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CLIMATE CHANGE ADAPTATION IN AGRICULTURE: THE CASE OF TERNOPIL OBLAST

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Abstract. The study aims to assess the geographical aspects of agricultural adaptation in the Ternopil region to climate change. Based on the analysis of climatic data, soil conditions, and other natural resources, as well as agricultural production data, the main risks and opportunities for the development of the agricultural sector under climate change conditions have been identified. Specific measures are proposed to enhance the resilience of agriculture to climate change.

Key words: climate change, agriculture, adaptation, Ternopil region, geographical analysis, agro-climatic resources, resilience, yield.

Introduction. Climate change is one of the most urgent global challenges, significantly impacting all areas of human activity, particularly agriculture. The Ternopil region, like many other regions in Ukraine, is experiencing the consequences of climate change, manifested in the increasing frequency of extreme weather events, shifts in the growing season, and changes in precipitation patterns. This creates significant challenges for the agricultural sector of the region, requiring the development of new adaptation strategies. Research on the adaptation capabilities of agriculture in the Ternopil region to climate change is a crucial task, as the results of this study can be used to develop effective measures to ensure food security for the region and the country as a whole.

The aim of the study is to develop scientifically grounded recommendations for enhancing the resilience of agriculture in the Ternopil region to climate change.

The agricultural complex of the Ternopil region plays a crucial role in the development of both the regional and national economies of Ukraine. Agriculture in the region is the main source of food supply for the domestic market and a significant

factor in ensuring the country's food security. In the current context, when the agricultural sector faces new challenges such as climate change, soil degradation, and the need for innovative technologies, the study of its characteristics and prospects is a highly relevant task for both scientists and practitioners.

The Ternopil region is located in the central part of the western region of Ukraine, which determines its climatic and natural conditions, favorable for the development of crop farming and livestock breeding. The total area of agricultural land in the region constitutes a significant portion of the territory, and agricultural activity has historically been the main component of the area's economic structure. This allows the region to focus on the cultivation of a wide range of crops, including cereals, industrial, and vegetable crops, as well as on livestock development, particularly pig farming and dairy cattle breeding [1].

However, the development of the agricultural complex in the Ternopil region faces numerous challenges. These include the depletion of land resources, an increase in droughts due to climate change, insufficient use of modern technologies, and limited access to investment resources. Moreover, the lack of proper infrastructure for the storage and processing of agricultural products reduces the profitability of agricultural production. Such challenges require the development and implementation of new approaches to land resource management, climate change adaptation, and the introduction of innovative technologies into production processes [2].

Given the listed problems and the importance of the agricultural complex, special attention should be paid to analyzing current trends in its development in the Ternopil region. This includes assessing agro-climatic conditions, land potential, and factors that influence the effectiveness of agricultural production. This study aims to substantiate measures that can increase the productivity of the region's agricultural sector and ensure the sustainable development of agricultural production under conditions of limited resources.

Ternopil region is known for its favorable natural and climatic conditions for agricultural production, which ensure a high level of yield for key crops. The area belongs to the forest-steppe zone, characterized by a moderately continental climate with a sufficient amount of precipitation, especially during the growing season. The annual precipitation averages 600-700 mm, and the average annual temperature ranges between 7-8°C, creating favorable conditions for growing cereal and industrial crops.

The region has a large land fund, the majority of which is used for agricultural purposes. Agricultural land occupies approximately 75% of the total area of the region, which amounts to about 1.06 million hectares. Of this area, arable land accounts for over 70%, making the region one of the leading agricultural sectors in Western Ukraine, as shown in Fig.1.

