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Analysis of effective sunflower cultivation zones using the example of Ukraine

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Abstract. The article provides a comparative analysis of the area of sunflower cultivation from 2000 to 2023 broken down by regions of Ukraine for two conditional periods of 2000–2010 and 2011–2021, and 2022–2023 war years. Thus, during the period under research the average area of sunflower seed cultivation increased from 2.84 million ha in 2000 to 6.66 million ha in 2021 i.e. by 2.34 times. The increase of these areas occurred due to the reduction of the area allocated for the cultivation of other crop rotations. During the first conditional period (2000–2010) Dnipropetrovsk and Zaporizhzhia regions which geographically belong to the steppe zone of Ukraine became the leaders with an area of sunflower cultivation of more than 500,000 ha (on average 469.8 and 487.8 thousand ha of sunflower). During the second conditional period (2011–2021) Dnipropetrovsk and Zaporizhzhia regions maintained their leadership (573.5 and 564.7 thousand ha). The zone of effective sunflower cultivation has expanded due to the expansion of cultivated areas in Kirovohrad region (550.6 thousand ha) which is situated on the border of the northern part of steppe and forest steppe. The occupation of a part of Ukraine pushed back Zaporizhzhia region from leading positions in sunflower cultivation while Dnipropetrovsk and Kirovohrad regions had more than 600,000 ha in 2022–2023. The further increase of cultivation areas at the expense of other crops contradicts the laws of agriculture and the zonal recommendations of scientific institutions. Therefore, an increase in the gross harvest of sunflower seeds is possible only due to the improvement and adaptation of cultivation technology, a balanced selection of sunflower hybrids better adapted to climate changes.

Key words: sunflower, gross harvest, climate change, effective cultivation zones.

INTRODUCTION

The favorable natural and climatic conditions for growing the vast majority of crops and strong human potential allow Ukraine not only to ensure its own food security, but also to become an active player on the global food market (Ulianchenko et al., 2014; Akdemir et al., 2017; Vasylkovska et al., 2021). An increase in the production of

agricultural products is impossible without the use of new growing technologies, the introduction of modern varieties and hybrids, and the rational use of zonal natural and climatic conditions. Therefore, the issue of mastering the latest technologies for growing agricultural crops which ensure the reduction of the gap between the potential and actual plant productivity combining such concepts as 'efficient' and 'comfortable' cultivation remains especially relevant (Vasylkovska et al., 2022).

Sunflower is the most preferred vegetable oil in Eastern Europe, the Balkans and the Black Sea region, and is the main oilseed crop in these regions (Kaya, 2020).

A basic understanding of food security primarily involves the availability and accessibility of food. Global food security is linked to international trade and food supply chains.

Barrera (2011), Debaeke et al. (2017), Čedík et al. (2018), Embrapa et al. (2018), Esfahani et al. (2019), Melnyk et al. (2020), Franchuk et al. (2022), Braun et al. (2023), Maryna & Yankovska (2023), and others were the researchers involved in the study of food security, in the analysis of the cultivation of agricultural products that are necessary to ensure food security, in the study of the effective cultivation of sunflower seeds.

Research conducted by Esfahani et al. (2019) aimed to draw public attention to the food crisis and various strategies for achieving food security in the countries around the world. The important element of food security is the provision of food to the population, and the processed products of sunflower, fats and E-group vitamins play a significant role in the food balance (Vasylkovska et al., 2022).

The use of biofuels is a possible way to ensure energy security (Čedík et al., 2018). Biofuels are used to reduce the impact of fossil fuel combustion on the atmosphere and reduce dependence on fossil fuel products.

The issue of food security became especially acute with the start of the full-scale war launched by Russia against Ukraine that affects the whole world. Ukraine is involved in the global food supply structure of primarily agricultural products and their processed products, so the full-scale Russian invasion significantly increased the risks of deterioration of food security at the global level (Embrapa et al., 2018; Maryna & Yankovska, 2023; Petrenko et al., 2024).

The countries of the Middle East and Africa are largely dependent on the agricultural products of Ukraine, especially on imports of grain and sunflower oil, which can cause problems with food security (Trunina et al., 2021; Braun et al., 2022).

In 2021, before the start of the war Ukraine ranked 58th among 113 countries according to the Global Food Security Index (Franchuk et al., 2022). However, with the beginning of the war the state of food security in the country significantly worsened, which according to the results of 2022 led to its fall in the specified rating to the 71st position in the world and the last place among European countries (Food security. International food policy research institute).

By applying export duties on sunflower seeds, Ukraine exports mainly sunflower oil, adding oils from other crops almost every year (Kaya Y. 2020; Vasylkovska et al., 2021).

The high liquidity of sunflower production in Ukraine is due to its export orientation. Therefore, a high level of farming culture is the basis for the production of competitive agricultural products (Tsymbal et al., 2022).

One third of the foreign exchange earnings from selling agricultural goods and their processed products is brought to the country through sunflower oil sales. However, the

complexity and in some cases the impossibility of exporting agricultural products and their processed counterparts through the ports of Black Sea reduces the inflow of foreign exchange earnings into the country (Kaya Y. 2020; Melnyk et al., 2020).

