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DEVELOPMENT OF INNOVATIVE TECHNOLOGIES IN ENVIRONMENTAL AND GENETIC RESEARCH FOR AN EFFICIENT CEREALS PRODUCTION UNDER THE CONDITIONS OF CLIMATE CHANGE IN UKRAINE

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Abstract

The purpose of the article is multi-year research and analyze of the dynamics of cultivated areas, production volumes and yield of cereal crops in Ukraine, in the context of world cereals production and export. Ukraine's prospects on the world cereals market have been established thanks to the formation of ways to adapt the production of wheat, barley and maize to the conditions of climate change. Graphically illustrated data of the State Statistics Service of Ukraine on cultivated areas, production volumes and yield of cereal crops in Ukraine, data of the Food and Agriculture Organization of the United Nations on world cereals production and export. It was established that the production of cereal crops in Ukraine during 1990–2021 increased by 69% – from 51.0 to 86.0 million tonnes thanks to an increase in maize production almost 9 times – from 4.74 to 42.1 million tonnes due to the growth of its of cultivated areas by 4.5 times – from 1.23 to 5.52 million hectares. During 2008–2022, the world production of cereals increased by 32%, and the world export of cereals increased by 76%. At the same time, the transformation of the structure of cultivated areas, climatic changes and the war of the rf against Ukraine led to the yield of cereal crops being much lower than the potentially possible level. For effective cereals production, a number of adaptation measures are proposed to overcome the negative impact of climate change, which consist in the use of innovative technologies in environmental and genetic research, which ensure the cultivation of high-yielding varieties and hybrids of cereal crops that are resistant to drought, diseases and pests, as well as the optimization of cultivated areas with the introduction of scientifically based crop rotations and organic technologies.

***Key words*:** *production of cereal crops, cultivated areas, innovative technologies, climate changes, Ukraine*

INTRODUCTION

Cereals production is the basis of the food base and security, export potential and foreign exchange earnings of any country. Cereals is a strategic food product for the population, a valuable raw material for the processing industry, and a fodder basis for animal husbandry. Therefore, today the strategic goal of the development of the cereals industry is the implementation of innovative technologies that will ensure highly productive and competitive cereals production [32]. The concentration of the latest scientific-technical achievements in such technologies will contribute to the realization of the potential productivity of varieties and hybrids of cereal crops in different soil-climatic conditions [8]. Thus, for the improvement of environmental and genetic research, it is important to development the implementation of innovative technologies, with ensure the promising formation of genotypes of cereal crops resistant to stress factors, the increase of their structural and functional organization and adaptive potential, especially in conditions of climate change [18; 19].

The relevance of the study increases in connection with the full-scale attack of the rf on Ukraine, when there were risks of an increase in world food prices and causing people to starve in many countries of the world. Therefore, today, the solution of global social problems of humanity based on the use of innovative technologies is an effective factor, especially in the conditions of

environmental, economic, energy and food crises, which were caused by climate changes and military actions of the rf.

An in-depth study of this important scientific and technological direction in agrarian science of Ukraine has not been comprehensively investigated, although some publications cover it in fragments. In particular, the establishment of the effective action of soil protection technologies and computer modeling for the intensification of agrarian production in Ukraine and the world in the second half of the 20th – the beginning of the 21st centuries are given in the scientific works of I. Borodai, O. Hloba, N. Kovalenko, S. Yehorova [8; 9; 10; 11; 12]. Short statements about information technologies can be found in collective monographs of the institutions of higher education [30; 33] and scientific research institutions [18; 19]. The production of cereal crops and the factors of intensification of cereals production are analyzed: in Ukraine [1; 32] and Romania [24; 25; 26; 27]. However, in order to develop effective measures aimed at stabilizing cereals production and increasing the efficiency of the cereals industry, taking into account the global challenges and threats of today, further analysis of the functioning of the cereals market of Ukraine is necessary.

The purpose of the article is to research and analyze the world cereals production and export, as well as to establish the prospects of Ukraine on the world cereals market thanks to the development of the use of innovative technologies in environmental and genetic research for the formation of ways to increase the efficiency of the production of wheat, barley, and maize in Ukraine under conditions of climate change.

