AGRO-ECOLOGICAL POTENTIAL OF SOIL COVER OF VINNYTSIA REGION

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Scientific monograph





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The monographic study examines the main components of the agroecological potential of the soils of the Vinnytsia region.The scientific work is aimed at forming the concept of modernization of soil conservation and environmental safety, namely, rational nature management at the expense of limited resource provision due to climate change. The research methodology is based on experimental studies of scientific topics on the topic: "Development of bio-organic technologies for growing agricultural crops for the production of biofuels and ensuring the energy independence of the agricultural sector". The expected results of the research are aimed at achieving complex ecological, economic, energy and social effects. The authors have considerable experience in research related to rational nature management, the development of land reclamation measures taking into account the concepts of rational nature management, which ensure the optimization of land use, as well as the biologicalization of agriculture. The scientific research of the authors has been commercialized, in particular, contracts have been concluded for the performance of research within the framework of farm contract and state topics.

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STUDY OF SOIL CONSERVATION TECHNOLOGY AND ENVIRONMENTAL STABILITY OF RURAL AREAS TAKING INTO ACCOUNT LIMITED RESOURCES AND CLIMATE CHANGE

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Abstract. The applied monograph is designed to solve the current problems of climate change, which is one of the most urgent threats with a long-term negative impact on the population, the environment, and the economy. The scientific work is *aimed* at forming the concept of modernization of soil conservation and environmental safety, namely, rational nature management at the expense of limited resource provision due to climate change. Significant attention is paid to the impact of global climate change on land resources, agriculture, forestry, water resources, bioenergy and biodiversity. The implementation of the proposed modernization system will be implemented based on the study of international experience of adaptation to climate change and the possibility of its application in Ukraine under martial law in a complex with the provision of ecological and social effects, guaranteeing the reduction of the impact of the degradation processes of the soil cover of Ukraine. *Methodology*. The research methodology is based on experimental studies of scientific topics on the topic: "Development of bio-organic technologies for growing agricultural crops for the production of biofuels and ensuring the energy independence of the agricultural sector". The expected *results* of the research are aimed at achieving complex ecological, economic, energy and social effects. The authors have considerable experience in research related to rational nature management, the development of land reclamation measures taking into account the concepts of rational nature

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management, which ensure the optimization of land use, as well as the biologicalization of agriculture. The scientific research of the authors has been commercialized, in particular, contracts have been concluded for the performance of research within the framework of farm contract and state topics. *Practical implications.* Previous scientific work of the authors includes: theoretical and practical research in the field of rational nature management and increasing soil fertility, land resources, agriculture and forestry, bioenergy and biodiversity. The state of modernization of the ecological security system under the conditions of sustainable development of rural areas was analyzed, priority directions of modernization of the ecological security system were developed in the context of achieving sustainable development of rural areas. The research will involve the development of alternative farming systems in the direction of the development of bio-organic technologies for growing agricultural crops for the production of biofuels and ensuring the energy independence of the agricultural sector, as well as the processing of products of the main agricultural crops, in accordance with the directions of the Strategy for Environmental Security and Adaptation to Climate Change until 2030. *Value/originality.* The authors also researched system variants of bio-organic technologies for growing the main agricultural crops used in EU countries and Ukraine. The studies confirmed the presence of significant problems, which led to the need for further scientific research and the need to develop a strategy for environmental security of rural areas based on sustainable development.

1. Introduction

The global trend of global warming and, as a result, climate change, characterized by an increase in temperature and a decrease in precipitation. All this leads to soil degradation from year to year – to the erosion, pollution, acidification and salinization mentioned above. According to FAO data, 20% of Ukrainian agricultural lands have undergone significant degradation, the rest are under threat. Ukrainian soils have lost about 30% of humus over the past 130 years, and the level of plowing in Ukraine is one of the highest in Europe – 53%. For comparison, in Poland this indicator is 36%, in Germany 34%, in the USA 17%. According to NAAS estimates, this situation leads to losses of about UAH 40 billion/year, and this became the impetus for Ukraine's accession to the Sustainable Development Program. According to the State Statistics Service of Ukraine, the structure of the soil cover of Ukraine is 24 million hectares, and in addition, Ukraine has 8% of the world's chernozem reserves and a high level of plowed soils. Fields contain different amounts of humus. The content of humus in the soils of Ukraine varies from 0.8 to 6.5%. The greatest decrease in soil fertility was noted in the eastern part and in the north. These are Chernihiv, Sumy, Kharkiv, Donetsk, Luhansk, Kirovohrad and Mykolaiv regions [1; 3–5; 12; 15; 25; 36–39].

2. Analysis of recent research and publications

The research will involve the development of alternative farming systems in the direction of the development of bio-organic technologies for growing agricultural crops for the production of biofuels and ensuring the energy independence of the agricultural sector, as well as the processing of products of the main agricultural crops, in accordance with the directions of the Strategy for Environmental Security and Adaptation to Climate Change until 2030.

