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IMPACT OF CLIMATE CHANGES ON AGRICULTURAL LAND USE IN UKRAINE

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Abstract
Climate change threatens crop yields through changes in temperature, precipitation, and more significant changes in weather conditions. Thus, it is important to monitor the potential impact of changing weather parameters on crop yields in order to adapt to climate change. Ukraine is of particular interest in this regard, as this country is an important player in the world grain market due to its large area of agricultural land. Historical climate data already indicate an increase in temperature in Ukraine, and climate forecasts show a further increase in temperature, especially in the South of Ukraine. Therefore, the purpose of the article is to determine the impact of climate change on agricultural land use in Ukraine.
The global trends 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, have been studied. The impact of global climate change on land resources, agriculture, forestry, water resources, energy, infrastructure, biodiversity, public health, emergency situations is analysed. The article describes the most noticeable manifestations of global climate changes on the territory of Ukraine, researches and summarizes their consequences on agricultural land use. The potential impact of climate change on the yield of major agricultural crops and possible economic losses are analysed. The article summarizes the results of studies of the dynamics of changes in climate indicators (air temperature and precipitation), the main consequences and risks of climate change for the agricultural sector of Ukraine are given.
Key words: global changes, climate changes, agricultural land use, productivity.

Introduction

Global climate change is one of the more important problems of the 21st century, which is particularly focused on humanity. It is characterized by various manifestations, among which the main are dangerous (extreme) weather cataclysms, sharp changes in weather, floods, floods, rain and rain, hail, strong winds, drought, etc. Such weather phenomena lead to significant ecological and economic losses around the world.
According to the World Meteorological Organization (WMO), the last decades have become the warmest years in the history of observation. At the same time, the period 2016-2021 was the warmest in the last 1400 years. Significant changes in thermal regime have led to the fact that since the mid-1970s the anomaly of the average annual global air temperature has exceeded 0°C both relative to the average temperature in the XX century (1901-2000) and the basic climatic period (1961-1990) (Zhuzel′ ZH., 2012). Since then, the average annual air temperature remains positive, and the speed of its change is steadily increasing.
Thus, in the Northern Hemisphere, such changes have also been noted since the mid-1970s, and in Europe-from the late 80's (Fig. 1). At the same time, 2018 and 2022 were reflected in Europe as the warmest for the entire period of instrumental observations. According to the National Oceanic and Atmospheric Administration (NOAA), the average air temperature during this period was almost 2.82°C higher than the average temperature of the XX century (1901-2000).

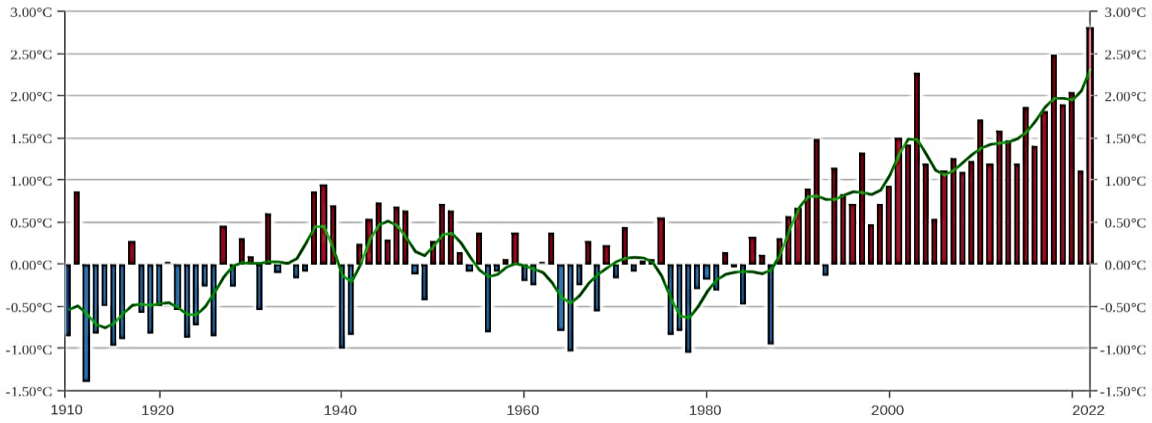

Fig. 1. Average annual anomalies of ground air temperature in Europe (according NOAA)

Increasing the surface air temperature, in particular in the northern hemisphere, led to food producers of food, the inter-year's variability of agricultural productivity. Increasing the unpredictability of climatic conditions threatens the provision of the Earth's population with food. Solving this food problem in the XXI century is the most important strategic task of the new century.