MATERIALS AND METHODS

The article uses a large array of information from scientific publications of the National Academy of Sciences of Ukraine, the National Academy of Agrarian Sciences of Ukraine, the Ministry of Agrarian Policy and Food of Ukraine. Statistical information from the State Statistics Service of Ukraine, Food and Agriculture Organization of the United Nations databases was used. Thanks to the comparative analysis and the calculation-constructive method, trends of long-term changes in the main indicators of the study were revealed: providing the population with arable land; world production and export of cereal; of cultivated areas, production and yield of wheat, barley and maize in Ukraine. The dynamics of the indicated indicators in Ukraine and the world during 1990–2022 are graphically illustrated.

The factors of disruption of the structure of cultivated areas are established and meteorological conditions are described, which affected the insufficient level of potential growth of yield and production of cereal crops in Ukraine. Attention is focused on the directions of development of innovative technologies, which, when used in environmental and genetic research, ensured the effective production of cereal crops in Ukraine under conditions of climate change. Thanks to the abstract-logical method, conclusions were formulated and a number of adaptation measures were proposed to overcome the negative impact of climate change and other negative manifestations.

RESULTS AND DISCUSSIONS

The dynamic growth of the world population is one of the global trends that causes a constant increase in food consumption. Therefore, solving the problem of providing the population with food is a priority task and a strategic direction of the economic policy of each country, aimed at ensuring its food and national security. According to the theory of the famous English economist T. R. Malthus (1766–1834), the population of the planet is growing all the time and soon there will not be enough agricultural lands to feed humanity [16]. In particular, during 1950–2022, the population of the planet increased by more than 3 times and amounted to 8 billion peoples (Fig. 1). At the same time, during this period, the area of lands suitable for growing agricultural crops remained almost unchanged, which in 2022 amounted to about 1.6 billion hectares. However, during this period, the world area of arable lands per

person, which in 1950 was 0.60 hectares, decreased by 67%. According to UN forecasts, the global population will increase to 9.6 billion peoples in 2050, which will reduce the supply of productive land resources to 0.17 hectares. This will lead to a significant increase in demand for food products, including cereals products. At the same time, to ensure a normal standard of living of the population, at least 0.50 hectares of arable lands per person is needed [20]. Thus, with a general decrease in the provision of arable lands to the population, the food problem can be solved thanks to the intensification of agrarian production based on the introduction of scientifically based technologies that ensure the reduction of the negative impact on the environment and the preservation of natural resources, as well as satisfy the consumers of the world market with high-quality agricultural products [24; 25; 26; 27].

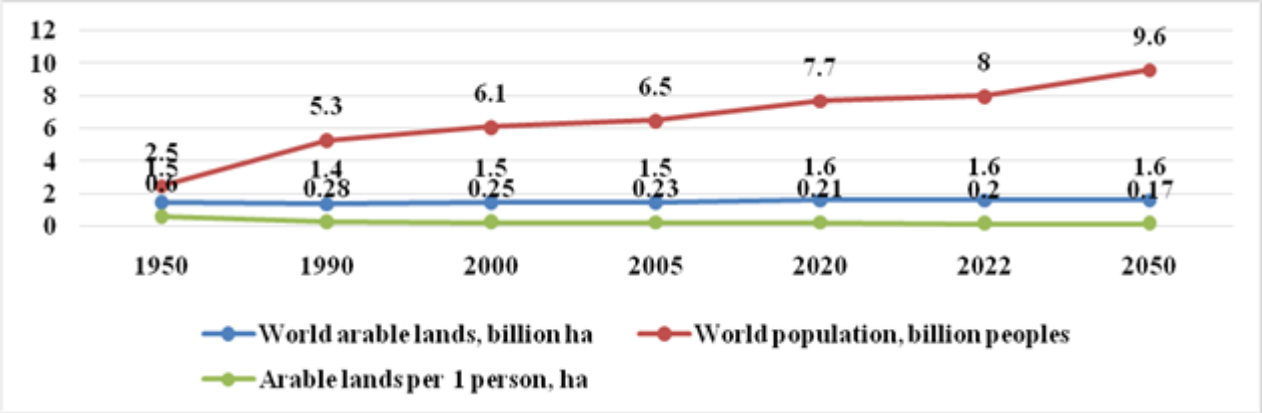

Fig. 1. Dynamics of providing the world population with arable lands, 1950–2050
Source: Own design based on the data from [20].