Scientifically oriented aspects of the basics of global climate change, land resources, agriculture, forestry, water resources, bioenergy and biodiversity are highlighted in the works of Ukrainian and foreign scientists. Theoretical, methodological, methodical and instrument provisions of soil conservation and ecological safety of rational nature management of bioecosystems Mazura V.A. aimed at greening agriculture at the expense of limited resource provision due to climate change [21–38; 41–46; 50–56; 78].

Scientifically oriented aspects regarding the foundations of economic and energy autonomy of agricultural enterprises, refusal to purchase mineral fertilizers, additional profit, ecological effect, etc. were substantiated by G.M. Kaletnik. etc. (2019).

On the basis of research carried out by Honcharuk I.V. (2020) established the provision of energy independence of agricultural enterprises and the agricultural sector in general, ecological disposal of agricultural waste, reduction of carbon dioxide emissions, increase in the yield of agricultural crops, increase in soil fertility, reduction in soil acidity, reduction in the cost of applying mineral fertilizers due to the introduction of digestate and increase in profitability agricultural enterprises [2–8; 59–60].

Tsytsiura Y.G. proves that biological agriculture can contribute to soil conservation, especially for the cultivation of sideral crops. Amanpreet S. and others. (2020) proposed models of organic crop rotations with elements of biologization when they are saturated with leguminous crops, and also made proposals for the comprehensive development of the field of organic production. Nosheen, S. and others. (2021) summarized the results of using biofertilizers of organic origin to preserve soil fertility [2–12; 37–39; 55].

Buchynskyi I.E. believes that climate fluctuations are a common phenomenon in nature, have a relatively orderly nature and occur in a wave-like manner. It makes many people think that the climate is changing "before our eyes". However, this is a fake climate change, it is only its "regular" fluctuation, and not a stable change in one direction.

Chabanyuk Y.V. (2018) substantiates the results of the comparison of correlation matrices of natural ecosystems, which demonstrated the formation of specific soil properties under the action of abiotic and biotic factors. Using a mathematical approach, it has been proven that chernozems are more stable, compared to gray forest soils, which quite easily lose their fertility due to anthropogenic influence, and also require ecologically stabilizing measures and protection in the process of agricultural use) [6; 13; 14–21; 35; 70–72].

Issues in the field of organic and biological agriculture are covered in the works of O. Demidenko and others. Experimental studies of Shkatula Yu.M. it has been proven that the use of mineral nitrogen fertilizers, which is not coordinated with the content of fresh organic matter in the soil, leads to the destruction of the organic composition of soils, the consequence of which is a decrease in their fertility. Atudorei D. developed models of crop rotations with elements of biologization when they are saturated with leguminous crops, and proposals were also made for the comprehensive development of the field of grain production [1; 2; 14; 36; 49; 80–84].

The analysis of international and domestic scientific sources and departmental materials shows the expediency of using biotesting methods, with the use of representatives of systematic groups of different ecosystems due to limited resource provision due to climate change. Obtaining reproducible and comparable data for determining the priority areas of modernization of the environmental safety system in the context of achieving the sustainability of the development of rural areas with the subsequent assessment of their risks is possible only by using the methods recommended by the Organization for Economic Cooperation and Development (OECD), when performed in laboratories accredited in accordance with the requirements ISO/IEC 17025 and GLP. These findings will form the basis of guidelines for environmental testing in Ukraine [22–28; 40; 42; 60–67].

Studies show that the climate of Ukraine has already started to change over the past decades (temperature and some other meteorological parameters differ from the values of the climatic norm) and according to the results of modeling, the air temperature will continue to rise for the territory of Ukraine in the future (although the magnitude of the changes is slightly different according to different forecast models) and there will be a change in the amount of precipitation during the year. This can lead to a shift in climatic seasons, a change in the duration of the growing season, a decrease in the duration of stable snow cover, and a change in the water resources of the local runoff [7–15; 29–39].

3. Literature review

Scientific work affects several related fields of science, in particular environmental, energy, economic, agricultural, balanced nature management, which will further contribute to the development of relevant fields of knowledge. Also, the implementation of the project is important for the implementation of a number of legislative and regulatory acts that will contribute to the development of the country, namely the Law of Ukraine "On Environmental Impact Assessment", the Law of Ukraine "On Alternative Fuels", the Law of Ukraine "On Combined Production of Thermal and Electric Energy (cogeneration) and use of waste energy potential", of the State Regional Development Strategy for 2021–2027, of the regional development program "New Ukrainian Village". The goals of the project will be aimed at solving environmental, energy, economic and social problems. Solving environmental problems by increasing the efficiency of the use of land resources while maintaining the protein balance and soil fertility. Along with that, in the conditions of climate change, it will be necessary to form a single agricultural policy, which will be implemented at the expense of informational and advisory work among agricultural enterprises, farms, and households with the aim of forming a nature-oriented and environmentally friendly worldview.