It should be noted that as early as 1,883 about 150,000 ha of sunflowers were grown in Ukraine.

In the pre-war year 2021, 16.3 million tons of sunflower seeds were collected in Ukraine from the area of 6.7 million ha. As a result of the occupation of a part of the country the area under sunflower cultivation decreased to 5.2 million ha in 2022, from which 10.5 million tons of sunflower seeds were collected. The decrease of both numbers from 2022 to 2021 turned out to be proportional amounting to 22.4% and 35.5%. That is, despite difficult political conditions, uncertainty and adverse weather conditions, the country managed not to reduce the size of the agriculture sector and plant productivity. That leads us to the conclusion that despite all adverse circumstances Ukraine is still ready to be among the guarantors of food security in the world.

The effective sunflower cultivation zones do not coincide with the zones of its comfortable cultivation. Thus, the areas where sunflower was traditionally grown are becoming less favorable for its cultivation requiring other more flexible crops or irrigation. The zones of comfortable cultivation of sunflower are shifting to the northwest of the country while the effective cultivation zones remain in the borders of the southern, eastern and northern steppes of Ukraine while increasing the area of cultivation at the expense of other agricultural crops (Vasylkovska et al., 2022).

The features of hybrids that determine their suitability for cultivation in the face of climate change are their plasticity to growing conditions, drought tolerance and suitability for early sowing to utilize winter moisture reserves (Debaeke et al., 2017; Miladinović et al., 2019).

The change in climatic conditions and as a result the change in land use technology requires the following stabilizing actions: the transition from classical farming technology to energy-saving technologies that involve minimal passage through a field, preservation of plant residues in the fields, reduction of fuel consumption and the impact of chemicals, improvement of quality seed production. These are the links in the food supply chain and a strategy used to achieve food security (Barrera, 2011; Tsymbal et al., 2022).

Therefore, the analysis of the effective sunflower seeds cultivation zones in Ukraine against the background of changes in climatic conditions is an urgent problem.

MATERIALS AND METHODS

The purpose of this article is to analyze the effective sunflower cultivation zones across the regions of Ukraine. The increase in the gross harvest of sunflower seeds over the past decades was not only due to the increase in yield, but also due to the increase in the sown areas.

The analysis of the expansion of the area of sunflower cultivation in Ukraine was carried out based on the zonal distribution.

The analysis of the sown areas of sunflower was carried out with the breakdown according to the regions of Ukraine.

The starting point of the research was 2000, and the end point was 2021. Thus, the research covers a period of 22 years which is divided into the following two conditional periods: the first conditional period (2000–2010) and the second conditional period (2011–2021).

The obtained results make it possible to visually assess the quantitative and qualitative changes in the effective sunflower cultivation zones.

In addition, a comparative analysis of the areas of effective sunflower cultivation for two conditional periods with data obtained during 2022–2023 against the background of Russia's military aggression was conducted.

The data from the State Statistics Service of Ukraine (Official site of the State Statistics Service of Ukraine), An official website of the European Union (Eurostat) and An official website of the International Association of Official Statistics (IAOS) was used in the research.

Statistical mathematical models and Microsoft Office Excel application program package were used for data analysis and construction of graphs (Vasylkovskyi et al., 2016).

RESULTS AND DISCUSSION

The main oil crop in Ukraine is sunflower. Currently, agricultural enterprises are actively engaged in the introduction of soybean and rapeseed into production, but the undisputed leader among oilseed crops in terms of the area occupied is sunflower.

The main sunflower growing regions are Ukraine, Russia, the EU, Argentina and China. Argentina is the only one that is not a Eurasian producer and has recently decided to increase soybean and maize crop areas (Vasylkovska et al., 2021).

Before the full-scale invasion, Ukraine was the world leader in gross sunflower harvest and sunflower oil production and export. During the last five pre-war years about 15 million tons of seeds were produced annually in Ukraine, but since 2022 the gross harvest rate has decreased by 25–30% due to military operations and the occupation of part of the country's territory.

There is a gradual and constant expansion of crop areas due to the high demand for oilseed derived products and the level of marginal returns from growing these crops. Thus, during the period under research the area under sunflower cultivation increased from 2.84 million ha in 2000 to 6.67 million ha in 2021 i.e., by 2.35 times.

Climatic changes, non-observance of the rules of crop rotation and violations of sunflower cultivation technology are the reasons for its unstable harvests in the southern and eastern regions of the country. Therefore, the creation of new hybrids with high genetic and adaptive potential, the use of high-quality seeds and the introduction of modern cultivation technologies should ensure an increase in the level of production efficiency due to an increase in yield at an optimal level of sown areas (Molinero-Ruiz, 2019; Melnyk et al., 2020).

It’s well-known that the increase in the gross harvest of sunflower is possible only at the expense of increasing its yield (Vasylkovska et al., 2021), because the area of sunflower cultivation has already reached the limit rate. There was a redistribution of agricultural areas in the direction of more profitable crops and a significant increase in the area of sunflower cultivation at the beginning of the century with the entry of Ukraine to the world market of agricultural products. Their further growth is unlikely as it

contradicts the basic principles of ecological agriculture and will lead to depletion and degradation of the country's soils.

