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Assessment of the impact of climate change on crop production in Ukraine: Adaptation mechanisms for mitigating the consequences

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Abstract. Climate changes in modern conditions have a significant impact on the development of agriculture, which is associated with changes in natural conditions in various territories, pollution of soils, air, water bodies and other components of the ecosphere. Such conditions make research on finding mechanisms that would allow mitigating the negative consequences on the development of the country's agriculture relevant. Thus, the study aims to investigate the interaction between climate change and the development of crop production in Ukraine. The main research methods used in the study were analysis, abstraction, and forecasting. As part of the work, an analysis of the trend in terms of climate change observed in Ukraine was carried out: the data clearly showed a trend towards warming of average annual air temperatures, and a decrease in average wind speed and precipitation. All this harms the development of agriculture. The study showed what losses businesses can suffer due to the negative impact of climate change, which can be reflected in both reduced fertility and financial losses. Based on all the information, recommendations were formed for both enterprises and representatives of state authorities, which will make it possible to adapt to such climate changes more effectively. This work makes it possible to better understand both the peculiarities of Ukraine's development from an ecological and economic point of view (in particular, its agricultural sector). In addition, it provides recommendations that can be used by enterprises or government officials to reduce the negative impact of environmental factors on agriculture

Keywords: pollution; aquatic resources; policy; macroeconomics; innovations

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INTRODUCTION

In the current environment, climate change, which is a temperature rise, change in climatic zones, melting glaciers and other natural changes, is one of the most important issues facing society. The negative impact of climate change on humanity as a whole is a significant and multifaceted phenomenon, causing serious threats that are already being felt and will increase in the future. They are leading to an increase in average annual temperatures and heat waves, which can lead to an increase in heatstroke and stress, especially in urbanised areas. Increased temperatures also contribute to the spread of diseases such as malaria and heart or lung disease. In addition, climate change is leading to an uneven distribution of precipitation, leaving some regions prone to prolonged droughts that threaten the availability of water for drinking and agriculture. Other regions may experience extensive flooding due to intense rainfall. Similar negative effects arise for other reasons, such as extreme weather events or rising sea levels. All of this leads to problems in economic development and food security, as such changes cause a decrease in crop yields and a change in the distribution of plants. In some regions, this can lead to food shortages, higher food prices, difficulties with food distribution, or even famine. Therefore, new ways of adapting agriculture to such conditions and mitigating such negative impacts on the development of this sector and companies remain relevant.

The assessment in this study was carried out on the example of Ukraine, which has also been studied by a significant number of scholars. Thus, the state of the environment in Ukraine, and in particular its legal regulation, was studied by I.O. Sivak (2022). The scientist described the current difficulties in the country in this area and also noted the role of improving the legal framework to increase the effectiveness of combating problems related to the state of the environment. In the context of war, the state of the environment in Ukraine was assessed by I.G. Patseva *et al.* (2023). They described the difficulty of assessing the impact of hostilities but noted their overall negative effect. Despite this, the scientists did not formulate advice to reduce this environmental impact. V. Skyba & K. Turyak (2023) assessed changes in the agricultural sector of Ukraine in the context of climate change. They noted that the growing areas of some of the country's main crops have been displaced and called for the state and businesses to be able to respond flexibly to climate change. However, the scientists did not specify any concrete steps to do so. Opportunities for the agricultural sector in terms of adaptation to climate change were explored by L.V. Moldavan (2023). The scientist described the role of the country's natural resource potential for agricultural development and outlined methods of supporting it in Ukraine in the face of climate change. However, little attention was paid to the study of the negative