In order to achieve the set goals, the implementation of the project involves solving the following tasks:

– to determine the conceptual provisions of the process of modernization of the system of soil conservation and ecological stability based on the structure and requirements of environmentally safe sustainable development;

– to form a system of factors, criteria, indicators from the positions of implementation of environmental modernization measures;

– to develop a system of stabilization of the structure of sown areas with a normative share of agricultural crops with resource-possible application of organic fertilizers of the new generation, the non-marketable part of the crop, the mass of sideral crops;

– development of soil protection systems of tillage and implementation of ecologically regulated system of protection of agricultural plants from harmful organisms;

– to develop a technology for improving the agro-ecological condition of the soils of rural areas through forestry management;

– to develop an information-analytical, science-based system of environmental safety monitoring at the regional level and forecasting for the long- and short-term perspective;

– to develop optimized and adapted systems of application of bio-organic agrochemicals in the system of soil use based on mobilization agrochemical approaches;

– to develop an algorithm for the implementation of the resource-innovative strategy of environmentally safe sustainable development, which will include the introduction of modern innovative industrial technologies both on the basis of supporting the development of high-tech and medium-tech industries, and stimulating the creation of new innovative poles of development;

– to develop a partnership model of interaction of agricultural enterprises in the production of biofuels to increase energy and economic independence.

Climate change refers to environmental risks that determine the ecological safety of the environment and are considered as long-term changes in meteorological elements (air temperature and humidity, precipitation, wind speed, cloudiness, etc.), deviation of their parameters from the climatic norm for a certain geographical latitude. This process is primarily accompanied by a change in air temperature and precipitation.

The signing of the UN Framework Convention on Climate Change by representatives of 175 countries shows that climate change is a significant threat to the environment and economic development [17–21; 35; 49–53].

Climate change is already happening and this process will intensify. Therefore, regardless of whether a person is involved in this or not, it is necessary to take measures to counteract these changes, to restrain the rate of temperature increase in order to avoid dangerous and irreversible consequences for the environment, economy and society in the future. It is necessary to try to adjust (adapt) and minimize the negative effects of the predicted climate changes, to use the benefits from them as effectively as possible where possible [27].

On the territory of Ukraine over the past 100 years, the average annual air temperature has increased by 0.7°C and the trend of its increase is maintained. Ukraine is threatened by abnormal temperature conditions, the transformation of steppes into deserts, a lack of drinking water, floods, and strong winds. All this negatively affects the economic development, environmental and national security of the state [77].

4. Conditions, objective and methods of research

The monograph has an interdisciplinary nature and is aimed at solving the current problems of today, namely socio-ecological-economic scientific research of integration processes and the development of technologies for the formation and functioning of ecological systems in conditions of sustainable development. The idea is to ensure the achievement of energy, economic and ecological stability and the development of sustainable land use while implementing a set of complementary components that provide for the improvement of the formation of modern environmental policy and the rational use of natural resources. Working hypotheses: development of technologies for soil conservation and ecological stability of rural areas, which provide for balanced management of natural ecosystems and forest management while implementing climate change prevention and adaptation measures (1); use of European experience in the development of organic, ecologically adapted technologies for growing agricultural crops on the basis of effective environmental protection in order to adapt to the natural and climatic potential of Ukraine (2); increasing the productivity of growing agricultural crops on the basis of a bioadaptive approach to the realization of genetic potential while simultaneously preserving soil fertility and stabilizing soil-accumulating processes using natural processes of their provision and the formation of a deficit-free balance of organic matter in soils, which will guarantee their constant productivity and ecological sustainability (3); development of technological measures of adaptation to climate change and risk reduction for the spheres of health care, people's livelihoods, sectors of the economy and natural ecosystems (4); the system of the latest approaches to the organization of rural areas and forest management, regarding the placement of remedial forest plantations to obtain the maximum protective and ecological effect (5); application of biofertilizers in order to increase soil fertility, change their acidity, dispose of agricultural waste and reduce costs for the purchase of mineral fertilizers (6); the formation of an environmental security strategy through the environmentalization of agricultural production in the face of changing climatic conditions, pollution of water resources, air and soil contributed to the creation of alternative and sustainable ways of meeting the growing energy needs under ecological stability and sustainable development of rural areas (7).

The purpose of the research is to form a strategy for the ecological stability of rural areas based on the development of a methodology for the analysis and evaluation of the processes of modernization of the soil conservation system and ecological stability of sustainable development, which includes general, specific and auxiliary indicators and indicators that characterize the state of the environment and the level of anthropogenic load on its individual components. as well as introduced modernization measures. The study of domestic and foreign experience in the creation and organization of eco-friendly reproduction of the fertility of agricultural lands, sustainable development of the branches of agriculture, balance and optimization of a rational combination of the branches of crop production. To assess the competitiveness of the products of commodity branches of agriculture through the creation of production and service cooperatives, clusters and associations in the conditions of the organization of ecological production in the branches of agriculture and processing industry. Development and transfer of innovative projects for the production of organic food products and alternative types of renewable energy in the multifunctional development of rural areas due to the rational use of natural and forest resources under the organization of cross-border cooperation, in particular the market for innovations, labor, products and services. To develop new competitive bio-organic technologies for growing agricultural crops, which provide for the development of regulations for the use of a complex of alternative types of fertilizers for their cultivation in terms of short-term and long-term action, a basic superstructure of the factor assessment of the block of soil fertility conditions, hydrothermal conditions of the territory, resource provision of enterprises in view of climate changes.