In previous studies, a comparative analysis of sunflower yield maps for two conditional periods was conducted in order to analyze the changes in the areas of comfortable conditions for growing sunflowers for 2000–2021. The zone of higher sunflower yields has moved from the central regions to the northwest of the country. At the same time, the transition of the southern regions to a zone with very low productivity took place (Vasylkovska et al., 2022).

Arid conditions have always been an obstacle for effective agriculture in Ukraine since most of its territory belongs to the zone of unstable and insufficient moisture. The number of rainless periods during the growing season of grain and oil crops can reach on average from 50 to 90 days in the steppe zone of Ukraine. In most cases, they are accompanied by increased temperature and decreased relative air humidity which leads to atmospheric and soil drought (Vasylkovska et al., 2021).

Due to its increased resistance to soil and air drought sunflower is considered a fairly drought-resistant crop. The temperature and other soil and climatic conditions of the forest steppe and steppe of Ukraine meet the biological needs of sunflower and are favorable for its cultivation. The northern regions of Ukraine are somewhat risky in this regard. However, the area of effective sunflower cultivation is precisely the steppe zone where the conditions for growing this crop are less favorable, and the yield is correspondingly lower (Andriienko et al., 2020).

However, the terms ‘comfortable cultivation’ and ‘efficient cultivation’ should be distinguished. Comfortable cultivation of agricultural crops is a cultivation in which the culture develops in the best way and at the same time gives the highest yield. Effective cultivation of agricultural crops is in turn a cultivation in which the largest amount of harvest is collected regardless of the yield obtained. Thus, if we analyze the sown areas across the regions of Ukraine, we will understand where sunflower seeds are collected the most.

The analysis of sunflower cultivation areas for the specified years in certain regions of Ukraine makes it possible to evaluate the transformations of these areas which occurred under the influence of changes in climatic conditions and hybrid assortment of sunflowers (Tables 1 and 2; Figs 1, 2). So, on average, during the first conditional period (2000–2010) the area of sunflower cultivation in different regions varied between 0.2–487.8 thousand ha while during the second conditional period (2011–2021) it was 3.59–573.5 thousand ha.

Let's consider each conditional time segment separately. In the first conditional period (2000–2010) the leaders among the regions of Ukraine were Zaporizhzhia with the average sunflower cultivation area of 487.8 thousand ha, and Dnipropetrovsk with 469.8 thousand ha. That is, to the first group of regions we included those where the area of sunflower cultivation exceeded 400,000 ha (Fig. 1, a – brown color). It should be noted that the increase in the area of sunflower cultivation in these regions was not gradual, but a sharp increase took place in 2003. And in the last five years of the first conditional period this number was consistently higher than 500,000 ha. According to geographical zoning, both regions belong to the steppe of Ukraine and border each other. The northern border of Zaporizhzhia region borders Dnipropetrovsk region, and the southern border is the long coast of the Sea of Azov.

Table 1. Sown areas of sunflower for the first conditional period (2000–2010) broken down by regions of Ukraine, thousand ha

No	Region / Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Avg. value.
1	Crimea	70.0	30.5	29.6	35.8	35.0	35.9	37.9	24.5	31.6	21.2	26.5	34.4
2	Vinnytsia	51.7	43.7	50.2	79.6	73.2	78.7	74.4	70.6	118.7	106.9	163.3	82.8
3	Volyn	0.0	0.0	0.0	0.1	0.1	0.2	0.1	0.2	0.5	0.3	0.2	**0.2**
4	Dnipropetrovsk	344.3	309.9	381.1	573.8	458.8	474.7	504.4	478.8	540.8	541.4	559.4	**469.8**
5	Donetsk	317.6	276.1	314.5	366.4	344.2	331.3	376.4	397.4	443.1	434.9	429.3	**366.5**
6	Zhytomyr	0.7	0.2	0.8	2.7	2.9	4.8	3.6	2.0	5.0	6.6	17.5	**4,3**
7	Zakarpattia	1.0	1.1	1.6	2.2	2.0	2.1	2.0	1.9	1.5	1.8	2.0	**1,7**
8	Zaporizhzhia	348.2	322.1	374.7	455.0	508.4	520.2	579.7	536.1	594.4	555.9	571.2	**487.8**
9	Ivano-Frankivsk	0.6	0.5	0.6	0.5	0.7	0.7	0.2	0.3	0.7	1.2	3.6	**0.9**
10	Kyiv	21.7	11.6	14.5	34.2	22.6	34.6	33.5	27.0	44.6	44.6	66.2	32.3
11	Kirovohrad	238.6	203.2	240.4	369.2	318.9	367.6	349.7	296.4	409.0	408.5	417.4	**329.0**
12	Luhansk	228.9	195.7	222.3	267.5	253.7	271.1	287.4	286.5	333.5	351.4	362.8	278.3
13	Lviv	-	0,0	0,1	0,2	0,3	0,2	0,6	-	0,1	0,0	0,1	**0.2**
14	Mykolayiv	235.1	199.9	217.6	385.5	325.0	355.4	392.9	274.7	420.2	401.1	396.6	**327.6**
15	Odesa	265.8	227.8	243.7	333.5	278.8	292.9	292.0	168.3	232.6	220.6	227.4	253.0
16	Poltava	158.2	116.7	137.8	214.2	154.6	186.9	185.6	169.8	212.1	217.1	236.7	180.9
17	Rivne	0.1	0.0	0.1	0.0	0.1	0.2	0.3	0.3	1.5	1.1	2.6	**0.6**
18	Sumy	41.6	26.1	28.0	38.7	22.0	29.0	33.1	32.5	63.1	60.4	85.5	41.8
19	Ternopil	1.5	0.9	0.9	1.3	1.1	1.2	4.4	1.9	6.9	5.2	10.8	**3.3**
20	Kharkiv	237.8	195.5	217.5	299.2	250.4	274.0	269.9	276.1	326.4	344.1	434.7	284.1
21	Kherson	177.6	167.6	164.4	210.0	256.1	281.0	351.8	259.9	327.8	290.5	294.1	252.8
22	Khmelnytskyi	4.2	2.4	2.6	5.6	6.3	5.0	5.1	5.1	14.1	15.2	27.6	**8.5**
23	Cherkasy	80.0	51.6	62.8	113.1	92.9	121.2	107.7	88.5	123.1	134.5	145.2	101.9
24	Chernivtsi	6.5	6.2	7.2	9.1	11.3	9.3	7.2	4.2	5.6	4.5	6.1	**7.0**
25	Chernihiv	9.9	6.8	6.5	12.6	7.6	10.9	11.8	8.4	22.6	24.0	39.0	14.6
Ukraine 2000–2010		**2,841.6**	**2,396.1**	**2,719.5**	**3,810.0**	**3,427.0**	**3,689.1**	**3,911.7**	**3,411.4**	**4,279.5**	**4,193.0**	**4,525.8**	**3,564.1**