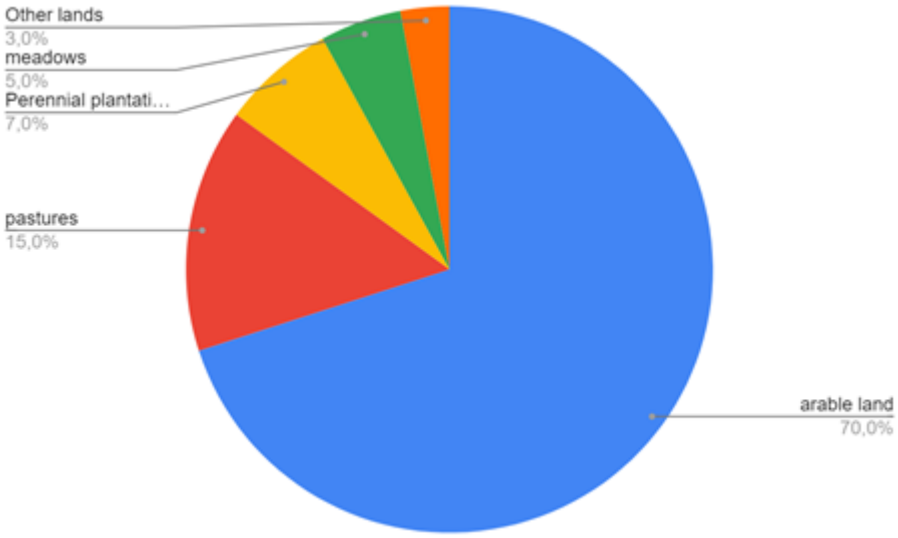

Fig. 1. Structure of Agricultural Land in Ternopil Region (%).
Source: Created by the authors based on data from [3].

The distribution of agricultural land and its condition vary depending on the microclimatic conditions and natural resources of each district in the region.

The primary soil types in the region include podzolized chernozems, gray podzolized soils, and meadow-chernozem soils, characterized by high humus content and significant agricultural potential. Chernozems cover most of the region and are highly fertile, facilitating their intensive use for cultivating nutrient-demanding crops such as maize, wheat, and barley.

To enhance productivity and maintain soil fertility, various agronomic practices are employed, including crop rotation, the application of organic fertilizers, and minimizing mechanical soil disturbance. However, in recent years, due to intensive use and frequent disregard for agronomic norms, a gradual depletion of land resources has been observed, necessitating a systemic approach to soil resource management.

The diagram illustrates the dynamics of harvested areas under wheat across all farm categories from 2000 to 2023. A clear trend of increasing wheat cultivation area is evident, accompanied by a linear trend line in Fig.2.