To achieve the goal, the following tasks are expected to be solved: the development of a new bio-organic technology for growing agricultural crops on the basis of soil conservation and sustainable development and food security (1); development of effective technologies for the application of various options for biofertilization of agricultural crops while preserving soil fertility and increasing yield (2); development of technological parameters for reducing the resource and energy intensity of technologies for reproducing soil fertility and ensuring stable, highly productive production of high-quality forestry products (3); development of models of energy-saving, soil-protecting tillage systems, frugal involvement in the biological cycle of biogenic elements of industrial origin with rational use of plant and animal husbandry waste for fertilizer (4); practical implementation, which involves production verification of the proven new bio-organic technology for growing agricultural crops, informational and advisory practice with the involvement of a network of agricultural formations of various forms of ownership with further promotion and production implementation (5).

5. Adapting to climate change in green post-war reconstruction

While Russia continues the war in Ukraine, it is difficult to think about climate change. However, even if the war ends today and greenhouse gas emissions are reduced to zero tomorrow, the climate will continue to change and must be adapted to. Adaptation to climate change refers to the adaptation of natural or human systems (such as forests, rivers, cities and even individual streets) to the potential or actual impact of climate change. If you don't adapt, children will play on playgrounds in the summer, the surface of which heats up to almost 60°C, people with weak cardiovascular systems will faint from the heat, and trees will fall on cars and power lines from gale force winds [34].

The research will involve the development of alternative farming systems in the direction of the development of bio-organic technologies for growing agricultural crops for the production of biofuels and ensuring the energy independence of the agricultural sector, as well as the processing of products of the main agricultural crops, in accordance with the directions of the Strategy for Environmental Security and Adaptation to Climate Change until 2030.

According to the study, 1 dollar invested in adaptation will help prevent the expenditure of 6 dollars in liquidation of the consequences of natural disasters. That is, adapting to climate change is much cheaper than dealing with the consequences. For Ukraine, this issue is currently very relevant. The fight against the consequences of climate change already costs Ukraine millions of hryvnias every year, and in 2020, 2,689 million hryvnias were allocated from the State Budget of Ukraine. For the prevention and liquidation of emergency situations is more than, for example, the annual budget of the entire Vinnytsia city united territorial community [24; 35; 67; 69; 73].

Adaptation will mitigate their impact on people's lives and nature. This is no less relevant for the regions that suffered as a result of Russian aggression, and now must look for ways to restore normal life, taking into account, in particular, the challenges associated with the environment. Taking into account the principles of environmental protection in reconstruction formed the basis of the concept of Green Reconstruction of Ukraine. In particular, these principles emphasize the need to implement the Strategy for Environmental Security and Adaptation to Climate Change, which was adopted in 2021. Adaptation is also listed as one of the priority directions in the ecological security section of the Recovery Plan of Ukraine [12–14; 31–45; 68–69; 74].

Each region is unique in its microclimate, landscape and geographical location. Therefore, the necessary adaptation measures for each of the communities will depend on their vulnerability to various manifestations of climate change: an increase in the duration of droughts, heat waves, gale-force winds, rising sea levels, severe frosts and snowfalls, abnormal downpours and floods, etc. In order to be ready for these challenges, the local authorities, together with the community, should identify individual vulnerable zones for each settlement and, based on the received information, develop an adaptation plan.

In Ukraine, according to the Ministry of Environmental Protection and Natural Resources of Ukraine, the average annual temperature has increased by more than 2°C since the beginning of the 20th century, including 1.2°C over the past 30 years (Figure 1).

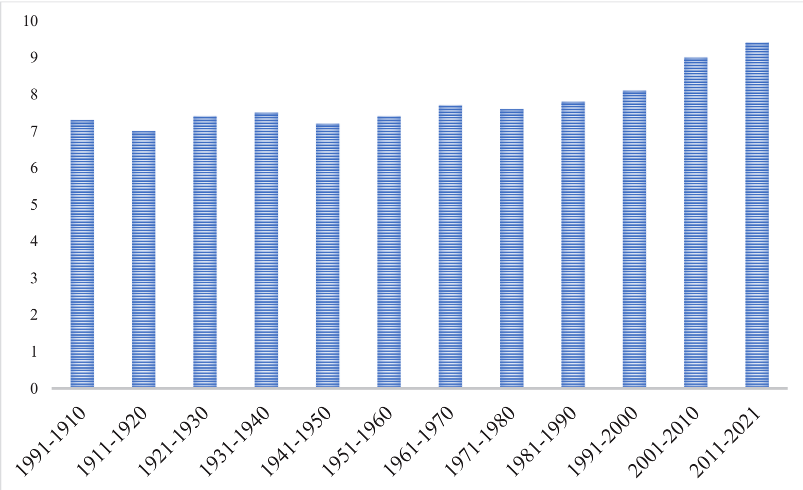

Figure 1. Average annual temperature in Ukraine

Source: according to the Ministry of Environmental Protection and Natural Resources of Ukraine