Table 2. Sown areas of sunflower for the second conditional period (2011–2021) broken down by regions of Ukraine, thousand ha

No	Region / Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Avg. value
1	Crimea	54.5	69.2	83.8	*	*	*	*	*	*	*	*	69.2
2	Vinnytsia	148.0	157.4	166.7	193.0	187.0	266.7	248.2	259.9	246.2	288.7	307.6	224.5
3	Volyn	1.2	2.9	1.9	2.8	2.5	6.4	15.9	23.6	31.4	39.6	39.8	15.3
4	Dnipropetrovsk	492.8	533.2	515.8	558.1	536.3	631.4	625.1	592.7	593.2	621.9	608.1	**573.5**
5	Donetsk	432.1	454.0	445.1	411.0	316.8	332.5	335.0	311.1	314.6	332.3	357.7	**367.5**
6	Zhytomyr	35.9	47.2	49.9	69.8	60.6	91.9	107.4	142.7	117.9	145.6	154.8	93.1
7	Zakarpattia	2.8	3.7	7.1	3.6	2.7	3.2	3.1	2.7	3.8	3.2	3.6	**3,6**
8	Zaporizhzhia	609.4	595.1	552.6	578.9	536.1	601.9	571.3	568.8	535.6	526.4	535.4	**564,7**
9	Ivano-Frankivsk	5.6	7.9	8.4	16.3	12.1	23.1	31.6	24.8	23.9	23.4	31.8	19,0
10	Kyiv	86.0	86.2	108.2	116.8	116.0	165.6	164.8	191.7	159.4	185.4	208.6	144,4
11	Kirovohrad	464.7	481.6	507.1	544.8	547.8	577.4	553.7	588.8	572.9	610.0	608.0	**550,6**
12	Luhansk	359.3	362.1	365.9	296.8	308.4	339.5	361.1	361.2	375.7	403.5	442.2	**361,4**
13	Lviv	1.1	2.6	8.1	14.2	11.0	26.3	35.1	34.1	25.5	31.4	40.5	20,9
14	Mykolayiv	382.0	467.7	437.5	459.1	475.6	558.5	532.6	559.9	499.2	513.0	518.0	**491,2**
15	Odesa	301.5	393.7	380.5	371.8	418.0	468.6	453.8	413.6	364.7	356.6	415.8	**394,4**
16	Poltava	233.8	241.5	250.3	284.3	315.2	312.5	311.7	329.8	323.6	383.6	387.5	**306,7**
17	Rivne	3.1	6.5	1.9	3.1	4.2	13.2	24.6	24.2	27.7	37.8	41.0	17,0
18	Sumy	116.4	134.6	161.5	175.5	175.2	196.9	201.7	213.4	236.7	281.5	266.3	196,3
19	Ternopil	13.0	12.2	13.4	19.4	30.9	55.1	82.1	70.8	59.9	89.8	83.2	48,2
20	Kharkiv	374.4	386.6	391.5	429.4	402.8	486.6	484.9	529.0	528.0	604.3	582.0	**472,7**
21	Kherson	323.1	354.7	296.1	312.4	300.6	383.3	356.6	341.7	353.0	335.3	348.9	**336,9**
22	Khmelnytskyi	35.7	40.1	40.7	34.6	40.0	115.8	146.2	157.5	140.2	175.6	162.5	99,0
23	Cherkasy	157.8	139.9	156.5	177.7	190.1	203.4	203.4	201.9	201.4	232.3	257.4	192,9
24	Chernivtsi	7.0	8.0	7.5	5.1	10.4	19.6	17.3	19.6	12.5	20.1	21.9	13,5
25	Chernihiv	75.4	93.1	132.1	133.7	165.9	207.3	193.5	203.0	211.9	239.6	242.5	172,5
Ukraine 2011–2021		**2,841.6**	**4,716,6**	**5,081.7**	**5,090.1**	**5,212.2**	**5,166.2**	**6,086.7**	**6,060.7**	**6,166.5**	**5,958.9**	**6,480.9**	**6,665.1**

* – there is no data since 2014 due to the Russian military invasion and the illegal seizure of Crimea.

