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DIVERSIFICATION OF OIL CROPS IN THE SOUTHERN STEPPE OF UKRAINE: ADAPTATION TO CLIMATE CHANGES AND ENVIRONMENTAL CONDITIONS

The leading role in the economy of Ukraine's agro-industrial complex belongs to the production of oilseed crops, which not only provide stable profits for producers but also positively impact the state's food security as a whole. Oilseed plants, particularly sunflowers, are highly liquid and enjoy stable demand in both domestic and foreign markets, increasing the area cultivated with these crops. However, in recent decades, the most significant growth has been observed in sunflower cultivation, which has led to a deterioration in the phytosanitary condition of fields, water regime issues, soil compaction, drying out, weed infestation, reduced yields of subsequent crops, climate change, and so on. The article analyzes the dynamics of oilseed crop cultivation in the Mykolaiv region from 2013 to 2023. State statistics indicate an increase in the area allocated for oilseed crops from 407.3 thousand hectares in 2013 to 476.2 thousand hectares in 2023. Most sown areas are occupied by sunflowers, whose share fluctuates between 70.1 % and 90.1 %. At the same time, the area under soybeans has decreased; however, a recovery was observed in 2023. Rapeseed, the second most important crop, shows fluctuations in area, reaching 117.6 thousand hectares in 2023. The yield of oilseed crops varies depending on climatic conditions and cultivation technologies; rapeseed demonstrates stable results (1.77–2.36 tons per hectare). The article also discusses the results of cultivating flaxseed, safflower, and brown mustard. In particular, despite its low yield, flax has growth potential due to its drought resistance and export opportunities to EU countries. The purchase prices for flax indicate high demand for this niche crop. The article emphasizes the importance of adapting technologies and varieties to ensure stable yields and increase the profitability of oilseed crop production in the region. Thanks to modern cultivation technologies, the yield of oilseed crops has increased from 23.6–28.8 % to 51.6 %. Introducing new elements will contribute to further yield increases without expanding cultivated areas. This will allow for the redistribution of oilseed crop sowing areas and partially diversify them, ensuring the adaptation of agroecosystems to climate change and the preservation of soil fertility. Additionally, the range of quality oils will increase. Research in this direction should continue as new varieties, substances, and fertilizers emerge.

Keywords: *plants of the oil group, winter rape, oil flax, sunflower, structure of sown areas, elements of technology, varieties and hybrids, productivity.*

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1. Introduction

Oilseed crops are crucial in today's agro-industrial complex, particularly regarding profitability. This group of plants has many uses: edible oils, biofuel production, paints, varnishes, cosmetics, animal feed, and more.

Sunflowers have gained the most popularity in recent decades among various oilseed crops. However, with global climate change and the deterioration of fertility indicators – such as soil drying and weed infestation – the issue of selecting other, less common oilseed crops is becoming increasingly relevant. The problem of diversifying oilseed plants is urgent. Specifically, some sunflower acreage will be gradually replaced with alternative drought-resistant crops characterized by high-quality, valuable oils that are economically attractive and less demanding in terms of growing conditions [1, 2]. Their inclusion in crop rotations could reduce economic risks, mitigate adverse impacts on soil fertility, and address climate change, partly due to the significant saturation of crop rotations with demanding crops like sunflower.

Diversifying oilseed crops can help ensure sustainable food security and ecological and economic stability in the agricultural sector. This measure can alleviate the risks associated with cultivating sunflowers as a monoculture, counteract climate changes, and reduce the prevalence of pests and diseases. This is supported by research conducted by author of [3], who reports on the positive role of diversifying oilseed plants. According to [4], achieving a broader range of products and more stable production positions by including crops other than sunflower is essential. By selecting less common oilseed plants and reducing sunflower acreage, it is possible not only to improve the structure of sown areas significantly but also to enhance the availability of crops in crop rotations with more favorable predecessors and increase productivity in the agricultural sector [5, 6]. Furthermore, the authors of [7] highlight the increasing adaptation of oilseed plants to diseases and climate changes. The authors report that diversification contributes to the overall resilience of agricultural production in the long term.