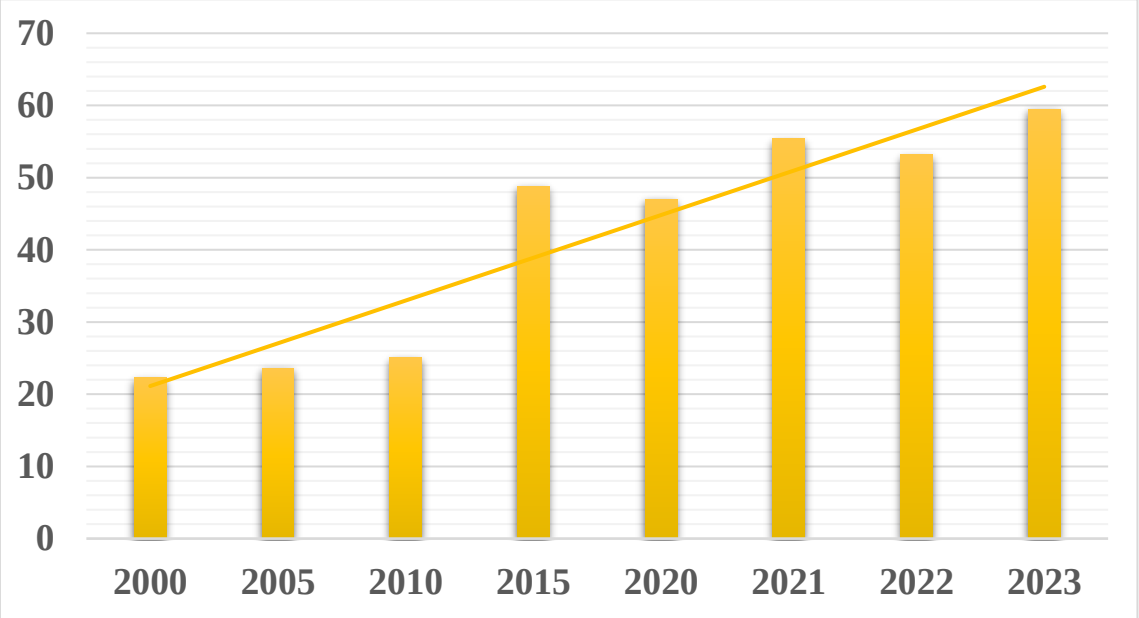

Fig. 2. Analysis of Wheat Yield Chart
Source: Created by the authors based on Source [3]

In 2000, the harvested area of wheat was approximately 20,000 hectares.

By 2023, this figure had increased to around 60,000 hectares, representing a threefold rise.

The linear trend observed in the chart indicates a relatively steady growth in harvested areas over the analyzed period.

Minor fluctuations in certain years can be attributed to weather conditions, changes in agricultural policy, or economic factors.

The impact of climate change, including rising temperatures and alterations in precipitation patterns, may have facilitated the adaptation of farming practices to more drought-resistant wheat varieties.

At the same time, the consistent growth reflects the effective implementation of modern agricultural technologies.

The expansion of wheat cultivation highlights the increasing focus on this crop as a cornerstone of Ukraine's agricultural structure. It demonstrates its high productivity, adaptability to climatic conditions, and significance in the agricultural economy.

Further monitoring is essential to account for the long-term effects of climate change and other external factors.

The yield of barley across all farming categories in Ukraine, according to the provided data, shows a substantial upward trend over the study period (2000-2023) in Fig.3.

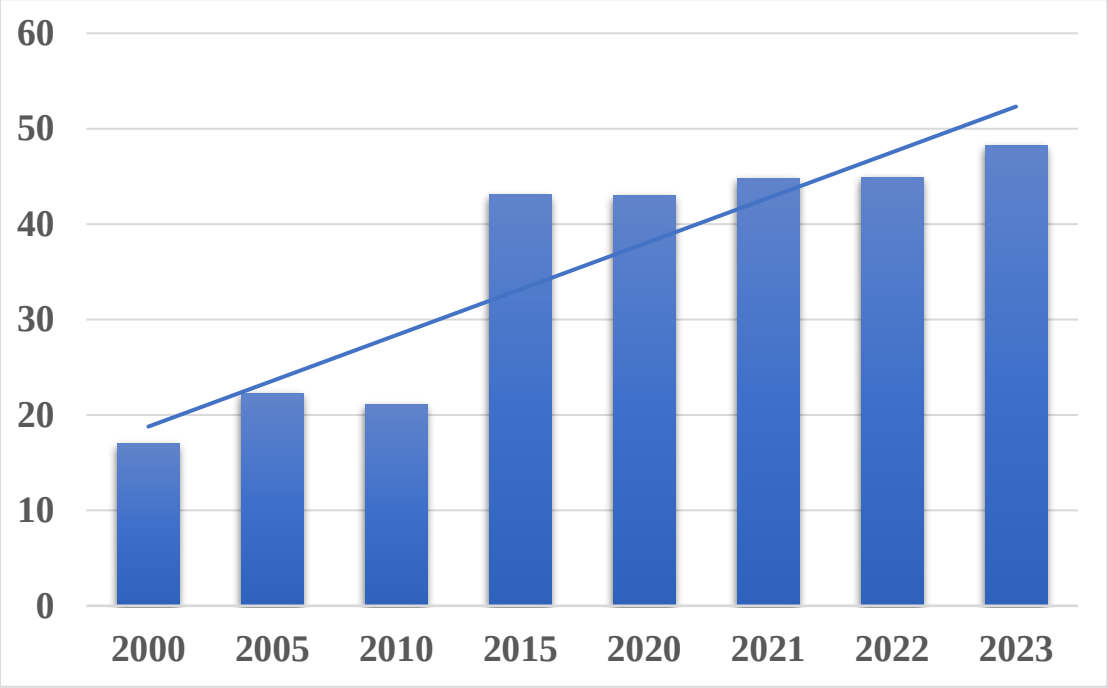

Fig. 3. Analysis of Barley Yields from 2000 to 2023
Source: Source: created by the authors based on the source [3]

In 2000, the average barley yield was 17.0 centners per hectare (centner/ha), reflecting a relatively low level of productivity, likely due to outdated farming technologies, low levels of intensification, and limited funding in the agricultural sector.