In recent years, the frequency of days with maximum summer temperatures above 35 and 40°C, which belongs to extreme weather phenomena, has almost doubled. In the greater part of Ukraine, there is already a trend towards increased droughts, an increase in the number and duration of hot periods and an increase in fire danger, the frequency and intensity of thunderstorms, heavy downpours, hail, and squalls have increased. Climate change on the territory of Ukraine increases risks for the health of the population, ecosystems, water and forest resources, sustainable functioning of the energy infrastructure and the agro-industrial complex, which can cause and is already causing colossal losses [24; 35].

UN data show that climate change will have devastating consequences for people living in poverty. Even under the best scenario, hundreds of millions of people will face threats to food security, forced migration, disease and death. And in the conditions of war, the number increases many times. In the future, climate change threatens human rights and the progress made in development, global health and poverty reduction over the past fifty years. The continuation of such a process will be detrimental to the world economy and will lead to a significant spread of poverty.

6. The current state and consequences of climate change. Land resources, agriculture, forestry

One of the important environmental problems of the 21st century is the change of the global climate. Climate change for agriculture in Ukraine is caused, first of all, by global warming, the direct consequence of which is droughts, which negatively affect the yield of agricultural crops, since the weather component of the harvest in our country is more than 50% [7; 24–28; 35; 67–68].

Therefore, the most important task of land users is the search and implementation of effective techniques for accumulation and rational use of available moisture reserves in the soil. In the modern world, agriculture remains a key branch of the economy, ensuring food security and the production of important types of raw materials. But it is a significant source of greenhouse gases. Therefore, there is a need to modernize existing models of agricultural production and improve methods of managing agricultural systems taking into account climate change. The fifth assessment report of the Intergovernmental Panel on Climate Change demonstrates the urgent need for substantial and sustainable decarbonization and climate change adaptation measures in the area of food security. Forecast estimates given in the Report demonstrate the negative impact of climate change on the yield of agricultural crops. In particular, in regions with a tropical and temperate climate, an increase in temperature by 2°C without adaptation to it will negatively affect the yield of wheat, corn, soybeans, and rice, although in some regions it will have positive consequences. An increase in the global temperature by 4°C, which will be accompanied by a reduction in the volume of water resources and an increase in competition for them, will become a risk factor for food security on a global scale [70].

The general conclusions for Ukraine regarding climate change according to the four scenarios of Representative Concentration Pathways (RCP) are as follows:

– temperature increase is expected throughout Ukraine: about 1.65°C (Steppe) and 1.74°C (Forest Steppe) for the RCP 4.5 scenario and between 2.68°C (mixed forest zone) and 2.98°C (Step) for the RCP 8.5 scenario;

– climate change will not significantly affect the level of precipitation. Under the RCP 4.5 scenario, the change in precipitation will vary from 13 mm in the Steppe zone to 55 mm in the Forest Steppe. The changes will be more noticeable under the conditions of the RCP 8.5 scenario – more than 80 mm in the zone of mixed forests and less than 13 mm in the Steppe zone;

– the largest reduction in production by 2070 due to climate change is possible in the Steppe zone: a probable reduction in wheat production by 11% for the RCP 4.5 scenario and 18% for the RCP 8.5 scenario. Currently, the agricultural sector of Ukraine is not extremely vulnerable to climate change.

However, changes in weather conditions (increased air temperature, uneven distribution of precipitation, which has a torrential nature in the warm period, ineffective accumulation of moisture in the soil) lead to an increase in the number and intensity of drought events. Together with other negative factors of anthropogenic influence, this can lead to the expansion of the zone of risky agriculture and to desertification in the southern regions of Ukraine. As a result of intense warming in recent decades, there have been changes in the structure of agricultural production, the area of field crops and their yield level.

The data show that the Steppe zone, in which 46% of the grain crops are concentrated, now provides only 35% of the total grain production, compared to 45% in 1990. The average grain yield in this zone over the past five years, despite its growth at 21% on a national scale, decreased from 35.8 t/ha in 1990 to 32.2 t/ha in 2013–2017. In Polissia and the Forest Steppe, an increase in yield was recorded from 30-37 t/ha to 48-53 c/ha Thanks to this, 65% of grain is produced in these zones, although the share of crops of this group of crops here is only 53%.

In addition to the significant territorial redistribution of the structure of agricultural crops, uneven dynamics and growth rates of their productivity are noted. Thus, compared to 1990, the average yield of grain and leguminous crops in the Forest Steppe and Polissia increased by 46– 61%, while in the Steppe it decreased by 10%. A similar situation can be observed in relation to the change in the level of productivity of the rest of the main crops. In general, the overall increase in grain and leguminous yields in Ukraine was due to the more moisture-provided regions of the state, the Forest-Steppe and especially Polissia.