With the increase in the number of the world population, the global consumption of cereals is steadily growing, which is one of the factors in increasing the volume of its production and export. In particular, during 2008–2022, there is a tendency to increase world cereals production by 32%, which in 2022 amounted to 2 791.3 million tonnes. During this period, world cereals exports increased by 76% and amounted to 480.3 million tonnes in 2022 (Fig. 2). Such a tendency to increase the production and export of cereals in the world indicates the ability to satisfy the demand for cereals products even for the expected annual increase in the population of the planet by 60 million peoples in the next 30 years.

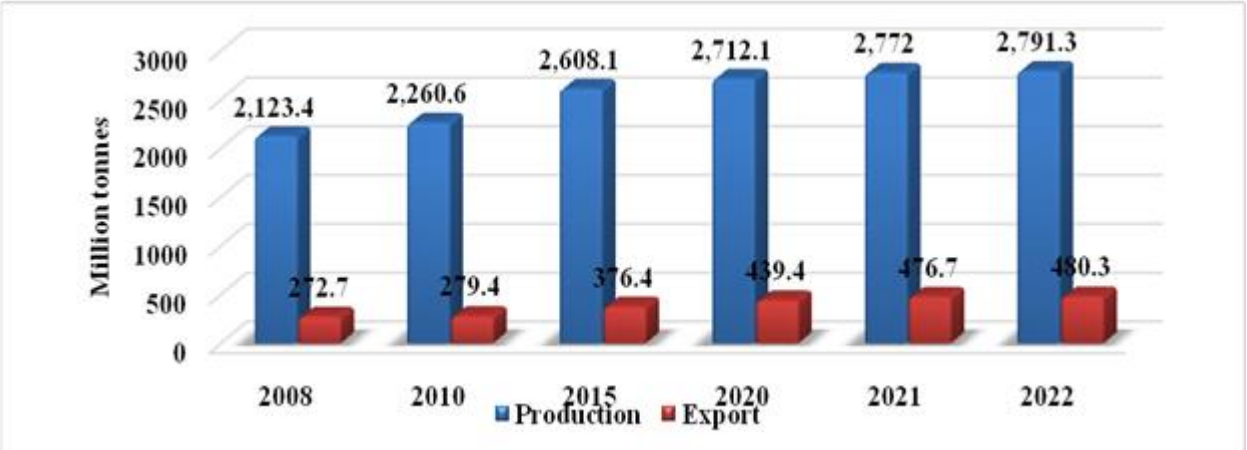

Fig. 2. Dynamics of world cereals production and export, 2008–2022
Source: Own design based on the data from [20].

Currently, the trends caused by negative factors, which are capable of restraining the further increase in global cereals production, have intensified. One of them is global climate change, recognized by the world community as one of the long-term factors that significantly worsen the cultivation of cereal crops and require coordinated actions by all countries of the world. For example, the duration and intensity of winter periods are decreasing, droughts and manifestations of other natural elements are becoming more frequent – droughts, dust storms, downpours, hail, frosts, freezing, icing, floods, flooding and inundation, which are associated with climate changes [32]. Reducing the duration and intensity of the winter period, reducing the number of frosty days and the depth of soil freezing, lead to early activation, reproduction and spread of harmful organisms [8]. Thus, with the preservation of the existing rates of warming, the probability of phytosanitary destabilization of agroecosystems, accompanied by the appearance of new groups of harmful organisms, increases. In addition, due to climate changes, there is an increase in erosion processes and landslides [12]. Therefore, an increase in cereals production in the face of global climate change is possible thanks to the introduction of scientifically based technologies for growing high-yielding varieties and hybrids of cereal crops that are resistant to drought, diseases and pests.