By 2010, the yield increased to 21.1 centners per hectare, which can be attributed to the gradual implementation of modern agricultural technologies, including barley varieties with higher genetic potential, as well as more efficient fertilization systems and plant protection methods.

In 2020, the yield reached 43.0 centners per hectare, more than double the 2000 figure. This surge indicates significant progress in agricultural technology, modernization of equipment, improvements in soil resource management, and the influence of favorable climatic conditions in certain periods.

By 2023, the yield reached 48.2 centners per hectare, marking the highest level over the entire period. This demonstrates the continued successful implementation of modern agricultural technologies.

Barley, as a crop, is sensitive to the conditions of the growing season, including the amount of precipitation, temperature regime, and the occurrence of extreme weather events. Between 2000 and 2023, both drought and favorable years were observed, which were reflected in the yields. For example, in years with more evenly distributed precipitation and the absence of critical temperature fluctuations (such as in 2021-2023), barley yields were higher.

A significant role in the yield increase is played by the adoption of modern technologies in agriculture. In the 2000s, there was a gradual update of agricultural machinery, increased use of mineral fertilizers, plant protection agents, and intensive

barley varieties. Improvements in soil treatment, precision farming, and crop rotation optimization also contributed to better yields.

The increase in barley yields results from the synergistic effect of several factors:

Improvement in cultivation technologies (mechanization, varieties, fertilizers).

Better management of agricultural technologies.

Certain effects of climate change, which create more favorable conditions for growing winter and spring barley in some regions.

These trends highlight the importance of further investment in agricultural technologies and adaptation to climate change for stable yield improvement.

Corn yield for grain shows significant and stable growth throughout the analyzed period (2000-2023) in Fig.4.