By selecting less common oilseed crops, it is also possible to obtain additional sources of oil that possess valuable properties and are

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in demand, as well as reduce dependence on traditionally recognized oils such as sunflower and rapeseed. Scholars who have studied the market and development of the oil and fat industry have drawn such conclusions [8].

Moreover, a growing demand for oils containing less unsaturated fats has grown. In [9] established that oils with such properties can be obtained from flax and hemp seeds. The increase in the area under niche oilseed crops can provide a commercial advantage and economic feasibility for their cultivation. At the same time, a more comprehensive range of oilseed crops will contribute to the preservation of soil fertility and financial stability, ensuring a more sustainable capacity for farms.

This necessitates reevaluating and assessing the selection of oilseed crops, determining their potential to stabilize the ecological and economic situation, soil fertility, climate change, etc., both in Ukraine and the Southern Steppe region.

The aim of this research is to identify the directions for the diversification of oilseed crops, specifically the partial redistribution of areas released from sunflower cultivation to other oilseed plants, and to develop technological elements to increase their productivity based on resource conservation and the reduction of anthropogenic impact on the environment and soils.

2. Materials and Methods

The research on several oilseed crops was conducted on southern black soil at the educational-scientific-practical center of Mykolaiv National Agrarian University from 2022 to 2024. Specifically, under practically identical growing schemes, the most common varieties and hybrids of the following crops were cultivated: winter rapeseed, safflower, oil flax, and significantly less common mustard and brown mustard, which were compared with sunflower, which currently occupies the most significant areas.

The reaction of the variety (hybrid) of the studied oilseed crop to the optimization of nutrition and plant protection in terms of their ability to form productivity was determined.

The experimental scheme included the following variants:

Factor A – variety (hybrid) of the crops.

Factor B – nutrition system: without fertilizers (control); recommended dose for the zone $N_{60}P_{40}$; optimized $N_{30}P_{30}K_{30}$ + soil spraying with the biopreparation Metavait Organic at 10 l/ha, plus pre-sowing treatment of seeds and plant sowing during critical periods of vegetation with modern biopreparations and micronutrients recommended for the cultivation of the studied crops.

Factor C – plant protection system: without protection (control); recommended (treatment with recommended preparations when exceeding the economic threshold of harmfulness); optimized (combination of agrotechnical measures with the use of modern biological origin preparations for treating crop plantings). The research was conducted in 3–4 repetitions. The total area of the plots was 80–120 m^2, with an accounting area of 30–50 m^2. The soil type was southern black soil, with an average supply of mobile forms of NPK and a humus content of 2.8–3.2 % (soil layer 0–30 cm).

All studies were conducted according to the relevant recommendations [10–13]. The years of research were typical for the cultivation zone; however, they varied somewhat in terms of temperature regime and especially in precipitation during the growing season.

3. Results and Discussion

The analysis of state statistics regarding the areas under oilseed crops in the Mykolaiv region indicates a growth trend from 2013 to 2023 (Fig. 1). In 2013, the total area of oilseed crops was 407.3 thousand hectares, which increased to 438.0 thousand hectares in 2018, and further to 476.2 thousand hectares in 2023. Notably, the lion's share of the total structure of oilseeds belongs to sunflowers, which accounted for between 70.1 % to 88.9–90.1 % over the years.

It is worth mentioning that the total volume of oilseed crops also includes soybeans. The area planted with this vital legume crop, known for its role as a precursor, a source of ecological and biological nitrogen fixation, and a plant capable of structuring the soil by enriching it with valuable organic matter, has gradually decreased. Specifically, in 2013, soybeans were sown on an area of 12.3 thousand hectares, which dropped to 5.4 thousand hectares in 2018 and further down to 2.6 thousand hectares in 2022. However, in 2023, this valuable leguminous and oilseed crop occupied 4.5 thousand hectares in Mykolaiv. While this is significantly less compared to 2013, it still represents a substantial increase in area compared to previous years.