Some negative impact on the world cereals market occurred as a result of the application of restrictive measures to contain the spread of the COVID-19 pandemic. In particular, due to the disruption of logistics chains, losses were caused in the process of world cereals production. It should be noted that after several years of the COVID-19 pandemic, at present the world's food security is facing a new crisis in the food market. The cost of fuel, fertilizers and plant protection products increased, which caused the risks of a 22% increase in food prices and the starvation of tens of millions of people in many countries of the world [20]. In this context, innovative technologies in environmental and genetic research are called to support the effective production of cereal crops, which will ensure the solution of global social problems of humanity, especially in the conditions of environmental, economic, energy and food crises caused by climate change.

Currently, the growth of world demand for cereals has led to an increase in Ukraine's position in the world ranking. According to the results of 2022, Ukraine managed to maintain the status of one of the main exporters of cereals, entering the top five in the world. In particular, Ukraine took fifth place in the world ranking for the export of wheat, third – barley, and fourth –maize. In addition, Ukraine remained in the top ten producers of the main cereals products in the world and took the seventh position in the production of wheat, fourth – barley, sixth – maize [20].

Analyzing the dynamics of cultivated areas of agricultural crops in Ukraine for 30 years, it can be stated that they were extremely unstable and changed significantly over the years. In particular, during 1990–2021, the cultivated area of cereal crops increased by 8.9% – from 14.6 to 15.9 million hectares (Fig. 3).

When choosing an agricultural crop for sowing, agrarians note the following factors: profitability, the presence of stable demand and the level of prices on the market. Therefore, during this period, there were significant changes in the structure of crops of the grain group. In particular, due to high competition on the foreign market, the sown area of wheat decreased by 6.5% – from 7.58 to 7.09 million hectares, and barley by 9.2% – from 2.73 to 2.48 million hectares. Instead, high-yield corn for grain became the main grain crop in Ukraine, the sown area of which increased 4.5 times – from 1.23 to 5.52 million hectares [22]. This transformation has also been driven by global climate change and the use of high-quality seeds, fertilizers, plant protection products, etc.

During this period, the cultivated areas of technical crops increased 2.5 times – from 3.75 to 9.25 million hectares, thanks to the expansion of sunflower and rapeseed.

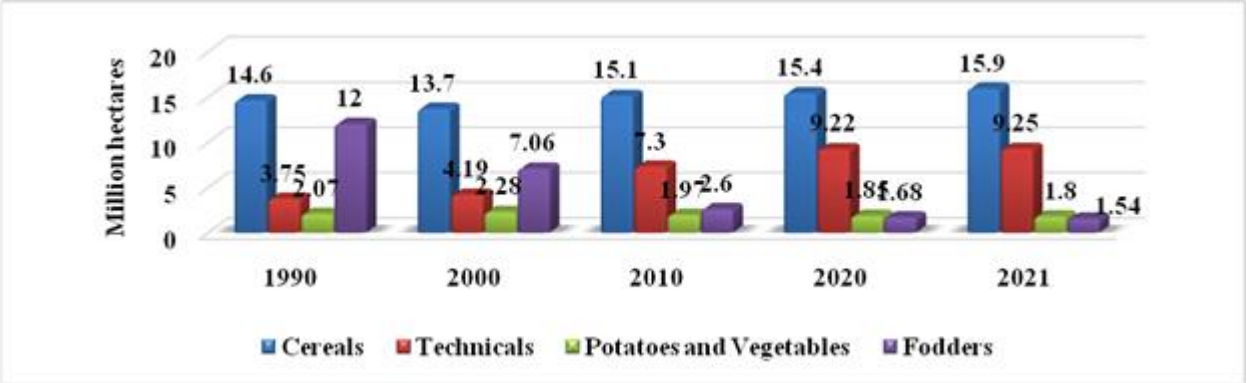

Fig. 3. Dynamics of cultivated areas of agricultural crops in Ukraine, 1990–2021
Source: Own design based on the data from [22].