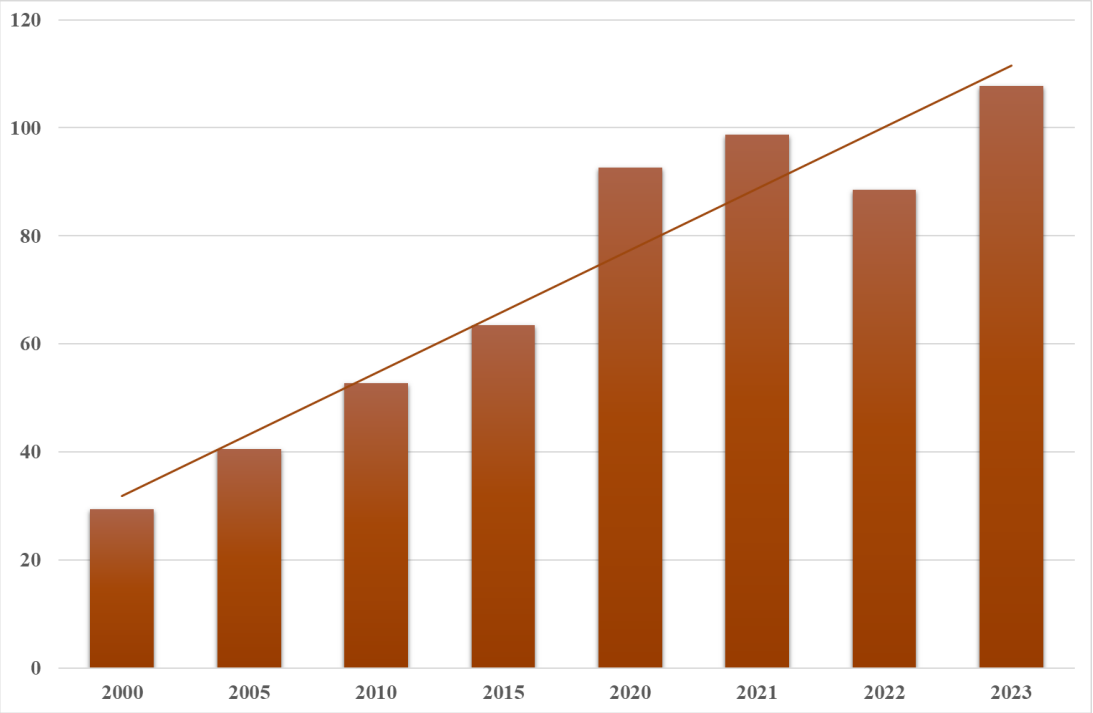

Fig.4. Analysis of Corn Yields for Grain (2000-2023)

Source: Source: created by the authors based on the source [3]

In 2000, the corn yield was 29.4 centners per hectare (centner/ha), reflecting a low level of efficiency at the beginning of the 2000s. This was due to insufficient intensification in the agricultural sector.

By 2010, the yield increased to 52.7 centners per hectare, representing an increase of more than 1.5 times compared to 2000. The main factor for this growth was the introduction of high-yielding corn hybrids, as well as improvements in cultivation technologies.

In 2020, the yield reached 92.6 centners per hectare, reflecting the widespread adoption of modern agricultural technologies such as precision farming, efficient irrigation systems, and balanced fertilization.

By 2023, the maximum yield of 107.8 centners per hectare was achieved, the highest figure for the entire period, highlighting the significant potential of corn as a high-productivity crop in modern agriculture.

The area allocated for corn also expanded significantly, from 24.5 thousand hectares in 2000 to 176.1 thousand hectares in 2021. However, in 2022–2023, there was a reduction in area to 121.4 thousand hectares and 114.2 thousand hectares, respectively. This decline could be linked to economic, geopolitical factors or changing climatic conditions.

Factors contributing to yield growth:

Agricultural technological progress: The use of hybrid varieties with high productivity, increased resistance to drought and diseases, and improvements in sowing methods and fertilization.

Climatic conditions: Moderate climate warming in Ukraine creates favorable conditions for growing corn, which requires a long warm period.

Irrigation technologies: The gradual introduction of irrigation systems in areas with water shortages has significantly improved production efficiency.

Investment in the agricultural sector: Increased private investments in modernizing equipment, automating production processes, and advancing agricultural technologies.

Corn for grain is a leader in terms of yield growth among other cereal crops in Ukraine. The more than threefold increase in yield from 2000 to 2023 indicates the successful integration of modern agricultural technologies with favorable natural conditions. However, the reduction in area in 2022–2023 requires further analysis to identify and mitigate the impact of negative factors.

To maintain this positive trend, it is essential to continue implementing new technologies, adapt to climate change, and develop systems for managing agricultural production.

Sunflower Yield in Ukraine (2000-2023) in Fig.5.

