Ukraine: Scientific and management solutions in the conditions of military actions. *Land Management, Cadastre and Land Monitoring*, 41(1). doi: 10.31548/zemleustriy2024.01.02.
[33] Tur, O. (2022). Consequences of military aggression as a basis for the formation of anti-crisis economic policy of Ukraine. *Problems of Modern Transformations. Series: Economics and Management*, 1(4). doi: 10.54929/2786-5738-2022-4-03-06.
[34] Tytykalo, R., Pavlovska, N., & Andriiets, M. (2022). Economic and administrative methods of restoration by local governments of the environment of Ukraine destroyed as a result of military operations. *Baltic Journal of Economic Studies*, 8(5), 184-190. doi: 10.30525/2256-0742/2022-8-5-184-190.
[35] VIIRS+CrIS Data Fusion Level-2. (n.d.). Retrieved from http://surl.li/tuhbkl
[36] Visible infrared imaging radiometer suite. (n.d.). Retrieved from https://www.earthdata.nasa.gov/data/instruments/viirs.

Оцінка впливу російсько-української війни на аграрний потенціал Херсонської області

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▶ **Анотація.** Актуальність дослідження полягає у необхідності оцінки впливу російсько-української війни на аграрний потенціал Херсонської області через значні економічні та екологічні збитки, зокрема, знищення і забруднення ґрунтів, що потребує термінового моніторингу їх якості та відновлення родючості для відновлення аграрної сфери регіону. Оцінка впливу російсько-української війни на аграрний потенціал Херсонської області та визначення перспектив його повоєнного відновлення були обрані за мету даної роботи. Дослідження здійснено з використанням загальнонаукових та спеціальних методів вивчення явищ і процесів: аналізу та синтезу, системний аналіз, метод аналогії і моделювання, системний аналіз, методи збору та обробки інформації. У якості інформаційної бази для аналізу використані дані баз NASA FIRMS, супутникові знімки Sentinel-2, а також знімки пожеж з ресурсу Giovanni. Додатково залучені результати відстеження супутників MODIS, VIIRS та VIIRS 2 Suomi. Здійснена взаємна кореляція врожайності сільськогосподарських культур та індексу Agricultural Stress Index, що доводить відсутність серйозного впливу посухи на врожайність сільськогосподарських культур Херсонської області за виключенням найбільш посушливих років. Встановлено залежність між врожайністю зернових, зернобобових культур та внесенням добрив і обробленням пестицидами через використання функції взаємної кореляції. Побудовано модель впливу внесення мінеральних добрив та пестицидів з використанням економетричної функції Кобба-Дугласа, що дозволяє прогнозувати оптимальні умови введення сільськогосподарського виробництва. Висновки, пропозиції та практичні рекомендації будуть корисними у розробці відповідних програм та заходів, спрямованих на повоєнне відновлення сільськогосподарського грунту та загальний розвиток аграрного виробництва країни

▶ **Ключові слова:** аграрне виробництво; врожайність; якість грунту; добрива та пестициди; індекс Agricultural Stress Index; функція взаємної кореляції; функція Кобба-Дугласа