The second group of regions (300–400 thousand ha of sunflowers) that also have significant areas of sunflower cultivation includes Donetsk with an average for this period of 366.5 thousand ha, Kirovohrad with 329.0 thousand ha, and Mykolayiv with 327.6 thousand ha (Fig. 1, a – red color). It should be noted that the number increased gradually for these regions and during the last three years it crossed the mark of 400,000 ha. This group of regions also belongs to the steppe of Ukraine, in particular Mykolayiv and Kirovohrad regions are positioned as parts of the southern and northern steppe respectively.

The next one is the third group of regions (200–300 thousand ha of sunflowers) with sufficiently high numbers of sunflower cultivation areas. This group includes Kharkiv region where the average sunflower cultivation area amounted to 284.1 thousand ha, Luhansk region with 278.3 thousand ha, Odesa region with 253.0 thousand ha, and Kherson region with 252.8 thousand ha (Fig. 1, a – orange color). The increase in the area of sunflower cultivation in the mentioned regions also happened gradually, and in the last three years of the specified period it exceeded 300 thousand ha, except for the Odesa region. Odesa and Kherson regions represent the southern steppe and have access to the Black Sea. Luhansk region belongs to the northern steppe, and Kharkiv region is part of the forest steppe.

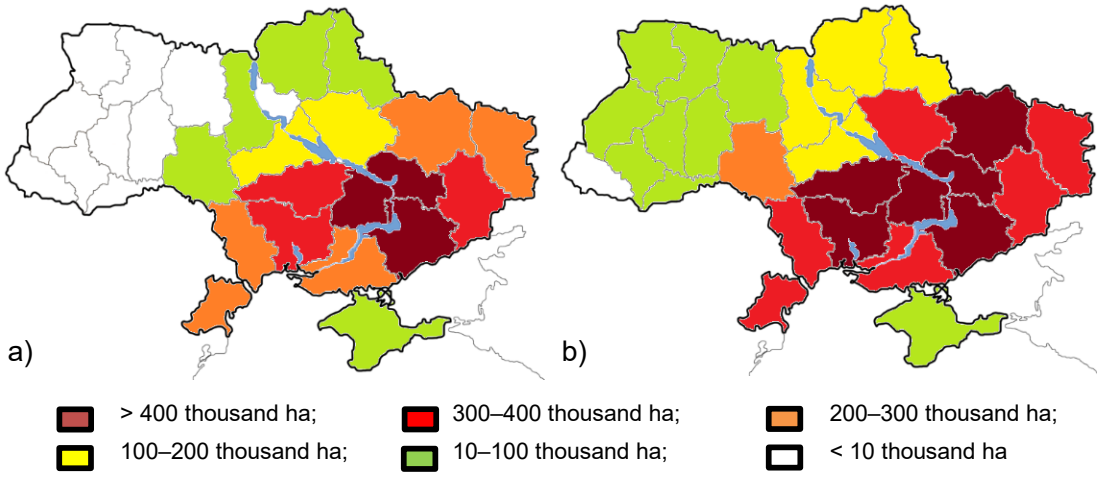

Figure 1. Maps of sunflower sowing areas for the conditional periods of 2000–2010 and 2011–2021 by regions of Ukraine.

Thus, all regions with significant areas of sunflower cultivation (first, second and third groups) belong to the steppe zone of Ukraine which is characterized by a significant annual amplitude of air temperature, a limited amount of precipitation, and periodic lack of moisture during the vegetation period.

The fourth group of regions (100–200 thousand ha of sunflower) includes Poltava and Cherkasy regions with sunflower cultivation area of 180.9 and 101.9 thousand ha respectively (Fig. 1, a – yellow color). Both regions belong to the forest steppe which is a transitional natural zone between the zone of mixed forests (Polissia) and the steppe. The annual amount of precipitation gradually increases according to the following principle: steppe – forest steppe - Polissia, so these areas have a more favorable water regime, but not so rich soils.

The fifth group of regions (10–100 thousand ha of sunflowers) has low numbers of sunflower cultivation areas and consists of the following regions: the Autonomous Republic of Crimea with 34.4 thousand ha, Vinnytsia region with 82.8 thousand ha, Kyiv region with 32.3 thousand ha, Sumy region with 41.8 thousand ha, and Chernihiv region with 14.6 thousand ha (Fig. 1, a – green color). It should be noted regarding the peculiarities of the regions of this group that it is very diverse in terms of geographical zoning. Therefore, in Crimea sunflower cultivation takes place in the steppe zone which is located to the north of the mountain range. Vinnytsia and Sumy regions are located in the forest steppe, and a large part of Kyiv region, and the entire Chernihiv region belong to Polissia. The 'cutting' of the area by a dense network of rivers and the formation of swamps is typical for the last two of them. Winter there is mild, with frequent thaws, especially in the west.