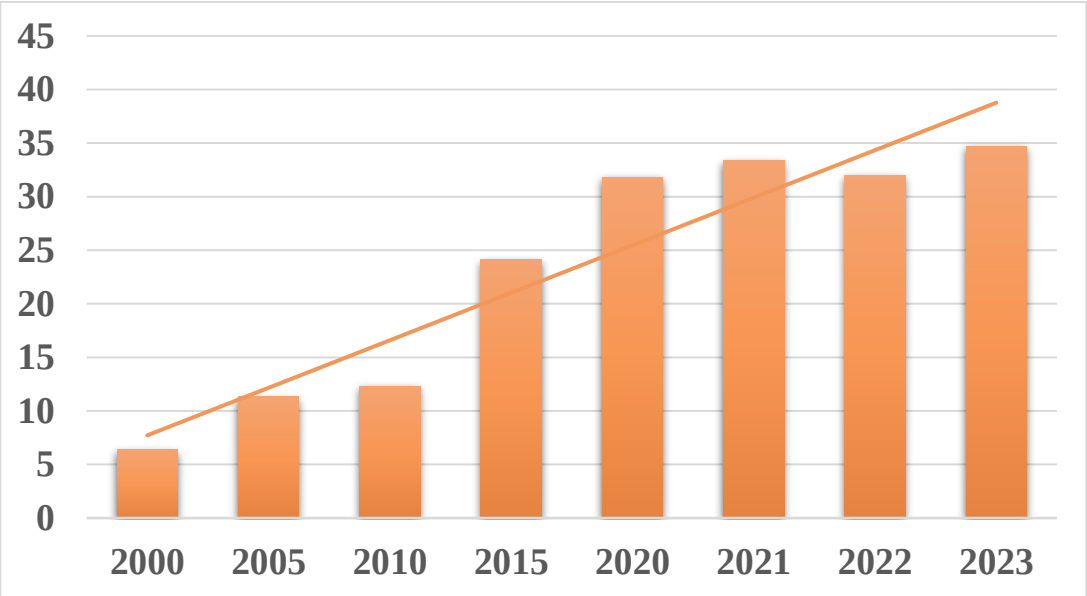

Fig.5. Analysis of Sunflower Yields (2000-2023)

Source: Source: created by the authors based on the source [3]

Key factors contributing to the increase in sunflower yields include:

Agricultural technological progress - the introduction of high-yielding sunflower hybrids resistant to diseases and pests has enhanced overall productivity.

Improvement in soil cultivation technologies - the adoption of modern technologies such as precision farming and minimal tillage has helped retain moisture and improve soil structure.

Increased use of fertilizers and plant protection products - the effective use of mineral fertilizers and modern pesticides has supported stable growth and development of sunflowers.

Climate change - increased temperatures and a longer growing season have been favorable for sunflower cultivation.

The area allocated for sunflowers expanded from 1.5 thousand hectares in 2000 to 100.2 thousand hectares in 2023, reflecting the growing demand for this crop and its economic profitability. The increase in area is driven by both market factors and the support for sunflower as a key oilseed crop in Ukraine's agricultural policy.

The rise in sunflower yields from 2000 to 2023 exemplifies how the intensification of agricultural production and improvements in agro-technologies can significantly increase crop productivity. The increase of 5.4 centners per hectare in 2023 compared to 2000 highlights the success of the agricultural sector in adapting to changing climatic conditions and economic demands.

To sustain and further enhance this trend, it is important to continue investing in agricultural innovations while maintaining attention to resource sustainability and soil fertility conservation.

The presented graph illustrates the dynamics of yields for key agricultural crops (wheat, barley, corn, sunflower) in the Ternopil region from 2019 to 2023. Analyzing this visualization allows for the identification of general trends and specific features of agricultural development in the region.

The sunflower yield in Ukraine showed significant growth from 2000 to 2023:

2000: The sunflower yield was low, at just 6.4 centners per hectare. This may indicate the absence of intensive cultivation technologies, limited use of high-yielding varieties, and other agronomic measures.

2023: The yield reached 34.7 centners per hectare, more than a fivefold increase compared to 2000. This rapid growth can be explained by improvements in agricultural technologies, the use of new sunflower hybrids, and enhanced fertilization and plant protection methods.