impact of hostilities on this sector. O.P. Mysnyk (2022), in turn, assessed the opportunities for the development of the agricultural sector of Ukraine's economy in the period up to 2030, considering the concept of sustainable development. The scientist described the country's significant potential in the agricultural sector and described the opportunities for its development, considering the basis of the concept of sustainable development. However, he paid little attention to the problems associated with the beginning of Russia's full-scale invasion of Ukraine and its impact on the environment and the agricultural sector. An econometric analysis of the impact of climate change was conducted by A. Skrypnyk *et al.* (2021). The study investigated the dynamics of sown areas under export-oriented crops in three agroclimatic zones of Ukraine and analysed their yields depending on the territories and climate change. O.H. Tarariko *et al.* (2017) also assessed the capacity of the Ukrainian agro-industrial complex to adapt to climate change based on climate change projections. The researchers described the need to develop effective methods of combating climate change and provided some of them, which concerned both changes in the context of technological processes of companies (use of the latest technologies) and management decisions. Risk management issues related to global climate change are highlighted in the study by O.M. Nechyporenko (2020). In his work, the researcher reveals the impact of climate change on the development of the agricultural sector and the state of food security in the country. At the same time, he analyses existing climate risk management strategies and proposes an algorithm for adapting to the climate crisis.

Thus, the study aims to assess the current state of the environment in Ukraine and climate change, as well as to investigate the interaction of these phenomena with crop production indicators. This will allow for more effective formulation of state policy in this area, and thus increase the efficiency of agriculture.

MATERIALS AND METHODS

The study analysed statistical data on average air temperature, precipitation, and wind speed in the period from 2010 to 2023. The study aimed to investigate the impact of climate on the development of crop production in Ukraine as a whole. The average monthly data for these indicators were used for the calculation, and subsequently, annual averages were calculated on this basis. This was done using the formula below (1):

$$C = \frac{(c_2+c_3+\dots+c_{12})+(c_1+c_{13})}{12}, \quad (1)$$

where: C – average annual value; c_1, c_2, \dots, c_{13} – the respective monthly averages for each month.

In Formula 1, given that the period for which the value was formed was even, 13 observations were used,

but the value for months 1 and 13 was calculated as a single value (their half-sum was used). By plotting a series of values using the formula above, it becomes possible to build a trend line for them and draw a conclusion about the decrease or increase in average annual air temperatures over time.

This study used information on the average air temperature (°C), maximum air temperature (in degrees Celsius), minimum air temperature (°C), average wind speed (m/s) and precipitation (mm). The indicators were analysed monthly, which was used to create graphs describing trends in the context of climate change in Ukraine. The period was chosen between 2010 and 2023. All subsequent plots and calculations were made using Microsoft Excel.

The approach used in the study was systematic. It was used to analyse the main factors influencing the development of agriculture in Ukraine (both from the economic and other points of view) by placing them within separate systems where they interact with each other and influence each other. This provided an opportunity to improve the effectiveness of the assessment of factors and their impact on the object of study. The main research method used in this study was analysis. It allowed us to formulate certain conclusions about the mechanisms of adaptation to climate change and mitigation of its effects on Ukrainian agriculture based on quantitative and qualitative data available from free sources of information. The historical method was also used, which allowed us to evaluate the data in terms of their historical change, in retrospect. The method of abstraction was also used, which made it possible to limit the influence of factors on the object of research in case the effect of such a factor was insignificant. This, in

particular, made it possible to increase the accuracy of the study. Forecasting was used to assess the prospects for the development of Ukraine and its agriculture in the face of active climate change. In addition, statistical research methods were used to analyse quantitative data.

RESULTS

In general, the following typical signs of climate change can be identified: an increase in the average annual temperature, changes in precipitation patterns (some regions are experiencing decreased precipitation, leading to drought conditions, while other regions may experience more intense rains, leading to floods and flooding), shifts in seasons (summers start relatively later and are prolonged; winters are becoming warmer, with less snowfall) Given this, climate change in Ukraine has become a serious challenge and requires attention and measures to adapt to new conditions. In particular, it leads to environmental pollution, which is a serious problem in Ukraine as a whole, much of which includes air, water, and soil pollution. Air pollution is caused by emissions from industrial plants, vehicles, and other sources, and hurts air quality, public health, agriculture and ecosystems. Water pollution, mainly from wastewater and chemical discharges, also threatens water resources and aquatic ecosystems. Soil pollution, in particular from pesticide residues and chemical fertilisers, can affect soil fertility and the safety of agricultural products. As shown later in the paper, prolonged droughts remain the most pressing of these for Ukraine. To assess climate change trends in Ukraine, it is worth considering the data that characterise it. The trends in average, maximum and minimum air temperatures are analysed in Figures 1-3.