Climate changes affect all regions of the world and all segments of the population. UN data show that more than a hundred millions of people in developing climate change in developing countries can remain outside the poverty line (Climate change and poverty: report…, 2019). Even with the best scenario, most of the population may face food safety, various diseases, deaths and migration. The continuation of such a process will be detrimental to the world economy. Studies show that climate changes can lead to a decrease in global agricultural growth by 2050. More than 500 million small farms can potentially be affected worldwide (Munich Security Report, 2020).

To date, much of the world, through the adoption of international climate agreements, has committed themselves to effectively fight global warming and be carbon neutral by 2050.

However, at this time, the efforts to contain global warming, especially from the economically developed countries, do not produce the desired result. Thus, according to an the Intergovernmental Panel on Climate Change (IPCC) instead of limiting global warming at a level up to 1.5°C within the Paris Agreement of 2015, today the world is on the way to warming at 4.4°C 2100.

Increasing global temperature by 4°C, in the first place, will be accompanied by a reduction in water resources and an increase in competition for them, which will become a factor in the risk of food security on a global scale. The number of people who will not be able to receive enough water for at least one month a year will increase by 2050 from 3.6 billion to more than 5 billion. From the Sahara, by 2050, more than 140 million people can become internally displaced persons (Groundswell: Preparing for Internal Climate…, 2018).

Achievement of 1.5°C is still possible, but it requires a 7.6% reduction in total emissions every year (Climate tipping points…, 2022). In this case, each delay increases the amount of emissions that need to be reduced in the future.

Under these circumstances, an important task of environmental economics is to study the impact of climate change on agricultural land use in Ukraine, as they can help to understand exactly what changes need to be made to agroecosystems and agricultural production to reduce the impact of climate change and increase resilience to its consequences. Thus, the study of the impact of climate change on agricultural land use is an important step in the implementation of sustainable development of Ukraine, which involves a combination of economic growth, social justice and environmental protection.

Methodology of research and materials

The theoretical and **methodological** basis of the research is the general theoretical methods of scientific knowledge, in particular, the dialectical method, system analysis, the fundamental positions of modern economic theory, the economics of nature management and environmental protection, the concept of sustainable development, the work of leading domestic and foreign scientists on the problems of protecting agricultural land.

Materials of research*:* in the study used data of the state land cadaster, normative legal acts, statistical data of the State Statistics Service of Ukraine and the Ukrainian Hydrometeorological Center, Ministry of Environmental Protection and Natural Resources of Ukraine.

Discussions and results

The climate is the determining factor of agricultural production. Agriculture is the most climbing industry. Its vulnerability, caused by the influence of dangerous meteorological phenomena, which largely determines the amount of total losses of the country's economy.

Agriculture is one of the most important sectors of the Ukrainian economy. As of 2020, the share of agricultural products in GDP of the country is 9.3%, which is quite high among other countries in the world. Ukrainian farmers supply agrofood products to 205 countries. In the period 2016-2020, the volume of trade between Ukraine and the EU, between Ukraine and the United States has currently exceeded $ 5 billion USA in a year. The share of agricultural products and food in total exports is about 40%, providing 2/5 of foreign exchange earnings to the country (Trusova N., Radchenko N., Shut′ko T., 2021; How Ukraine can become one…, 2022).

According to the estimates of various experts, there are identified opportunities in Ukraine to feed more than 600 million people, which is 15 times greater than the domestic need for food (How Ukraine can become one…, 2022). Ukraine has significant natural and socio-economic resources, which determines

its sustainable development. At the same time, issues of sustainable development have recently become particularly relevant. After all, both in the economy and in the social life of the population, problems related to climate change are becoming more and more tangible.

The climate of Ukraine is temperate continental with subtropical Mediterranean on the southern coast of Crimea. In the north-western and western parts of the territory of Ukraine, the climate is mild with a moderate temperature regime and excessive humidity, although in the south-eastern and eastern parts there is a deficit of precipitation and a slightly elevated temperature background. The continentality of the climate increases from west to east.

In general, Ukraine receives a sufficient amount of moisture and heat, which causes favorable natural and climatic conditions on its territory. However, during the last thirty years, significant changes in the climate system have been observed in Ukraine. An indicator of these changes is a change in the average annual air temperature of the lower layer of the atmosphere (at a height of 1 meter above the surface), a change in the thermal regime and precipitation structure, an increase in the number of dangerous (extreme) meteorological and weather phenomena, which leads to losses both for the population of the country due to mold and and for various sectors of the economy.