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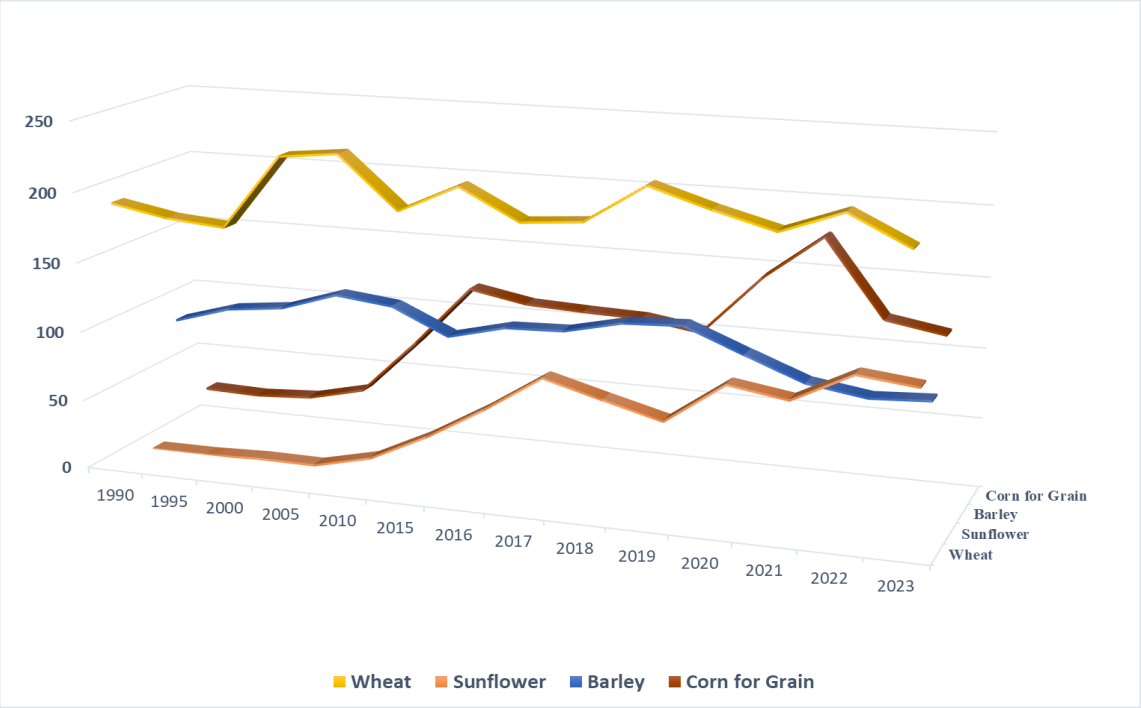

Fig.6. Analysis of the Yield of Main Agricultural Crops in the Ternopil Region (1900-2023)

Source: Source: created by the authors based on the source [4]

General Trend:

The graph demonstrates an overall trend of increasing yields for all the crops considered. This indicates the effectiveness of implemented agricultural technologies, the use of modern varieties, and adaptation to changing climatic conditions.

Despite the general positive dynamics, the growth rates of yields for different crops vary. The most significant growth is observed in corn, which can be attributed to the expansion of land allocated to this crop and the introduction of high-yielding hybrids.

Crop-Specific Dynamics:

Wheat: Wheat yield shows stable growth throughout most of the period, although some fluctuations are observed, likely due to weather conditions and other factors.

Barley: Barley yield also shows a growth trend, but it is less pronounced than for wheat. This may be due to lower demand for barley in both domestic and international markets.

Corn: Corn yield demonstrates the most rapid growth among all the crops studied. This is attributed to the expansion of corn acreage and the introduction of high-yielding hybrids.

Sunflower: Sunflower yield also shows significant growth, indicating its increasing role in the region's agricultural production.

The dynamics of yield are influenced by various factors, including:

Climatic Conditions: Atmospheric precipitation, temperature, and the number of sunny days directly affect the growth and development of crops.

Agricultural Practices: The use of modern varieties, fertilizers, plant protection products, irrigation, and other technologies helps increase the yield of agricultural crops.

Government Support: State programs supporting agriculture, such as subsidies, loans, and the provision of seeds and fertilizers, stimulate producers to enhance productivity.

Market Factors: Prices for agricultural products and demand in both domestic and international markets influence the choice of crops and the volume of production.

Based on the available data, further growth in the yield of agricultural crops in the Ternopil region can be expected. However, factors such as climate change (increased droughts, extreme weather events) could negatively affect yields; fluctuations in global agricultural product prices may reduce incentives for production; and resource availability (access to water, fertilizers, plant protection products, and other resources) will impact further yield growth.