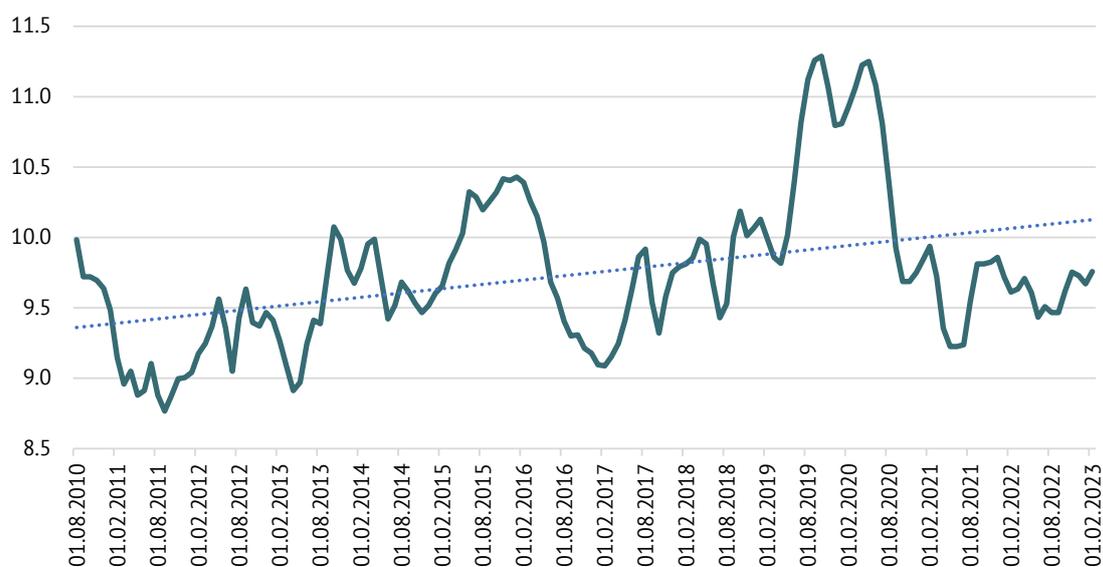


Figure 1. Data on average annual air temperatures in Ukraine for the period from August 2010 to February 2023, °C
Note: here and in all the figures below, the calculation of annual averages for the graphs is based on the data shown in Materials and Methods and the methodology described in the section
Source: compiled by the author based on Meteorological station Weather statistics. Climatic data by year and month (2023)