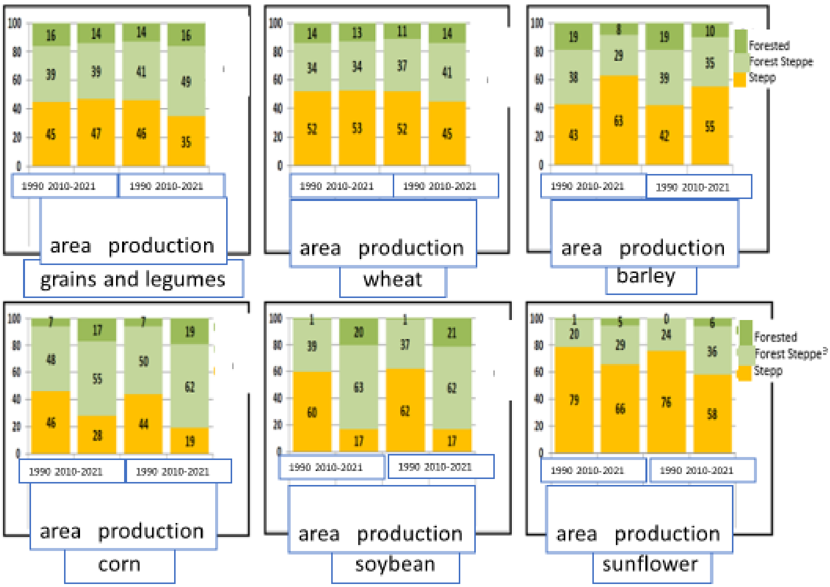

Figure 2. Change in the structure of crops and production of the main agricultural crops, % of the total for the country

In the conditions of climate change, the level and conditions of moisture in the territory of the state is the leading factor limiting the level of production productivity and the use of the natural potential of agriculture. In order to mitigate the negative processes of climate change on agricultural production, it is necessary to implement the objectives of the Irrigation and Drainage Strategy in Ukraine for the period until 2030. Recurrence of droughts in different agro-climatic zones is 20–40%. Over the past 20 years, droughts have recurred almost twice as often. There is a dangerous tendency to increase the recurrence of dry conditions in the zone of sufficient atmospheric moisture, covering Polissia and the northern regions of the Forest Steppe.

According to the fifth information report on climate change in Ukraine, favorable conditions are expected for the intensive development of dairy cattle breeding and pig breeding in the western Polissia and the right-bank forest-steppe, and meat cattle breeding in the Steppe and western regions of Polissia.

Therefore, from the point of view of increasing agricultural productivity, climate change has both positive and negative consequences. The positives include: improvement of conditions and shortening of harvest times; the possibility of effective introduction of late-ripening varieties (hybrids), which require more thermal resources; improvement of overwintering conditions of agricultural crops and perennial grasses; increasing the efficiency of fertilizer application. The negative ones include: deterioration of grain quality due to an increase in the concentration of carbon dioxide in the air; more frequent and stronger droughts during the growing season; acceleration of humus decomposition in soils; deterioration of soil moisture in the southern regions; failure to ensure complete vernalization of cereals; an increase in the number of pests, the spread of pathogens of plant diseases and weeds due to favorable conditions for their overwintering; the increase in wind and water erosion of the soil, caused by the increase in the number of droughts and extreme precipitation; an increase in the risk of freezing of winter crops due to the lack of stable snow cover with a significant decrease in temperature.

Manifestations of climate change, which are critical for the agricultural sector, also affect forestry, changing the optimal indicators of ecological conditions for forest ecosystems. Thus, the increase in summer extreme temperatures threatens the disappearance of certain species and the appearance of new (including invasive) species, which will affect the species composition and reduce the area of forests. In particular, the study provides the following forecasts for the main forest-forming species:

– common oak – until the end of the 21st century, favorable conditions for the growth of oak will remain only in the west – in the Carpathians and foothills, and satisfactory – in the Lviv region, in the rest of the territory of the modern zone of mixed broad-leaved forests, the conditions for oak will be unsatisfactory and even extreme;

– European spruce – there will be an even further narrowing of the zone of suitable conditions for this species, in fact there will be no favorable conditions for its growth in Ukraine;

– Scots pine – conditions suitable for pine growth (mostly extreme and unsatisfactory) will remain only in the west and on a small area in the north, which will lead to a significant deterioration of the state of pine forests in Ukraine;

– forest beech – conditions suitable for beech growth will be found only in the Carpathians and foothills;

– hanging birch, black alder – there will gradually be a narrowing and displacement of zones with conditions suitable for the growth of these species (especially birch). Conditions optimal for alder and suboptimal for birch will remain only in Transcarpathia (Dniester basin).