The last, sixth group (up to 10,000 ha of sunflowers) includes the following regions with a very low level of sunflower cultivation areas: Volyn, Rivne, Zhytomyr, Ivano-Frankivsk, Ternopil, Khmelnytskyi, Lviv, Zakarpattia, and Chernivtsi regions (Fig. 1, a – without color). On average, during the first conditional period, the area of sunflower cultivation in each of them ranges from 0.2 to 8.5 thousand ha. Volyn, Rivne, and Lviv regions where this number is the lowest should be mentioned in this regard. In 2000 and 2007 sunflowers were not sown at all in Lviv region. Volyn and Rivne regions partly belong to the Polissia zone and partly to the forest steppe zone, that is, the zone of broad-leaved and mixed forests. At the same time, it should be taken into account that due to the negative reaction of sunflower to cultivation on acidic soils, in Polissia it was recommended to allocate no more than 1% of arable land for it.

Thus, after conducting the analysis of the effective sunflower cultivation zones for the first conditional period (2000–2010) it can be stated that sunflower had the largest cultivation areas in the regions of the steppe zone, especially the southern ones (Fig. 1, a). It should be noted that the expansion of sunflower cultivation areas during this period occurred gradually due to the reduction of the cultivation areas of less profitable agricultural crops.

The comparative diagram for the years 2000–2010 and 2011–2021 makes it possible to estimate the area of sunflower cultivation during the conditional periods.

During the next period under research i.e., the second conditional period (2011–2021) the further transformation of sunflower cultivation areas took place in individual regions. At the same time there were quantitative (increase of an area within a region) and qualitative (transition of regions from one conditional group to another) changes among the regions of Ukraine. Quantitative changes can be traced using the comparative diagram for 2000–2010 and 2011–2021 (Fig. 2), and qualitative changes are shown on the map of sunflower acreage for the conditional periods in the regions of Ukraine (Fig. 1).

To a large extent the reason for these changes is the pursuit of profit which did not leave anyone behind, and those farms that did not grow sunflower before, or did not grow it in significant quantities, turned their attention to it.

As it was already mentioned, the cultivated area of sunflower grew steadily during the second conditional period (2011–2021) throughout the territory of Ukraine (Table 2, Fig. 1, b) and increased from 3,564.1 to 5,749.0 thousand ha. The largest increase in the area of sunflower cultivation was observed in the following regions: Kirovohrad

(one of the leaders of the second conditional period) with 221.6 thousand ha, Kharkiv and Mykolayiv with 188.5 and 163.6 thousand ha respectively.

The first group of regions significantly expanded due to the addition of Kirovohrad and Mykolayiv regions which moved from the second group (300–400 thousand ha), as well as Kharkiv region which moved from the third group (200–300 thousand ha) due to the rapid growth of the sunflower cultivation area.

Similarly to the first conditional period, the first group includes those regions where the area of sunflower cultivation exceeded 400,000 ha. However, it steadily exceeded 0.5 million ha in such regions as Dnipropetrovsk (573.5 thousand ha), Zaporizhzhia (564.7 thousand ha) and Kirovohrad (550.6 thousand ha) (Fig. 1, b – brown color). It should also be noted that Mykolayiv (491.2 thousand ha) and Kharkiv (472.7 thousand ha) regions with a slightly smaller area of sunflower cultivation have also crossed the 500 thousand ha mark in the last five years.

The second group of regions (300–400 thousand ha) also underwent transformation. Just like the previous period it includes Donetsk region with an average sunflower cultivation area of 367.5 thousand ha. Odesa (394.4 thousand ha), Luhansk (361.4 thousand ha) and Kherson (336.9 thousand ha) regions moved from the third group to the second due to the increase in the area used for sunflower cultivation. It is interesting that Poltava region moved from the fourth group directly to the second one due to the growth of the number under research to 306.7 thousand ha (Fig. 1, b – red color). If we look at the map of Ukraine, we will see that territorially these regions are close to the leaders, and belong to the steppe zone and partly to the forest steppe zone.

The third group (200–300 thousand ha) includes only Vinnytsia region which is located in the forest steppe. Sunflowers were grown on an area of 224.5 thousand ha there. It is worth noting that during the second conditional period the area of sunflower cultivation in Vinnytsia region increased almost three times compared to the first one which ensured its transition from the fifth group directly to the third one (Fig. 1, b – orange color).

The fourth group of regions (100–200 thousand ha) includes Sumy (196.3 thousand ha), Cherkasy (192.9 thousand ha), Chernihiv (172.5 thousand ha), and Kyiv (144.4 thousand ha) regions (Fig. 1, b – yellow color). The attention has to be drawn to the fact that during the specified period the area of sunflower cultivation in Cherkasy region did not increase significantly. The region did not change its group, but on the contrary a significant increase in the number under research caused the transition of all other regions from the fifth group to the fourth one. The regions that formed the fourth group are compactly located in the northern part of the country and represent forest steppe and Polissia.