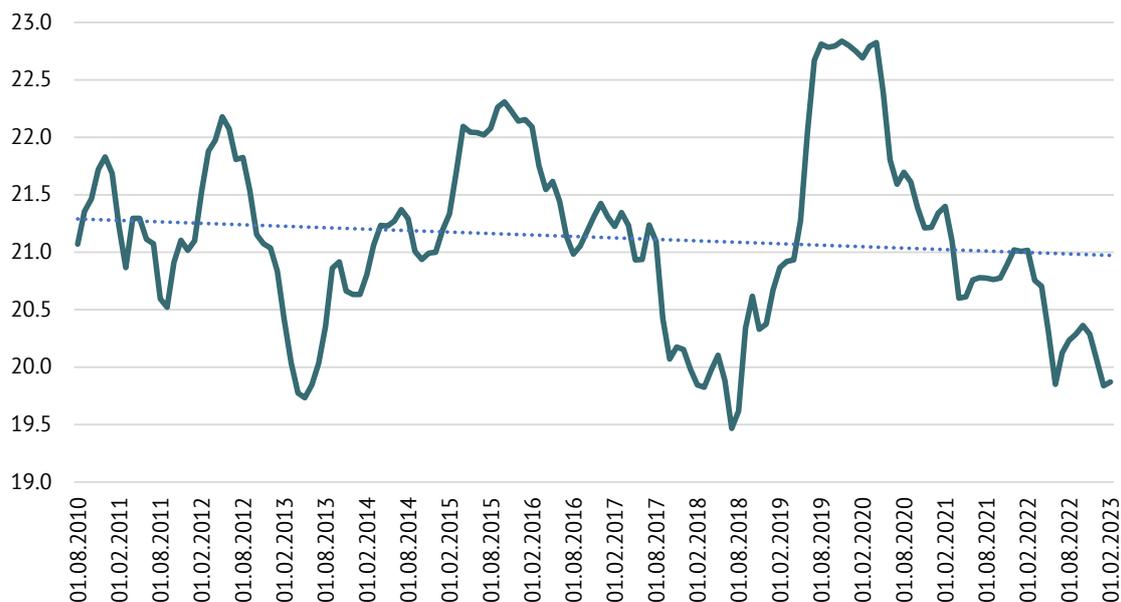


Figure 2. Data on average annual maximum air temperatures in Ukraine for the period from August 2010 to February 2023, °C

Source: compiled by the author based on Meteorological station Weather statistics. Climatic data by year and month (2023)

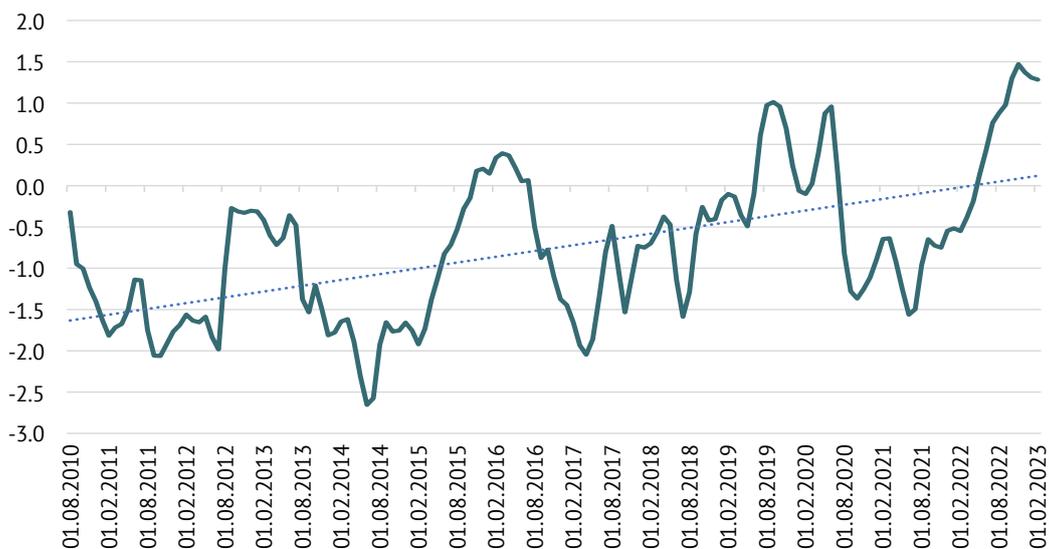


Figure 3. Data on average annual minimum air temperatures in Ukraine for the period from August 2010 to February 2023, °C

Source: compiled by the author based on Meteorological station Weather statistics. Climatic data by year and month (2023)

As can be seen from Figures 1-3, the average annual air temperature in Ukraine is generally increasing. Although the situation may vary from month to month and year to year (some periods may be colder or warmer), the construction of trend lines allows us to see the warming trend in recent years (in particular in Figures 1 and 3; Figure 2 shows a slight decrease in maximum temperatures, but it does not change the overall upward trend). It is worth noting that such an increase in air temperature, even if it does not seem high, can significantly complicate the process of growing agricultural products. For example, the increase in maximum temperatures means that the country as

a whole is experiencing warmer winters, which can be dangerous for plants. For example, between 2019 and 2020, the average annual temperature increased by 0.3°C (3%), and at the same time, there was a decline in gross receipts of agricultural companies by an average of about 10%. In particular, due to the warm, snowless winter of 2020, Ukraine lost 568.2 thousand ha of winter crops (37% less than last year) and millions of dollars in exports (Buono, 2021; Lazareva, 2021; Nalau & Verrall, 2021).