7. Vulnerability assessment of the city of Vinnytsia

Vinnytsia is the administrative center of Vinnytsia Oblast, located in the right-bank part of Ukraine within the Podilsk Highlands (Figure 3). The geographical location of the city contributes to the formation of a temperate continental climate on its territory. Vinnytsia occupies an area of 113 km^2 and has a population of 371 thousand people. The city on the banks of the Southern Bug, the administrative center of the region and the modern cultural and economic center of Ukraine. A large number of green areas, park areas, architectural monuments, hotels, shopping centers, themed pubs and restaurants – all this is here in sufficient quantity for even the most demanding tourists. We can say with full confidence that Vinnytsia is quite legitimately considered a real pearl of Podillia, combining comfort and a unique atmosphere of a city that carefully preserves its history and skilfully uses modern opportunities.

Despite the participation of relevant specialists, the assessment results can serve as a pilot illustration showing the procedure for applying the methodology and cannot be the only basis for developing a plan of adaptation measures for these cities. A comprehensive assessment of the city's vulnerability to climate change using the proposed methodology requires the presence of a working group of specialists and thorough

Figure 3. Location of Vinnytsia on the map of Ukraine

preliminary work of its representatives with the necessary statistical information. However, even a cursory assessment by a specialist of seven groups of indicators allows to see the vulnerable elements of the urban ecosystem and can be the basis for priority adaptation measures.

Research results indicate that the climate of Vinnytsia [6; 7], as well as the whole of Ukraine, has already begun to change. According to forecasts, the changes will continue in the future, which may cause significant negative consequences for the nature, population and infrastructure of the city. Table 1 presents the results of this assessment. The description of vulnerability indicators is presented in descending order – from the most vulnerable to the least vulnerable group. Recommendations for increasing Vinnytsia's resilience to climatic manifestations are also presented. The city of Vinnytsia is most vulnerable to flooding (16 points) and to natural hydrometeorological phenomena (14 points). The reason for this is the presence of large water bodies on the territory of the city, the shallowness of groundwater, as well as the wear and tear of the sewage and stormwater systems.

The climate of Vinnytsia is temperate-continental with mild summers, mild winters and a sufficient amount of precipitation (within 550 mm). The most precipitation falls in summer (almost 75%), the least in winter. In summer, there are frequent showers, thunderstorms, sometimes hail. Winds are typical for all seasons, especially for summer. The snow cover is available on the territory of the city from the second half of December to the

Table 1

Vulnerability assessment of the city of Vinnytsia

№ indicator	Group 1. Vulnerability to heat stress	Group 2. Vulnerability to flooding	Group 3. Vulnerability of urban green areas	Group 4. Vulnerability of persistent hydrometrological phenomena	Group 5. Vulnerability to deterioration of water quantity and quality	Group 6. Vulnerability to infectious diseases	Group 7. Vulnerability of the city's energy systems
1	1	0	1	4	0	0	2
2	2	2	1	2	0	4	4
3	1	1	1	2	0	2	2
4	1	2	1	4	0	0	0
5	0	2	0	2	0	4	2
6	0	0	0	-	1	-	-
7	0	1	0	-	2	-	-
8	1	2	0	-	1	-	-
9	0	2	0	-	1	-	-
10	0	2	1	-	1	-	-
11	0	1	0	-	1	-	-
12	0	1	1	-	0	-	-
In total	**7**	**16**	**6**	**14**	**8**	**10**	**10**

beginning of March, its height is 8-10 cm. The annual humidity coefficient is 0.92. The thermal regime is characterized by features of continentality (a change in the large amplitude of temperature fluctuations between winter and summer, which for Ternopil is 23−24ºC). The average temperature of the warmest month (July) is +18...+19°C, and the coldest (January) is -4.5...-5°C. The invasion of continental air masses leads to significant temperature fluctuations: in summer up to +37°C, in winter up to -34°C. The duration of the frost-free period is 150-165 days. The vegetation period of plants is 205-209 days, the period of active vegetation is from the first decade of April to the end of October.

Many weather-related risks in the city will intensify as climate change intensifies, however, if a plan of measures for the adaptation of the city (taking into account the characteristics of the city and expected climate changes) is developed and implemented responsibly, then the expected consequences can be mitigated and somewhat minimize. That is why it is important to take into account the results of the assessment of the vulnerability of cities to the consequences of climate change during the preparation of the General Development Plans of the cities of Ukraine and local plans of adaptation measures to climate change.

Based on the modeling of climate change processes carried out by climatologists of the Cambridge Group from different countries of the world under the auspices of the UN FAO, a further increase in air temperature in the range of 2 to 6ºC in the period up to 2100 is predicted. Such an increase in temperature and concentration of CO_2 in the air will have a direct impact on the Earth's biosphere, in particular on the productivity of the agro-industrial complex, yield and quality of agricultural crops. The negative climate changes in the near term include an increase in air temperature, increased effect of droughts, reduction of snow cover, violation of uniformity the arrival of atmospheric precipitation, which in the complex leads to the activation of erosion processes and soil degradation.

The greatest increase in temperatures occurred in the winter period – December and January by 1.9 and 2.0ºC, respectively. In the summer months – in June and August, the temperature increased by 1.5 and 1.6ºC, respectively. The transition from winter to spring also accelerated, with the temperature rising in March by 1.4°C and in April by 1.1°C.