The cultivated areas of potatoes and vegetables remained almost stable, decreasing by 13.1% – from 2.07 to 1.80 million hectares. However, the cultivated areas of fodder crops tended to reduce from 12.0 to 1.54 million hectares. Such a rapid decrease, by almost 8 times, caused a reduction in the planting of maize for silage and green fodder, perennial and annual grasses.

So, over the past 30 years, there have been significant changes in the structure of cultivated areas of various groups of crops: cereals, technicals, and fodders. This led to a violation of the use of optimal precursors and periods of returning cereal crops to the previous place of cultivation in crop rotations, which reduces their productivity due to a reduction in moisture reserves in the soil, a decrease in its fertility level, an accumulation of infectious diseases, the spread of specific weeds and pests [8].

At the beginning of the 21st century, the agrarian production of Ukraine, thanks to the developed genetics and technologies of growing agricultural crops, along with the introduction of scientifically based crop rotations, achieved success in obtaining high productivity indicators of cereal crops [32]. At the same time, during 1990–2021, Ukrainian agrarians managed to increase the national production of cereal crops by 69% – from 51.0 to 86.0 million tonnes only thanks to the increase in the production of maize per cereal from 4.74 to 42.1 million tonnes due to a significant increase in cultivated areas of this culture (Fig. 4).

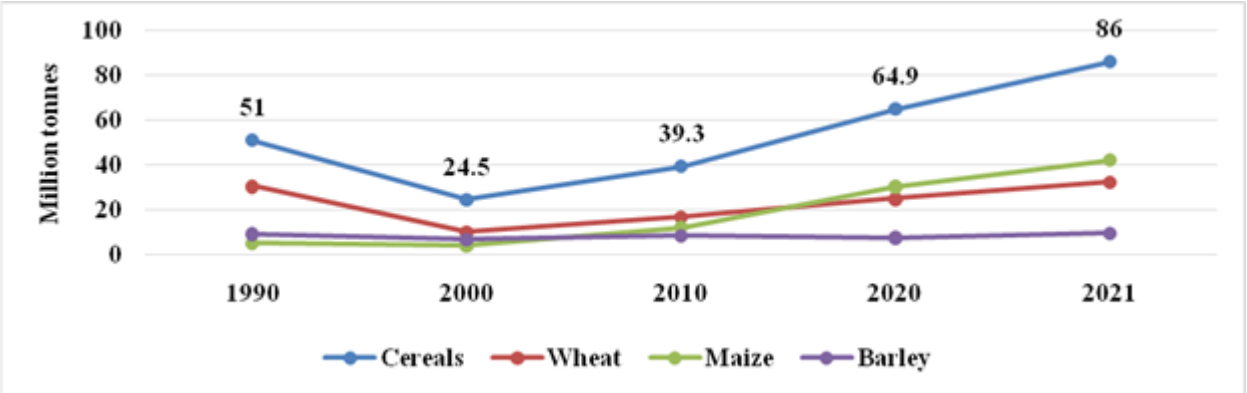

Fig. 4. Dynamics of cereal crops production in Ukraine, 1990–2021
Source: Own design based on the data from [22].

However, non-observance of scientifically based crop rotations due to excessive cultivation of maize per cereal caused a violation of the environmental balance of natural landscapes of Ukraine and increased erosion processes in the soil, which reached the highest level in the world. Such an unjustified transformation had a negative impact on the yield of cereal crops. In particular, over 30 years, this indicator

increased only 1.5 times – from 3.51 to 5.39 t/ha (Fig. 5). During this period, wheat productivity increased by only 29% – from 3.52 to 4.53 t/ha, barley by 9% – from 3.51 to 3.82 t/ha, which is significantly lower than the potentially possible level.