Sunflower yields in the Kherson region dropped from 2 tonnes per hectare to less than one that year, with corn crops also suffering significantly. In the Odesa

region alone, losses of UAH 6.5 billion were recorded. The following year, the situation was different: while the average temperature dropped by 22% (1.8°C), gross harvest volumes increased by 22.6%. In general, due to the very hot year of 2020, which set a significant number of temperature records, 570 thousand ha were lost in Ukraine due to prolonged droughts and unusually

severe spring frosts (Ukraine may not..., 2021). Thus, there is a possibility of a situation where, in the face of a cold winter, planted crops will begin to germinate earlier than necessary, which will complicate their development and may lead to a loss of the crop in general. Figures 4 and 5 provide information in terms of average wind speed and precipitation.

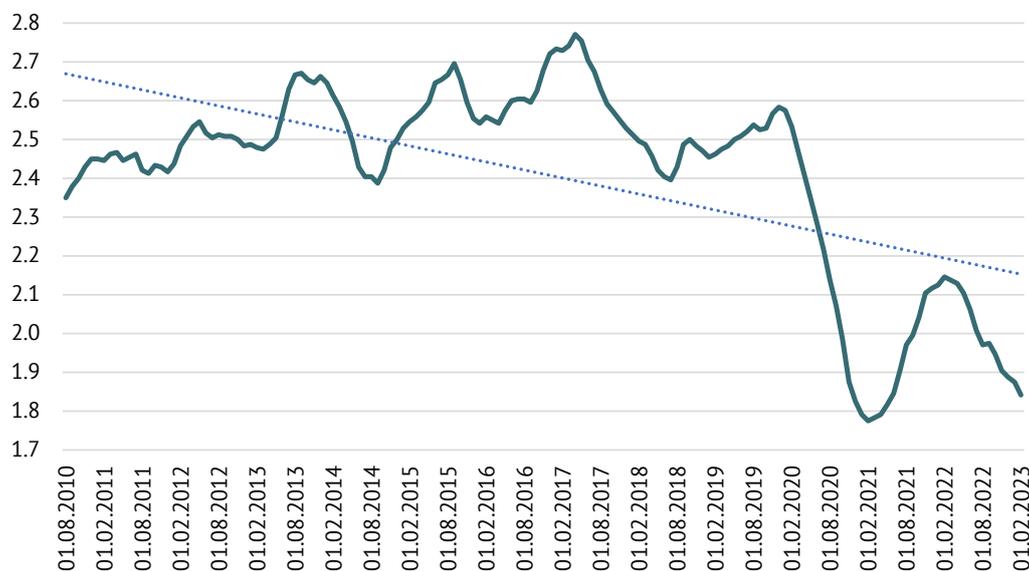


Figure 4. Data on the average annual wind speed in Ukraine from August 2010 to February 2023, m/s

Source: compiled by the author based on Meteorological station Weather statistics. Climatic data by year and month (2023)



Figure 5. Data on the average annual precipitation in Ukraine in the period from August 2010 to February 2023, mm

Source: compiled by the author based on Meteorological station Weather statistics. Climatic data by year and month (2023)

As can be seen from Figures 4 and 5, both average annual precipitation and wind speed data in Ukraine have decreased over the selected period. In the context of agricultural development, this also hurts the industry, as it reduces the natural ventilation of fields

and affects seed dispersal and pollination; when considering precipitation data, the decline in precipitation indicates a need for increased manual watering of plants, which can also complicate the process of growing them.

Thus, gradual climate change around the world, and in Ukraine in particular, is causing significant problems in terms of doing business in the agricultural sector. For example, over the past 20 years, climate change-related natural disasters have caused more than \$2 billion in losses in Ukraine's agricultural sector, which has complicated business operations (Climate Change and..., 2021). As can be seen from the Figures above, there are clear changes in Ukraine, even over short periods, in terms of weather changes over time. However, their interaction with data on company performance is not always obvious. Considering the interaction in terms of collection volumes and precipitation, in 2020, compared to 2019, precipitation increased by 11.8%, while in 2021, compared to the previous year, it decreased by 8%. This is not surprising, as Ukraine is indeed facing an annual rainfall deficit of 578 mm, while sustainable agriculture requires at least 700 mm. Over the past five years, the average annual rainfall has been around 553 mm, and in recent years it has dropped to 557 mm. This lack of precipitation combined with increased evaporation due to rising temperatures requires intensive irrigation. The cost of irrigation for farmers has increased by about 25%, adding to the difficulties of growing crops (Climate and Agriculture..., 2021). The drought in spring and summer resulted in losses that included 200 thousand ha of corn and slightly lower yields of other crops across the country (Ukraine may not..., 2021). Grain harvest volumes in 2021 decreased significantly in Ukraine due to the drought. Nevertheless, due to the increase in prices for this product on the international market, companies in the sector were able to make excessive profits this year. Experts estimate that a continuation of this trend of decreasing precipitation may lead to the need to actively irrigate about 70% of agricultural land in Ukraine, which is 30% more than now (Dankevich 2020). This will lead to a significant increase in the cost of growing crops, and thus negatively affect the country's position in the international arena.