The increase in air temperature during this period led to an increase in heat input during the growing season. Thus, the sum of positive temperatures during this period increased by 736º, and effective temperatures above 5ºC – by 673º C. This growth was especially noticeable in the last 10-12 years.

Strategy of adaptation of crop production to climate changes involves a scientifically based selection of crops suitable for cultivation both under favorable conditions of moisture supply and capable of withstanding moisture deficits and reacting less to drought.

The optimal parameters of these indicators have been determined for hybrids of different maturity groups. Another group of measures aimed at reducing the risk of regional climate changes should include the following:

– optimization of the specific weight of black steam in individual areas of the region;

– development and implementation of resource-saving, ecologically safe and soil-protecting methods of watering agricultural crops for reducing the dependence of productivity of the plant industry on the influence of adverse weather conditions;

– improvement of soil properties for better moisture accumulation;

– restoration of forest protection strips in order to prevent soil degradation and land desertification;

– development of innovative technologies for growing agricultural crops aimed at accumulation and economical use natural moisture.

8. Climate modeling of the city of Vinnytsia

Studies of the climate of Ukraine show that during the last ten years the temperature and some other meteorological parameters differ from the values of the climatic norm (1960–1990). The average annual air temperature over the past twenty years (1991–2010) has increased by 0.8°C relative to this indicator, there has been a redistribution of the amount of precipitation by regions of Ukraine and by seasons (although in general the amount of precipitation has remained practically unchanged during the year) and an increase in the amount the manifestation of individual storms (very heavy rain, strong wind, very heavy snowfall, heavy fog, etc.), as well as the occurrence of heat waves became more frequent during the last decade.

Climate modeling for the territory of Ukraine indicates that the increase in air temperature in general will continue. A further change in the amount of precipitation during the year will lead to a shift in the climatic seasons, a change in the length of the growing season, a decrease in the duration of the permanent snow cover, a change in the water resources of the local runoff, etc. The consequences of climate change, manifested in the urban environment, cause a negative impact on it.

The concentration of a significant number of people in cities, the peculiarities of the local microclimate, which may exacerbate some of the negative consequences of climate change, a change in the dominant supporting surfaces of the city, high-rise buildings, the presence of a network of urban transport and a well-developed infrastructure (which may suffer damage from the negative impact of climate change and cause significant discomfort for the city's population) makes the city significantly more vulnerable to the manifestations of climate change compared to other territories.

The main potential negative consequences of climate change that can manifest in cities include: heat stress; flooding; reduction of areas and disturbance of the species composition of urban green zones; spontaneous hydrometeorological phenomena; decrease in the quantity and deterioration of the quality of drinking water; increase in the number of infectious diseases and allergic manifestations; disruption of the normal functioning of the city's energy systems. In order to assess the vulnerability of cities to the negative consequences of climate change, we have developed seven groups of indicators, with the help of which it is possible to determine the most dangerous consequences of climate change for the city and establish for which of these consequences it is necessary to develop adaptation measures, for which it is desirable and for which it is unnecessary.

Groups of indicators were tested to assess the vulnerability of the city of Vinnytsia, which is located in the center of Ukraine. To facilitate the preparation of the city's adaptation plan, a list of adaptation measures (by individual consequences) has been drawn up and the main principles of its preparation have been defined:

1. Adaptation to climate change in the city requires a comprehensive approach and implementation of measures at different levels.

2. During the formation of the city-wide plan for adaptation of the city to climate change, it should be noted that there are measures that help to mitigate several negative consequences of climate change at once, therefore, their implementation will be the most effective for the adaptation of the city.

3. If the plan is developed by industry or by negative consequences, it should be carefully analyzed to see if there are any measures that contradict each other.

4. For certain negative consequences of climate change, it is important to develop a system of monitoring/early warning of the population/risk management – this will make it possible to at least partially minimize the damages caused by meteorological factors;

5. One of the important organizational tasks during the development of city adaptation measures is the implementation of a powerful information campaign aimed at different target audiences (from the youngest residents of the city to the oldest).

9. Practical value and conclusions

Global climate change has become one of the most urgent environmental problems to which humanity's attention is focused. Its consequences are dangerous weather cataclysms, sudden weather changes, floods, floods, strong winds, showers and rains, hail, droughts, which lead to significant ecological and economic losses all over the world. According to the World Meteorological Organization, the last three years have been the three warmest years on record. Increasing unpredictability of weather conditions threatens food production, rising sea levels increases the risk of natural disasters. Adaptation to global climate change is the process of adaptation in natural or human systems in response to actual or expected climatic impacts, which will reduce their negative consequences and take advantage of favorable opportunities. The humanitarian and environmental consequences of climate change and the pattern of extreme weather are likely to be significant. Globally, more and more people are expressing concern about the potential negative impacts of climate change on society and the economy, which could harm sectors ranging from agriculture to water resources. The worst impacts of climate change are likely to fall disproportionately on the poorest and most vulnerable, who already have few resources to evacuate in the event of a disaster and are ill-prepared to deal with the new challenges of climate change.

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