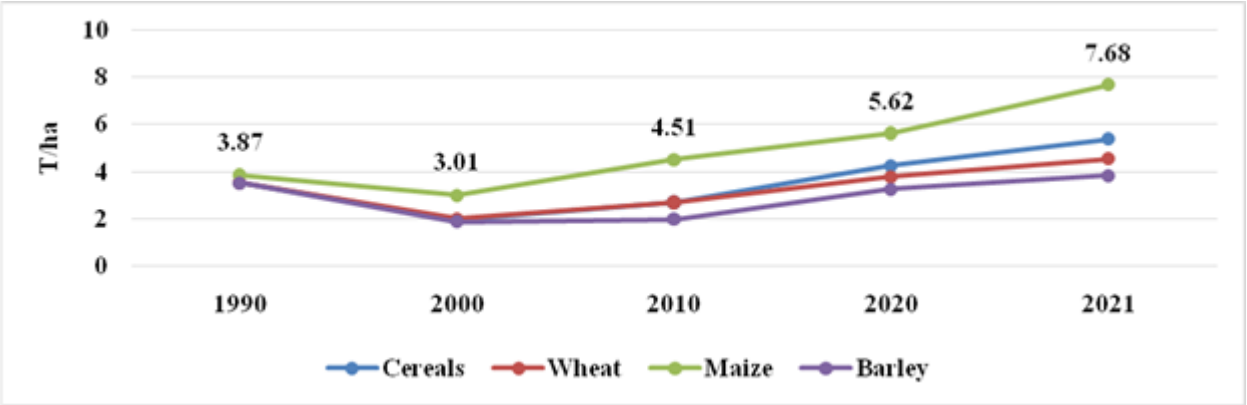

Fig. 5. Dynamics of cereal crops yield in Ukraine, 1990–2021
Source: Own design based on the data from [22].

Therefore, agrarians need to reorient themselves to the implementation of scientifically based crop rotations with effective saturation, placement and ratio of crops, taking into account soil and climatic conditions and the specialization of farms, which ensure the use of optimal rates of application of organic and mineral fertilizers, siderates, post-harvest crops, biohumus, as well as application of differentiated tillage [11]. The main principle of construction and development of scientifically based crop rotations in Ukraine is the placement of wheat, maize, barley and other cereal crops after scientifically based predecessors, observing periods of return to the previous place of cultivation [1]. This ensures an increase in the level of soil fertility, productivity and preservation of the environment.

In 2022, 51 million tonnes of cereal crops were harvested in Ukraine with a yield of 4.7 t/ha from an area of 10.9 million hectares, which is 94% of the total area of crops [21]. This is the lowest figure in the last ten years, which was negatively affected by several factors such as: weather conditions – rainy summer and autumn; the inability of some agrarian producers to optimize the application of fertilizers for plant protection products; lack of elevators, which forced to leave part of the maize crop to winter in the field. In 2023, the situation may worsen significantly due to shortages and high prices for fuel, mineral fertilizers, and plant protection products. This will force Ukrainian agrarians to apply less fertilizers and plant protection products, which will lead to a decrease in the yield of agricultural crops, but to a healthier environment and higher quality agri-products.

To solve these problems, a number of adaptation measures have been proposed to overcome the negative impact of climate change which consist in the use of innovative technologies in environmental and genetic research.

In the second half of the 20th century, economic-mathematical modeling began to be widely used to establish the functional and quantitative determination of environmental and genetic systems at all levels of the organization [2; 3; 4]. In particular, they developed linear economic-mathematical models that provide solutions to optimization problems based on the use of the simplex method, which consistently improves their solution [10]. One-dimensional correlation and regression models were used, with the help of which the parameters of cereal crops variability were determined for each individual genetic trait [8].

The use of correlation and regression models in environmental and genetic research remains relevant to this day. For example, in genetic studies of the dependence of maize cultivation on systematic environmental changes, for the

evaluation of pre-selected better samples, the connection between its various adaptive features and properties is revealed [29].

An important role in effectively ensuring the integrity of the growth and development of cereal crops is played by an approach that consists in the complex application of various types of correlation – genomic, morphological and functional [15]. For example, to establish factors that cause dependence between morphological-genetic features of winter wheat, determine the value of each factor for the occurrence of dependence, as well as the leading component.

Thanks to the joint research of Ukrainian and Moldovan scientists, a regression model was built to establish the level of adaptability of different genotypes of winter wheat and maize to environmental conditions – the complex influence of air temperature and lighting [17]. The synergistic effect of these factors has been established: the smaller one of them, the stronger the influence of the other.