As for the net income of enterprises, in 2020 and 2021, they grew by 2% and 16%, respectively, adjusted for inflation. Thus, despite the weather conditions, agricultural companies were able to increase their profits. This suggests that for agricultural companies in Ukraine, company revenues are much more strongly influenced by factors other than weather conditions, such as the price of inputs, which increased significantly during the COVID-19 crisis, which led to an increase in net income. In turn, in 2022, despite the natural conditions, companies' revenues decreased by 34% in real terms compared to 2021 due to the start of the full-scale invasion. Although there are currently factors in the country that are much more influential on the welfare of agriculture than natural disasters, they must also be considered to reduce their negative impact in the long term. If similar declines in the revenues of agricultural companies continue in the future, it is possible to expect a significant

negative social and economic impact on the country. In particular, this will affect the state budget, given that the tax revenues of companies exceed the losses associated with their support. Such a reduction in budget revenues could have a significant negative impact on the budget, especially in the context of a significant budget deficit during the war.

Thus, various methods can be proposed to facilitate the process of adaptation of the agricultural sector to climate change. One of them is investing in and developing new crop varieties that will be able to withstand climate change or be more adapted to it, and not be so negatively affected by it (Reid, 2019; Ovcharenko *et al.*, 2022). In addition, the implementation of sustainable land management practices is effective, for example, crop rotation, conservation tillage (Olabi & Abdelkareem, 2022). These methods help to improve soil health, reduce erosion, and thus increase the resilience of agricultural systems to climate change. The transition of farms to renewable energy sources is also effective. This will help reduce greenhouse gas emissions, which will improve natural development in the long term, and the energy generated from wind or solar power can also power irrigation systems and other agricultural machinery. It is also important to invest in efficient water management methods, which may include rainwater harvesting and use technologies, as well as water-efficient irrigation systems. This is especially important for growing crops in the face of rainfall variability, and in particular, the identification of a downward trend in rainfall (Heil & Muni-Morgan, 2021). For all of the above methods to be used, the state should pursue appropriate policies aimed at raising awareness among farmers, businesses, and the public about the challenges posed by climate change and the importance of taking the measures described above. However, at the moment, the introduction of any new technology that can ensure efficient irrigation of land can cost several billion dollars of investment, which is a very large sum for Ukraine, and it seems impossible to attract such funds in the framework of a full-scale invasion.

So far, only methods that can be used by farmers to improve the situation in agricultural development in Ukraine concerning climate change have been considered. However, this problem should also be addressed at the level of advisory services. Thus, the state should implement policies aimed at increasing the resilience of the agricultural sector to climate change. Such actions should be well coordinated at different levels of government, from local to national and international. This requires establishing institutions and financing mechanisms to support agricultural adaptation to climate change, which may not be easy, particularly in the context of Russia's full-scale invasion of Ukraine. It is important not only to engage with government officials at the national and regional levels, but also on the international stage, in particular, to share experiences,

technologies, or theoretical knowledge on how to reduce the negative impact of climate change on the country.