The fifth group of regions with a small area of sunflower cultivation (10–100 thousand ha) has also undergone significant changes. Crimea remained an unchanged part of the group, and all the others moved from the sixth group due to the significant expansion of land areas allocated for this profitable crop. Therefore, the group includes Khmelnytskyi (99.0 thousand ha) and Zhytomyr (93.1 thousand ha) regions, the Autonomous Republic of Crimea (69.2 thousand ha), Ternopil (48.2 thousand ha), Lviv (20.9 thousand ha), Ivano-Frankivsk (19.0 thousand ha), Rivne (17.0 thousand ha), Volyn (15.3 thousand ha), and Chernivtsi (13.5 thousand ha) regions. It is immediately noticeable that in Khmelnytskyi and Zhytomyr regions the area of sunflower cultivation exceeded 100,000 hectares during the last five years. All regions of the fifth group,

except Crimea, belong to the west and northwest of the country where the sunflower has never been widespread, but its popularity is gaining momentum every year, and the cultivation areas are constantly growing. If we talk about zonal classification, then these regions, apart from the steppe Crimea, belong to Polissia, the zone of deciduous forests, and the Carpathians.

Zakarpattia was the only representative of the sixth group (up to 10,000 ha). The area of sunflower cultivation there doubled during the period under research, but it still remained small amounting to 3,600 ha.

Analysis of the maps of sunflower sowing areas (Fig. 1) makes it possible to evaluate the leaders of cultivation over time in Ukraine. As we can see when comparing the maps of sunflower sowing areas for two conditional periods (Fig. 1), there was an expansion of sunflower cultivation areas. The expansion of cultivation zones took place in the steppe, as well as the forest steppe and Polissia zones of Ukraine.

Thus, with an increase in average annual temperatures and a decrease in seasonal precipitation sunflower fields began to move from the southern arid regions to the north and west of the country where the climate over the past 50 years has become somewhat warmer and more favorable for this culture. The phytosanitary conditions of the new regions of sunflower cultivation are close to optimal, and the negative impact of the main harmful organisms has significantly decreased starting from the central forest steppe zone to the Polissia zone. A number of the following reasons that limited the cultivation of sunflower in the farms of the steppe zone are absent in the northern regions: the parasite weed sunflower broomrape (*Orobanche cumana*), the causative agents of the main diseases, and climatic conditions. Violation of the crop rotation rules and high saturation of the sunflower crop caused a sharp increase in the contamination of the fields by the broomrape (Andriienko et al., 2020; Duca et al., 2023).

The further development of Ukraine's agriculture and the increase in sunflower production were threatened by Russian military aggression. Therefore, the biggest problem for Ukraine is not just a decrease in the area of cultivation of sunflowers and other agricultural crops, but the loss of control over a significant part of Zaporizhzhia, Donetsk and Kherson regions as well as the entire Luhansk region. Hence regarding the year 2022 it will be more appropriate to talk not about the area sown with sunflowers, but about the area from which it was possible to harvest it since part of the sown areas came under occupation, some were destroyed including those that were deliberately burned by the enemy, on some part of the areas the harvest was grown, but not collected due to hostilities and the destruction of agricultural machinery.

Thus, in 2022 the area where sunflowers were harvested decreased by 31% compared to the previous year i.e., from 6.7 million ha to 4.6 million ha. But in 2023 they somewhat increased and amounted to 5.2 million ha. This is due, inter alia, to the successful military campaign for the liberation of the occupied territories, the restoration of agricultural activities and the logistics infrastructure.

But not only the loss of territory is the reason for the fall in productivity, but also the complication of conducting economic activities in general and agriculture in particular. Therefore, the regions that always sowed and collected a large amount of sunflower seeds but suffered partial occupation sharply reduced the area of sunflower cultivation. Thus, on the comparative diagram (Fig. 2) we can see that in Donetsk region 113.9 thousand ha of sunflower were sown in 2022–2023 which is only 31.8% of the

pre-war cultivation volume. In Zaporizhzhia region 141.2 thousand ha (26.4%) were sown, and in Kherson this number was only 12.9 thousand ha (3.7%).