Currently, the climate of Ukraine is in the trend of global warming, which has covered the entire territory of our country. At the same time, the rate of increase in air temperature is even slightly ahead of the global average. Thus, according to the assessment of the National Oceanic and Atmospheric Administration (NOAA), the territory of Ukraine has entered the regions of our planet where the temperature is increasing at the highest rates.

In addition, according to statistical data of the British Meteorological Bureau, February 2019 became the second warmest February in the entire history of observations for most European countries, including Ukraine (Fig. 2). This conclusion was made on the basis of meteorological data that was collected during a two-week period (February 11-25) every year since 2000.

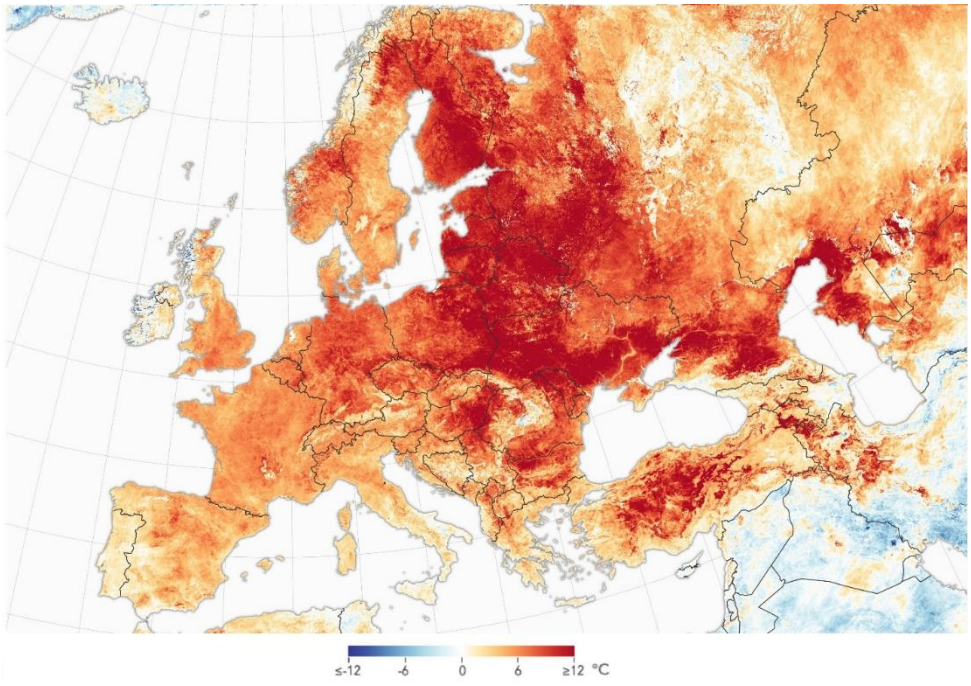

Fig. 2. Anomaly of the average February temperature of the earth's surface in Europe (An Unusually Warm February…, 2021)

Various scientific studies (Babichenko V. and et., 2022; Balabukh V., 2022) indicate that the modern climate of Ukraine is characterized by uneven warming over the territory, which is especially pronounced in the summer and winter months. Over the past 30 years, the average annual air temperature in Ukraine has increased by more than 1°C. At the same time, the increase in air temperature in the cold period (November-March) is on average 1.3°C, and in the warm period (April-October) – 1.1°C. Thus, we observe a clear increase in air temperature in Ukraine for the period 1991-2020 compared to 1901-1990 (Fig. 3).