DISCUSSION

Current assessments of the impact of climate and environmental change on various areas have estimated K. Abbass *et al.* (2022). They noted the significant impacts of climate change on socio-agricultural, socio-economic, and physical systems, emphasising the potential for catastrophic consequences. They highlighted issues such as worsening food security, including higher food prices and inadequate food distribution systems, as well as a range of challenges related to forest development. They suggest some policy actions to reduce these impacts, particularly in the agricultural sector. Thus, it would be effective to consider seasonal variations and cultivation methods, develop new crop varieties with desirable properties, introduce changes in management and inputs, and promote technological and socio-economic adaptation. The use of renewable energy sources would also be effective, as well as raising awareness of these issues among businesses and the public. It is worth noting that the paper above also made similar recommendations on how to improve the efficiency of agricultural development in Ukraine.

The importance of confronting climate change was also stated by S. Khalid *et al.* (2017). The scientists wrote that the review of global climate trends conducted in their paper showed significant risks and vulnerabilities associated with climate change to the environment. They drew attention to the indebtedness, urgency and severity of these impacts, as well as the importance of the resources affected, underscoring the importance of ongoing scientific research. The importance of understanding the role of the processes that influence weather and climate change was also explored by J. Ringard *et al.* (2022). They emphasised the importance of understanding the physical processes behind changes in the environment, especially during the summer season, and discussed the relevance of studying them to find more effective methods to counteract them.

A.M. York *et al.* (2021) discussed climate change as a multi-level collective action issue, emphasising the need for a comprehensive understanding of decision-making processes at different levels of society. They noted that an effect such as climate change requires a response at all levels, from individuals to global organisations. Each level can influence climate change actions and policies. In modern conditions, despite the importance of addressing climate change, insufficient measures are often taken, both by businesses or society and the state. D. Alagador & J.O. Cerdeira (2020) examined in their study the problems associated with planning protected areas to optimise species resilience in a dynamic environment, i.e., one in which climate change is occurring and budgetary constraints exist. In

particular, the scientists identified the role of technology in this process and noted its importance in creating opportunities for quality development in the country to improve the environmental situation.

The impact of climate change on agriculture and mitigation strategies was studied by G.S. Malhi *et al.* (2021). They noted that the growth of the world's population puts significant pressure on agriculture, which is also constantly growing. Although it is unclear how the climate will change in the future, the current course of climate change is harming agriculture. To overcome these challenges, numerous mitigation and adaptation strategies have been developed, covering various strategies related to the methods of processing agricultural products, the use of certain inputs for their growth. However, it is important to interact to combat climate change not only at the micro but also at the macro level. Thus, government officials should ensure planning and coordination at the regional and local levels to maximise the effectiveness of these strategies. Such measures should increase farmers' incomes and increase (or maintain) the resilience of agriculture to similarly severe disasters, and thus have a positive impact on agricultural development and food security in the long run. S. Skendzic *et al.* (2021) wrote that climate change has a significant impact on agricultural plants. They analysed how changes in the weather affect insect pests (scientists noted that their number has increased significantly due to climate change, which has led to the need to find new opportunities to combat them. They also pointed out that although it is not known for certain how the changes in the situation will develop in terms of the environment, it is clear that farmers need to prepare for them.

J.P. Aryal *et al.* (2020), adaptation to climate change is crucial for agricultural sustainability. Successful adaptation in agriculture requires a combination of strategies, including the adoption of different technologies, sustainable land management practices, and the establishment of enabling policies and institutional frameworks. Therefore, as noted by scientists, institutional development and adequate financing are crucial for agriculture to successfully face climate challenges. A.A. Chandio *et al.* (2020) conducted an empirical study that focused on assessing the impact of agricultural production in China from 1982 to 2014. As China's population is growing, addressing the adverse effects of climate change on agriculture is crucial for food security; and while this is a critical topic for this country, it is also relevant for other countries. The main findings of the study showed that climate change, in particular factors such as CO₂ emissions, cereal area, fertiliser consumption and energy consumption, have a positive impact on agricultural value added. Conversely, rising temperatures or changes in precipitation have a negative long-term impact but a positive short-term impact on agricultural value added. Based on these findings,

the researchers recommend that the Chinese government take specific measures to overcome these challenges. Actions to this end may include the introduction of accurate weather forecasting, improved irrigation systems, and the modernisation of farmland infrastructure to adapt to climate change. A similar study was conducted by N.T.L. Huong *et al.* (2019). The researchers used empirical data from Vietnam to estimate the impact of certain climate changes (including temperature and precipitation) on farmers' net income. The study found that the impact of these climate variables on net income is non-linear; in this case, it is still possible to find a solution that will maximise efficiency. The researchers noted that adaptation measures are important to mitigate the negative effects of climate change on agriculture. Farmers who adopt adaptation strategies will take risks in their agricultural practices and therefore achieve better results in their operations. The study above also concluded that farmers, and agricultural enterprises, can significantly improve their performance in the face of climate change if they use them.