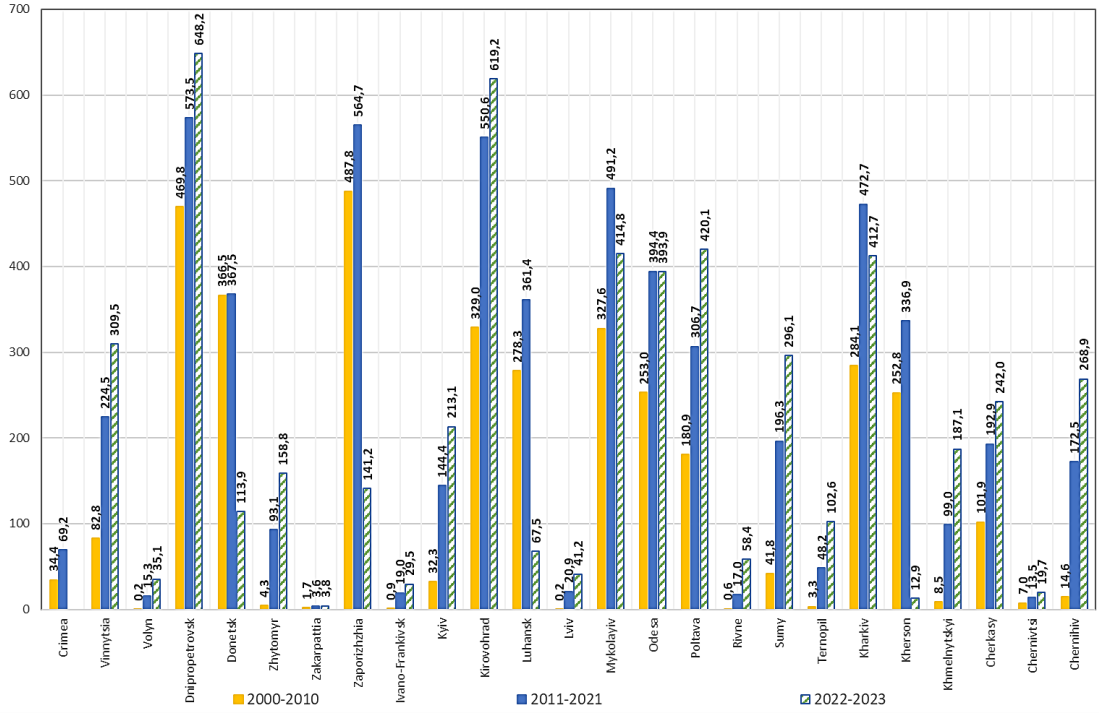

Figure 2. Comparative diagram of sunflower seed cultivation areas for the following conditional periods: 2000–2010, 2011–2021, and 2022–2023.

A separate problem is the issue of using precise technologies and GPS in wartime. Agricultural production in Ukraine is quite technically developed. Producers widely use elements of precision agriculture, GPS, agricultural drones to monitor fields and apply technological materials. All this requires stable and high-quality GPS coverage. Interruptions in the operation of communication and GPS systems occur during air raid alerts due to the use of missiles and reconnaissance and combat drones by the aggressor country which negatively affects the execution of technological processes, and in some cases makes them impossible. The problem is exacerbated in areas closer to the combat zone.

The demand for Ukrainian oil in the world in the pre-war period gave impetus to the development of the domestic oil industry, however, the high profitability of sunflower production carries certain risks. An increase in sunflower acreage reduces the share of other less profitable crops in crop rotation. Therefore, the further expansion of sunflower seed sowing areas is not rational, and the increase of the gross harvest becomes possible only due to the change of cultivation technology, the use of adapted zoned hybrids, the use of energy-saving technologies, and the preservation of moisture in the soil.

Ukraine accumulated potential for a while and had an extremely difficult time entering the world market of agricultural products. Finally, since the end of the last decade it has become the world leader in the export of sunflower oil. Ukraine had all the

prerequisites for a further increase in the export of sunflower seed processing products which was facilitated by active integration processes, market orientation towards the EU and Asian countries. Ukrainian sunflower oil was actively bought by India, EU countries, China, and countries of Western and South Asia. However, with the start of a full-scale destructive war launched by Russia against Ukraine in February 2022 the export of agricultural crops and their processing products was stopped. Due to the hard efforts of the Ukrainian army which moved the combat zone away from the Black Sea ports and the diplomatic efforts of Ukraine and the world it became possible to resume trade in the top export positions for Ukraine which provide the opportunity to receive foreign exchange earnings for the preservation of the country's economic potential and survival.

CONCLUSIONS

It should be noted that despite the full-scale war in Ukraine and active military operations in the East and South of the country, constant air raid alerts and missile attacks by Russia agricultural enterprises of Ukraine are trying to grow the entire range of agricultural crops and even sell a significant part of the produced and processed products.

During the period under research the area of sunflower cultivation increased from 2.84 million ha in 2000 to 6.66 million ha in 2021 i.e., by 2.34 times. During the first conditional period (2000–2010) it increased by 1.6 times, and during the second one (2011–2021) grown by 1.4 times. The occupation of part of Ukraine removed Zaporizhzhia region from among the leaders in sunflower cultivation while Dnipropetrovsk and Kirovohrad regions have more than 600,000 ha in the period of 2022–2023. The further increase of cultivation areas at the expense of other crops contradicts the laws of agriculture and the zonal recommendations of scientific institutions, therefore, an increase in the gross harvest of sunflower seeds is possible only due to the improvement and adaptation of cultivation technology, a balanced selection of sunflower hybrids more adapted to climate change.

The change in climatic conditions, the shift of comfortable cultivation zones to the northwest of the country, the expansion of effective cultivation zones in the steppe and forest steppe zone, the change in the variety and hybrid composition make it possible and profitable to grow sunflower in regions that were previously considered not suitable for this.

The research presented in this article will be the basis for further study of changes in the hybrid composition of sunflower for individual climatic zones based on the State Register for each of the mentioned periods.

Therefore, it is extremely important to preserve the potential of Ukraine in the world market of sunflower oil which is an important element of food security of Ukraine and the world.

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