Despite the advantages of technological progress, the region's agricultural sector faces several challenges. One of the most pressing issues is soil degradation, particularly erosion and the depletion of the fertile layer. This problem is especially critical in regions with intensive land use, where monocultures are grown without crop rotation. Therefore, an important focus is the implementation of agricultural practices that ensure the restoration of soil fertility, such as crop rotation and the use of organic fertilizers [5].

One of the important aspects of the agricultural sector's development in the Ternopil region is the use of innovative technologies that enhance the efficiency of agricultural production. In particular, the popularity of precision farming is increasing, which includes the use of drones, GPS navigation, and modern sensors for soil analysis and resource management in Fig.7.

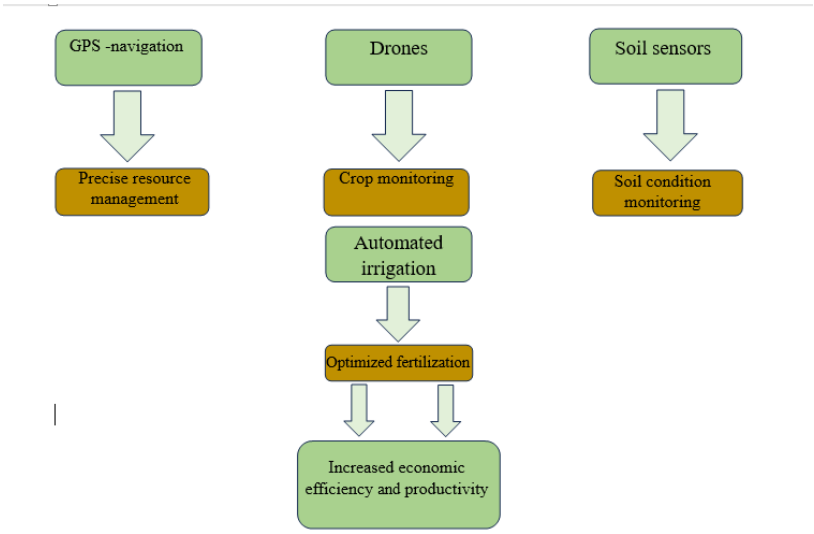

Fig.7. Key Directions and Outcomes of Technology Use in the Agricultural Sector of Ternopil Region
Source: Source: created by the authors based on the source [3]

As a result, farmers can reduce costs on fertilizers and pesticides, maintaining ecological balance while improving agricultural productivity [5].

Climate change also presents a significant challenge to the agricultural sector, manifesting as droughts, unpredictable weather conditions, and changes in temperature. These factors reduce crop yields and increase risks for farmers. In response, farmers in Ternopil are increasingly focusing on introducing drought-resistant plant varieties and adapting irrigation methods. The development of crop insurance is also essential, as it will help farmers minimize financial losses in the event of unfavorable weather conditions [7].

Thus, despite a number of challenges, the agricultural sector in Ternopil region has significant potential for further development. The analysis shows that, on the one hand, the region possesses favorable natural resources and a strong land fund for agriculture. On the other hand, issues such as soil degradation and climate change require urgent solutions and adaptive measures.

Promising areas for the development of the agricultural complex include the further implementation of innovative technologies, particularly precision farming and climate-resilient agricultural practices. The development of state support programs, crop insurance, and investment in restoring soil ecology are also crucial. Such a comprehensive approach will enhance the agricultural productivity of the region, ensuring the sustainable development of the agricultural sector.

Climate change has become one of the greatest challenges for agriculture in Ukraine, particularly for the Ternopil region. Increasing temperatures, changes in precipitation patterns, and more frequent extreme weather events (droughts, floods, frosts) are impacting yields, the structure of agricultural crops, and the resilience of agro-systems to stressful conditions.

Adapting agriculture in Ternopil region to climate change is a complex and multifaceted process. However, thanks to the joint efforts of farmers, scientists, and the state, there is reason for optimism. The implementation of modern technologies, the

development of resilient farming systems, and adaptation to new climatic conditions will ensure the stable development of the region's agriculture and food security for the population.

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