Thus, Ukraine needs to apply methods that would reduce the impact of climate change on the development of agriculture in the country. However, it is worth remembering that such results can only be achieved if there is effective cooperation between the state, businesses, and citizens, especially in wartime. Therefore, first and foremost, the authorities should formulate a policy that would effectively meet the needs of all components of the country's population and achieve significant progress in meeting their needs.

CONCLUSIONS

Climate change has a significant impact on Ukraine, especially in crop production. It is causing changes in temperature, precipitation patterns and wind speed, which affects crop yields. Data shows a clear link between weather changes and the performance of agricultural

companies in Ukraine. Climate change-related natural disasters have caused more than \$2 billion in losses in the agricultural sector over the past two decades, complicating business processes. Unpredictable weather conditions, such as droughts and temperature fluctuations, can have a significant impact on crop yields and subsequently on farmers' incomes. The study showed that agricultural enterprises lost millions of dollars in profits due to drought due to reduced fertility of crops such as corn, wheat: in 2020 alone, 200 thousand ha and 568.2 ha of these crops were lost, respectively, which is a huge loss.

While the impact of climate change on agriculture is clear, other factors such as resource prices and political instability also affect agricultural revenues. In 2020 and 2021, agricultural companies managed to increase their profits despite the weather conditions, but in 2022, the onset of the full-scale invasion led to a significant decline in company revenues, highlighting the sector's vulnerability to external shocks. In the long term, adaptation to climate change through investment and development of climate-resistant crop varieties, implementation of sustainable land management, water management is crucial for the sustainability of crop production.

Further research is needed to assess the impact of climate change on other sectors of the Ukrainian economy, not just agriculture. In addition, it is important to find ways to combat the negative impact of these changes using all possible methods. In addition, it is important to conduct research in the context of assessing foreign experience in this area and finding opportunities to use it in Ukraine.

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None.

CONFLICT OF INTEREST

None.

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Оцінка впливу змін клімату на рослинництво в Україні: механізми адаптації для пом'якшення наслідків

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Анотація. Зміни клімату в сучасних умовах чинять значний вплив на розвиток сільського господарства, що пов'язано із змінами природних умов на різних територіях, забрудненням ґрунтів, повітря, водойм та інших складових екосфери. Подібні умови роблять актуальними дослідження з приводу знаходження механізмів, що дозволили б пом'якшити негативні наслідки на розвиток сільського господарства країн. Таким чином, ціллю даного дослідження стало дослідити взаємодію між зміною клімату та розвитком рослинництва в Україні. Основними методами дослідження, що були використані в рамках роботи, стали аналіз, абстрагування та прогнозування. В рамках роботи було проведено аналіз тенденції у розрізі зміни клімату, що спостерігаються в Україні: дані чітко показали тенденцію до потепління середніх річних температур повітря, зниження середньої швидкості вітру та кількості опадів. Усе це спричиняє негативний вплив на розвиток сільського господарства. В дослідженні було показано, яких втрат можуть зазнати підприємства у зв'язку із негативним впливом змін клімату, що можуть відобразитися як зі зниженням родючості, так і фінансовими втратами. На основі усієї інформації було сформовано рекомендації, як для підприємств, так і представників державної влади, що дадуть змогу більш ефективно пристосуватися до подібних змін клімату. Дана робота дозволяє краще зрозуміти як особливості розвитку України з екологічної точки зору, так і економічної (зокрема її сектору сільського господарства). Крім того, вона надає рекомендації, що можуть бути використані підприємствами чи представниками влади для зниження негативного впливу на сільське господарство з боку екологічних чинників

Ключові слова: забруднення; водні ресурси; політика; макроекономіка; інновації