The next position in terms of oilseed crop areas after sunflowers in the Mykolaiv region is occupied by rapeseed. In 2013, rapeseed was sown on 46.6 thousand hectares; in 2018 – 36.9 thousand hectares; in 2021 – 59.1 thousand hectares; and by 2023 – 117.6 thousand hectares. Despite significant fluctuations in rapeseed area, the yield of this crop remains stable, ranging from 1.77 to 2.08–2.36 tons per hectare. The region's maximum yield of rapeseed seeds was achieved in 2021, reaching 2.67 tons per hectare.

It should be noted that the yield levels of all crops, not just those in the oilseed group, vary significantly and depend on the weather and climatic conditions of the growing year, the adopted elements of technology, predecessors, selection of varieties or hybrids, and other factors. This can be illustrated by the example of oilseed flax cultivation (Table 1).

The yield of this crop varied significantly under the influence of the studied elements of technology and variety selection. If, on average, from 2022 to 2024, the control yield of seeds for the Orpheus variety was at the level of 1.22 t/ha. For the Dobrodar variety, it was 1.27 t/ha, then under the most favorable combination of nutrition and plant protection factors, it increased to 1.51 and 1.71 t/ha, respectively, or by 23.8 % and 34.6 %. This is quite positive, as besides the yield level, the oil content in the seeds increases, the conditional yield per unit area rises, and other essential quality indicators improve.

It has been established that the productivity indicators of oil flax fluctuated depending on the growing year conditions, with the highest productivity observed in the favorable 2023 year in terms of moisture. The lowest yield was recorded in the arid 2024 year, with a significant difference between the two years.

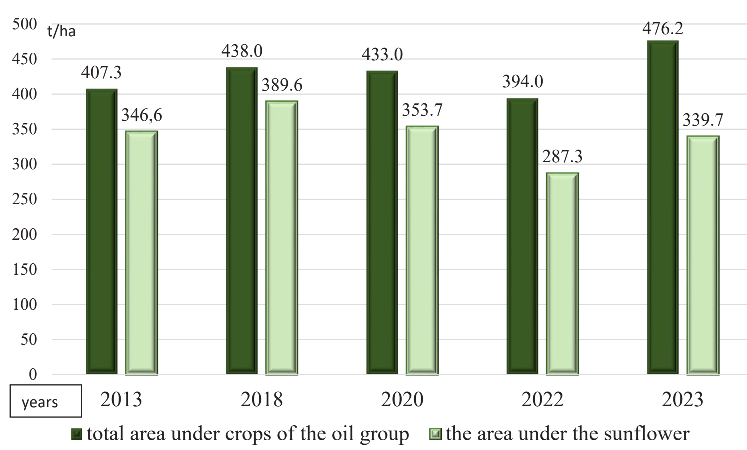

Fig. 1. The Total area of oilseed crops and sunflowers within the Mykolaiv region (according to State Statistics, 2023) is a thousand hectares

Table 1

The yield of oilseed flax varieties under the influence of studied factors, tons per hectare

Nutrient system (Factor B)	Protection system (Factor C)	2022	2023	2024	2022–2024
variety Orpheus (Factor A)					
Without fertilizers	without protection	1.20	1.28	1.17	1.22
	recommended	1.23	1.32	1.20	1.25
	optimized	1.24	1.32	1.20	1.25
Recommended	without protection	1.38	1.49	1.35	1.41
	recommended	1.43	1.56	1.40	1.47
	optimized	1.44	1.57	1.41	1.47
Optimized	without protection	1.44	1.55	1.41	1.47
	recommended	1.45	1.56	1.41	1.47
	optimized	1.46	1.56	1.42	1.51
variety Dobrodar (Factor A)					
Without fertilizers	without protection	1.25	1.36	1.20	1.27
	recommended	1.30	1.42	1.26	1.33
	optimized	1.30	1.42	1.27	1.33
Recommended	without protection	1.45	1.57	1.40	1.47
	recommended	1.48	1.63	1.47	1.53
	optimized	1.49	1.63	1.47	1.53
Optimized	without protection	1.59	1.77	1.50	1.62
	recommended	1.67	1.82	1.57	1.69
	optimized	1.69	1.83	1.61	1.71
LSD05	by Factor A	0.02	0.03	0.01	–
	by Factor B	0.07	0.09	0.08	–
	by Factor C	0.02	0.03	0.01	–
	by Factor ABC	0.09	0.11	0.09	–