The use of cluster, factor and discriminant models expanded the systematic research of genetic mechanisms of radiation transformation of cereal crops based on the influence of small doses of radiation on their structural-functional organization and adaptive potential. It was established that irradiation in small doses has the greatest effect on the organization of processes of epigenetic control of the formation and development of signs of the reproductive and generative spheres of barley, as well as its productivity [28].

System analysis using multidimensional models solves a more complex problem – assessment based on the aggregate manifestation of quantitative signs and system properties: nature, state, specifics of the genetic organization of processes that occur with cereal crops [14].

At the beginning of the 21st century, methods of system analysis to solve the problems of adaptability and resistance of cereal crops to stress factors are becoming widely developed. In particular, the features of the combined effect of radiation and toxic factors on the growth and development of cereal crops are determined thanks to the application of non-linear economic-mathematical models [5].

It can be concluded that using the achievements of molecular genetics and systems engineering, the development of environmental and genetic research is taking place. In particular, the system processes that take place at all stages of the formation of cereal crops are expanding, including self-organization, self-development, and self-regulation. The application of economic-mathematical modeling and computer technologies significantly accelerates the obtaining of quantitative and qualitative research results.

Of great importance is the use of geoinformation technologies, which were formed and continue to development on the basis of the achievements of the system of scientific knowledge: mathematics and statistics, informatics and programming, economic-mathematical modeling, cartography and ecology, monitoring of agrophytocenoses, remote sensing, aerospace research of ecosystems, GPS technologies, computer graphics and others [33].

In the second half of the 20th century, automated design systems began to be used. In 1981, the American Environmental Systems Research Institute (ESRI), which is now one of the leaders in the geoinformation technology industry, created the most widespread and developed "ArcGIS" software [6]. Thanks to its additional modules, consideration of characteristics and interpretation of spatially distributed data is provided for visualization and analysis of processes occurring in agroecosystems. It supports relational Database Management Systems (DBMS), has developed business graphics – view form, tabular form, diagram form, which creates professionally designed cartographic information [10].

In the mid-1990s, thanks to the technical capabilities of the "ArcGIS" software, the use of geoinformation technologies in environmental and radiological research expanded. In particular, Ukrainian scientists have developed model-analytical geoinformation technology that analyzes and provides forecasts of pollutant migration in

cereal crops [5]. Its main information components were the physical-chemical and biochemical characteristics of pollutants, as well as natural and anthropogenic environmental conditions, including the nature of the surface, angles of inclination, mechanical and chemical composition of soil rocks, characteristics of cereal crops, and others. The analysis of these characteristics ensured the definition of the main blocks of the economic-mathematical model – indicators of the rate of introduction and removal of pollutants [30].

At the beginning of the 21st century, Ukrainian scientists began the joint application of geoinformation technologies and remote sensing technologies, which were created on the basis of the American computer programs "Noaa", "Landsat" and the French "Spot" [7]. Their importance lies in the comprehensive use of the information base: based on satellite images, aerial photography and remote sensing, cartographic information, image decoding materials, and experimental research. In particular, they predict and assess the consequences of natural disasters: floods, storm warnings and destruction, detection and monitoring of cyclones, control of forest fires, the risks of which increase with climate changes, both in Ukraine and in the world [23].

With the use of methods of geoinformatics and mapping, remote sensing and indication, the use of reclamation systems is optimized [12]. In the context of the international Ukrainian-Dutch project "Watermuk", modern geoinformation technologies are being created for effective management of irrigation in arid conditions, both in Ukraine and the world [10].

To determine the influence of environmental conditions on the optical properties of cereal crops, using the "Rapid Eye" satellite, ground spectral analysis data are obtained [31]. In particular, the spectral characteristics of vegetation cover are revealed as vegetation indices of brightness and redness. Favorable conditions for the growth and development of cereal crops are characterized by smaller values of the spectral brightness coefficients, and when the conditions deteriorate, an increase in their redness is noted. On their basis, with the use of geo-environmental, geodynamic, landscape-environmental methods and geoinformational mapping, a system of local anti-erosion zoning of lands is being developed [13].