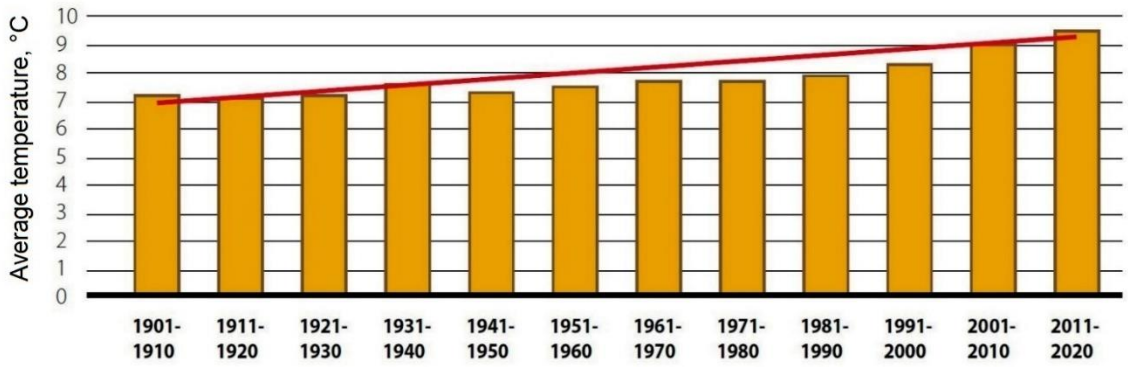

Fig. 3. Average annual surface air temperature in Ukraine

As shown by the given data (see Fig. 3), an increase in the average annual air temperature in Ukraine has been observed since the middle of the 20th century. Moreover, the following decade was warmer than the previous one: 1961-1990, the increase occurred by 0.3°C, 1991-2000 – by 0.5°C, 2001-2010 – by 1.2°C, 2011-2019 – by 1.7°C. In the period 1991-2020, such a positive anomaly (deviation of air temperature from the climatic norm) across the entire territory of the state was the largest in the entire history of instrumental meteorological observations. Such changes indicate a significant change in the climatic norm and acceleration of the increase in surface air temperature in Ukraine.

The change in the temperature regime is not uniform on the territory of Ukraine and has a regional character. The climatic norm of the average annual air temperature increased in the latitudinal direction from south to north and northeast. The greatest increase in temperature occurred in Polissia and in the Forest-Steppe zone, in some places the indicator exceeded 1.5°C (Fig. 4) (Balabukh V., Lavrynenko O., Malyts′ka L., 2014).

a) 1961-1990 *b)* 1991-2020

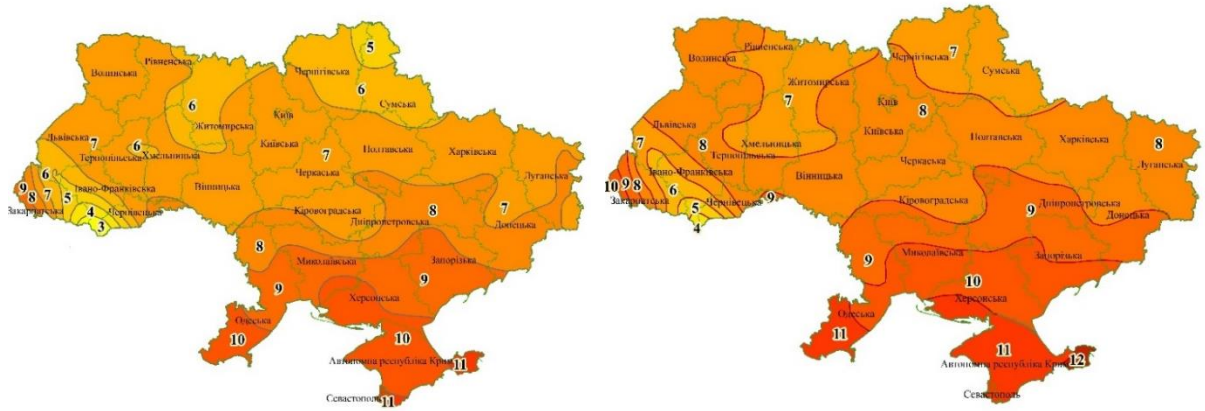

Fig. 4. Average annual surface air temperature in the basic (*a*) and modern (*b*) climate periods

Climate is also one of the main factors that determine the development of agriculture. At the same time, for this type of activity, it acts as a basic natural resource, as well as a risk factor for producers of agricultural products.

The impact of climate on agriculture is obvious. Today, as a result of climate change, agriculture is facing serious challenges, and at the same time, it is one of the main sources of greenhouse gas emissions that cause climate change.

Emission of greenhouse gases occurs at every stage of the agricultural cycle. After all, the production of livestock and crop production leads to emissions of carbon dioxide, methane and nitrogen oxide. According to the reports of the Intergovernmental Panel on Climate Change (IPCC), livestock production is responsible for 39% of anthropogenic methane emissions and 65% of anthropogenic nitrogen oxide emissions. In general, agriculture accounts for about 15% of the global volume of greenhouse gas emissions. Moreover, according to various estimates, by 2050, such emissions may increase to 30%.

According to the National Cadastre of Greenhouse Gas Emissions, the share of agriculture in total greenhouse gas emissions in Ukraine in 2020 was 13.2% (Ukraine's greenhouse gas…, 2022). The main

sources in the agricultural sector are intestinal fermentation and agricultural land (soil), which account for 17.9% and 76.4% of the total emissions in the sector in 2020 (Table 1). In general, emissions in this sector decreased by 52.0% compared to the base year, and by 6.9% compared to the previous year.