The levels of sunflower yields also changed with a similar dependence across years and studied factors. The optimization of nutrition and plant protection contributed to a substantial increase in grain yields of both hybrids of this crop under cultivation, as clearly illustrated in Fig. 2. The Forward hybrid had a higher yield potential on average from 2022 to 2024 compared to P64LE25. The maximum yield was achieved in variants combining optimized nutrition and plant protection systems, where it was 3.19 and 2.51 t/ha for the hybrids, compared to absolute controls of 2.2 and 1.74 t/ha of grain, respectively, demonstrating a significant advantage of the Forward hybrid. Its oil content in the grain was determined to be at 47.0 %, while without fertilizers and plant protection, this indicator was 43.6 %. Naturally, the conditional oil yield per unit area was also significantly higher. This indicates the importance of optimizing nutrition and plant protection in increasing grain yield and improving quality. Similar patterns were established for cultivating other currently less common oilseed crops. For example, the yield of safflower seeds of the Ladynyi variety in control was at the level of 1.57 t/ha, while in the most optimal variant of the experiment, it was 1.90 t/ha; for the Dobrynia variety, these figures were 1.60 and 2.10 t/ha, respectively.

Gray mustard (variety Dijonka) yielded 1.21 and 1.45 t/ha seed yields in the variants above. The variety Zabahanka achieved yields of 1.43 and 1.80 t/ha on average for 2022–2024. An even more significant difference was observed between the studied hybrids of winter rapeseed: on average, over three years of cultivation, the seed yield of the hybrid Abakus was at levels of 1.61 and 1.93 t/ha, while the hybrid Phoenix CL reached 2.02 and 2.56 t/ha, respectively. A similar dependence and difference were found between the varieties of spring turnip: Prestige increased from 1.12 in control to 1.47 t/ha with optimized nutrition and protection, while Euro 12 ranged from 1.19 to 1.57 t/ha of seeds on average for the years 2022–2024.

For all studied oilseed crops over three years, which differed in temperature regime and precipitation, it was established that their yield increased with the improvement of technology elements, mainly through the optimization of nutrition and plant protection during their growing periods. Differences among the selected varieties (hybrids) within oilseed crops were also identified. This indicates the need to choose the most adapted varieties to provide higher and more stable yields regardless of growing year conditions. This will ensure a guaranteed total output of oilseed crops under equal technology elements and weather conditions. In other words, with equal investments in production, profitability will be significantly higher for more productive and regionally adapted varieties (hybrids).

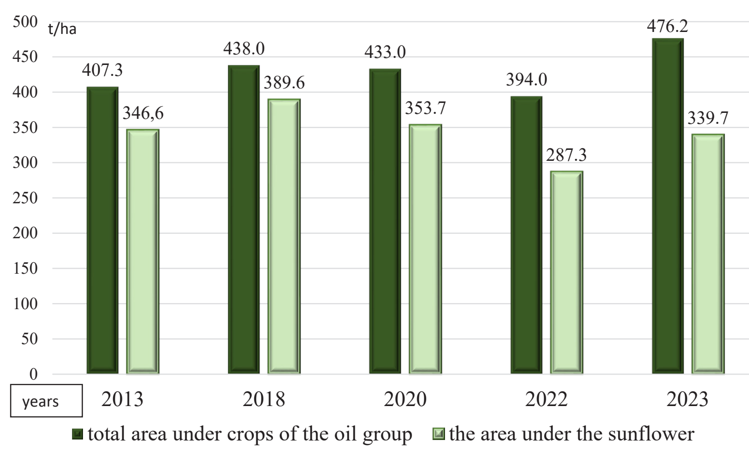

Fig. 2. Grain yield of sunflower depending on the optimization of nutrition and plant protection across hybrids (average for 2022–2024), t/ha

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It should be noted that in the Southern Steppe zone of Ukraine, sunflowers exhibited the highest yield throughout all years of research (Fig. 3). However, in specific farms, particularly in the dry year of 2024, its productivity was significantly lower, reaching as low as 0.7 t/ha. This is related to factors such as the preceding crop, the availability of nutrients for plants, soil structure, weediness, tillage practices, and more.