Thus, thanks to geoinformation technologies, modeling and forecasting of pollution of agroecosystems is carried out, dependencies between the level of pollution and the development of cereal crops are determined, harmful substances are monitored and measures are planned to reduce the risks of their negative impact on agrophytocenoses.

CONCLUSIONS

It has been established that with the increase in the number of the world population to 8 billion peoples in 2022, the global consumption of cereals is steadily increasing, which is one of the factors in increasing the volume of its production and export. In particular, during 2008–2022, there is a tendency to increase world cereals production by 32%, which amounted to 2,791.3 million tonnes in 2022, and world cereals exports by 76%, which amounted to 480.3 million tonnes in 2022. Despite military actions rf, Ukraine managed to maintain its status as one of the main exporters of cereals, entering the top five in the world in 2022.

During 1990–2021, the production of cereal crops in Ukraine increased by 69% – from 51.0 to 86.0 million tonnes due to an increase in the production of maize per cereal almost 9 times – from 4.74 to 42.1 million tonnes due to the growth of its cultivated areas by 4.5 times – from 1.23 to 5.52 million hectares. Due to high competition on the foreign market, wheat cultivated areas decreased by 6.5%, barley – by 9.2%. Cultivated areas of technical crops increased 2.5 times – from 3.75 to 9.25 million hectares, thanks to the expansion of sunflower and rapeseed. At the same time, the cultivated areas of fodder crops decreased by almost 8 times – from 12.0 to 1.54 million hectares due to a sharp decrease in the sowing of maize for silage and green fodder, perennial and annual grasses.

The transformation of the cultivated areas led to the violation of the use of optimal predecessors and periods of return of cereal crops to the previous place of cultivation in

crop rotations. In addition, due to climatic changes, prolonged droughts, dry spells, dust storms, rising air temperatures, lack of precipitation and other manifestations of the elements occurred. Therefore, during 1990–2021, the yield of cereal crops in Ukraine increased only 1.5 times – from 3.51 to 5.39 t/ha, wheat yield by 29% – from 3.52 to 4.53 t/ha, barley by 9% – from 3.51 to 3.82 t/ha, which is significantly lower than the potentially possible level.

A number of adaptation measures are proposed to overcome the negative impact of climate change, which consist in the use of innovative technologies in environmental and genetic research for the effective cultivation of high-yielding varieties and hybrids of wheat, barley and maize, resistant to drought conditions and harmful organisms.

In the second half of the 20th century, with the expansion of the use of economic-mathematical modeling in Ukraine, the development of such technologies took place. At the beginning of the 21st century, the cooperation of Ukrainian scientists with foreign scientists significantly expanded their use. Together with Moldovan scientists, non-linear, correlational and regression models are being developed for the effective growth, development and functioning of cereal crops in conditions of climate change. Thanks to innovative research, the use of the achievements of molecular genetics and system engineering – genetic and environmental – became the most effective in Ukraine.

An example of effective international cooperation was the confirmation by Ukrainian scientists of the effectiveness of geoinformation software products developed by American and French scientists. In particular, to analyze and provide forecasts of the migration of pollutants in agroecosystems.

Thanks to the combination of the use of geoinformation technologies and remote sensing technologies, the directions of environmental and radiological research of cereal crops in the conditions of climate change are expanding. Their use contributes to forecasting and prevention of natural disasters and reducing the risks of negative effects of harmful substances in agrophytocenoses. Thanks to the joint research of Ukrainian and Dutch scientists, geoinformation technologies have been developed to improve the efficiency of irrigation systems when growing cereal crops in arid conditions.

Wide use of innovative technologies in environmental and genetic research has ensured the promising formation of stress-resistant genotypes of cereal crops with increased adaptive potential, especially in conditions of climate change. Their cultivation, along with the optimization of cultivated areas, the use of scientifically based crop rotations and organic technologies, will ensure highly productive and competitive production of cereal crops in different soil and climatic conditions of Ukraine and the world.

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