The next step in research is sowing winter rapeseed, followed by safflower. The cultivation of gray mustard and oil flax provided practically identical seed yield levels, while the lowest seed productivity was observed in turnip. At the same time, this crop has several advantages regarding its use and cultivation, as it is one of the most undemanding to soil fertility and is resistant to diseases and pests. Paying attention to and increasing the areas under oil flax is also necessary. In production, its yield is low, averaging around 1.0 t/ha in most years, although the potential of this oilseed crop can approach 2.0–2.5 t/ha or even more. Flax oil, like turnip oil, is used in the food and medical industries and is a raw material for producing varnishes, paints, oils, etc. Despite their value, these crops remain niche. Regardless of market conditions and global price dynamics, the purchase prices for flax are significantly less dependent on seasonal fluctuations than sunflower or soybean. In February 2024, the purchase price for flax was 500–530 USD/t, while seeds grown using organic technology were priced at 1630–1680 USD/t. Flax is exported by EU countries, which were leaders in purchases in 2022. The flax market will continue to gain relevance. Moreover, this crop has several advantages regarding drought resistance; flax seeds do not shatter and can be sown using no-till systems, which significantly reduces costs, among other benefits.

Considering the demand for niche crops, it is advisable to gradually redistribute part of the area from sunflower to other oilseed crops.

The research results assert that the selection of new varieties (hybrids) of oilseed crops adapted to the growing conditions, along with implementing modern innovative technology elements, contributes significantly to increasing yields and improving the leading quality indicators of seeds. Of course, productivity growth will, in turn, promote economic development, stabilizing producers' profits and ensuring the state's food security.

Although turnip is an undemanding plant, its yield can increase by 0.25 t/ha even with pre-sowing seed treatment. Regarding nutrition optimization, in [14] report on the importance of organo-mineral fertilizers for turnip in enhancing seed productivity, which aligns with our findings. This conclusion was reached by [15].

[16] also emphasize the importance of selecting new adapted varieties that can significantly increase yield levels and seed quality by improving technological elements. This is confirmed by the results of research conducted on oilseed crops by [17–19]. Studies on modern sunflower hybrids have identified the role of soil nutrient availability and their response to nutritional optimization [20].

[21] report on the significance of selecting new varieties (hybrids) of oilseed crops in terms of their ability to increase oil content in seeds.

The main elements of technology significantly affect both yield levels and seed quality. The authors of [22] reported on this, having studied fertilization systems, particularly with organic matter. The need for improving technological elements in the cultivation of oilseed crops has been indicated by several researchers, including [23, 24].

They also established that optimizing technological processes in oilseed crop cultivation can substantially enhance industry productivity and expand the use of new types of oils and alternative energy sources while simultaneously reducing dependence on traditionally standard fuels and preserving the environment.

The impact of different oilseed crops on the environment and the justification of their economic efficiency have been studied by [25, 26]. This aligns with the results of work regarding the negative impact of sunflowers on key soil fertility indicators, especially with prolonged cultivation in the same field. It is better to occupy part of the area under sunflower with other oilseed crops.

In research, the yield levels of all oilseed crops significantly fluctuated due to the weather conditions that prevailed during their growing season. [27] established the influence of climate on the ability of oil plants to form productivity. In this regard, in [28] substantiates the need to select the most resilient and stress-adapted oil crops and their varieties (hybrids), which aligns with research findings.

The results of studies confirm that for the successful cultivation of oilseed crops, it is essential to select the most productive ones, including niche crops with valuable oil qualities, and to improve technological elements. There are no insignificant details in this matter; it is necessary to identify the crops and the most adapted varieties (hybrids) capable of ensuring high yield and seed quality. Technological elements should include resource-saving measures using the most modern effective products for optimizing nutrition, plant protection, etc. This simultaneously increases plants' resilience to adverse factors.

Thus, the authors of [29] report a significant increase in sunflower productivity due to applying modern biopreparations and growth regulators in various combinations. Our previous studies have confirmed this in safflower cultivation [30]. Moreover, optimizing nutrition based on resource conservation using biopreparations significantly enhances the yield level of sunflowers and leads to effective plant moisture utilization.

Growing oilseed crops with higher value than traditional sunflowers opens new horizons for farmers. This not only increases profits but also contributes to a more rational use of resources, which in turn can positively impact the region's economic stability. By choosing more valuable oilseed crops, producers gain the opportunity to expand the range of high-value oils, enhance the profitability of their farms, and ensure sustainable development and food security for the country. In the post-war period, it was especially important to improve soil conditions and strengthen the farms' economy. Oilseed crops can become a reliable tool for achieving these goals. It is essential to

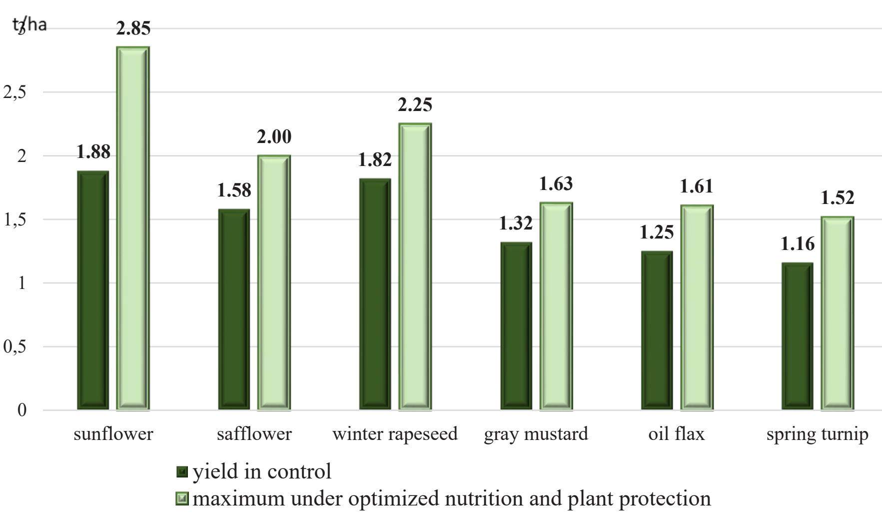

Fig. 3. Average yield of oilseed crops (by varieties and hybrids) in the oilseed wedge (2022–2024), t/ha

select and cultivate these crops carefully, relying on advanced technologies, particularly those developed during our research.

The conducted research, presented in this article, will enable agricultural producers to efficiently utilize land allocated for oilseed crops, particularly by optimizing the redistribution of sunflower-planted areas in favor of less demanding and more profitable niche oilseed crops. Diversification through the introduction of crops such as rapeseed, flax, safflower, or mustard helps restore nutrient balance and improve soil structure.

Such approaches represent an ecologically and economically viable solution for ensuring the sustainable development of agricultural production. They contribute to preserving soil fertility, reducing the use of agrochemicals, increasing the economic profitability of enterprises, and enhancing the productivity of agricultural landscapes.

4. Conclusions

From 2013 to 2023, there has been a significant increase in the area allocated for oilseed crops in the Mykolaiv region, indicating the growing popularity of these crops among agricultural producers. Sunflower remains the primary oilseed crop, occupying a substantial share of the sown area (70.1–90.1 %). This highlights its economic importance to the region. Rapeseed shows fluctuations in sown areas, with a notable increase to 117.6 thousand hectares in 2023, while its yield remains stable, making it an essential element of crop rotation. The yield of all oilseed crops significantly depends on climatic conditions and cultivation technologies, which necessitates adapting technological elements to climate changes. Despite its low yield, oil flax has growth potential due to its drought resistance and export opportunities to EU countries. High purchase prices for flax indicate a stable demand for this niche crop. To ensure stable yields and increase profitability, it is essential to implement new technologies and adapted varieties. Given the demand for less common crops, it is recommended to gradually redistribute areas from sunflower to other oilseed plants, such as flax and rapeseed, which could contribute to the diversification of agricultural production in the region. Thus, the analysis of the dynamics of oilseed crop cultivation in the Mykolaiv region indicates positive trends in the farm sector that require further study and the implementation of effective agro-technologies to ensure sustainable development.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship or other, which could affect the study and its results presented in this article.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial technologies intelligence when creating the presented work.

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