Table 1

Changes in greenhouse gas emissions in agriculture in Ukraine

Category	Total emissions of direct GHG	Emissions, kt CO2-eq.			
		1990	2016	2017	2020
Enteric Fermentation	CH_4	39311	8789	8596	7447
Manure Managemen	CH_4, N_2O	6775	1957	1920	1945
Rice Cultivation	CH_4	216	89	94	83
Agricultural Soils	N_2O	37678	28431	27619	31846
Liming	CO_2	2592	140	169	131
Urea Application	CO_2	270	451	512	235
Total for the sector		**86542**	**39857**	**38910**	**41687**

Agriculture significantly affects the accumulation of carbon in the soil, as well as the emissions of carbon dioxide as a result of changes in the intended use of land. Such negative phenomena can occur due to the conversion of forest lands to agricultural use, depletion of soil organic matter (humus) (SOM) on arable lands and pastures, etc.

Climate change related to agriculture is truly a global problem today. Agriculture is the most vulnerable sector of the economy to fluctuations and climate changes. This is due to its sensitivity to changes in climatic factors and due to the projected increase in crop yields as a result of the elimination of the technological backwardness of Ukraine's agriculture from the leading countries of the world. As you know, agroclimatic conditions for agricultural activities are determined by three main indicators: the amount of heat and moisture during the growing season, as well as the conditions for overwintering agricultural crops.

In general, the agro-climatic conditions of the territory of Ukraine are quite favorable for the development of agriculture. However, modern warming causes a significant change in the agro-climatic conditions of development, growth and productivity of agricultural crops. Such changes are accompanied by a significant increase in air temperature, especially in the winter months, a temporal shift in the formation of natural processes, an increase in the number of long thaws, an extension of the frost-free period and the duration and heat supply of the growing season of agricultural crops, changes in the duration of individual seasons. In addition, as a result of climate change, an increase in the frequency of extreme weather events, a decrease in soil moisture, depletion of water resources, the development of soil degradation, etc. (Voloshchuk V., Boychenko S., 1998; Krakovs′ka S. and etc., 2008).

In general, according to the research of the Technology Needs Assessment (TNA), which is implemented by the United Nations Environment Program and the Copenhagen Climate Center of UNEP, the agricultural sector of Ukraine is characterized by the following consequences and risks of climate change (Ukraine, Europe, 2022):

1. An increase in the productivity of major agricultural crops in the short term until 2030 and, at the same time, a potentially critical decrease in yields until 2050.
2. An increase in the growing season, which leads to a shift in the start of the sowing campaign by an average of 2 weeks earlier, as well as the possibility of harvesting two crops.
3. Reduction of production productivity due to lack of appropriate technical equipment under the scenario of rapid climate change.
4. The shift from the south to the north of the zones of cultivation of agricultural crops, the formation of a new agro-climatic zone in the south of Ukraine with the annual sum of temperatures exceeding 3400°C.
5. Increasing soil moisture loss due to increased droughts as a result of rapid growth of thermal resources.
6. An increase in the intensity of strong winds, which prevent the timely application of plant protection products and lead to the development of soil erosion.
7. Reducing the capacity of agricultural land use to adapt to climate change.
8. An increase in the level of infectious diseases as a result of changes in the migration routes of insects, birds and animals.

9. An increase in the risk of damage to plants due to diseases and pests due to favorable conditions for their development, especially in the winter period.
10.Reduction in the efficiency of animal husbandry due to a decrease in the gross production of traditional fodder crops and the need to grow non-traditional crops (sorghum, triticale, millet, etc.).
In general, the climate significantly affects the formation of the yield of agricultural crops and the spatial structure of agricultural production. According to many scientists, the warming of the climate in Ukraine as a whole has a positive effect on the productivity of crop production. Thus, according to the results of the research work "Conducting a spatial assessment of the degree of favorability of future climatic conditions for the productivity of the main grain crops and forest plantations" (Final report on the results…, 2014) in Ukraine, an increase in the yield of winter wheat is predicted in all natural and climatic zones. In particular, by 10-15% for the Forest Steppe, by 20-30% for the Steppe and Polissia. Moreover, in favorable years (under conditions of normal moisture), the yield of winter wheat, as well as grain crops in general, can increase by 2-2.5 times in the entire territory of Ukraine. Thus, it is assumed that climate changes will contribute to an increase in the yield of both winter wheat and other cereals in the near future. It is predicted that winter and spring wheat, rice, soybeans, and barley will grow much better, their ripening period will accelerate, and the yield will increase by 20-30%. At the same time, the yield of corn may decrease (Adamenko T., 2008).
In addition, the European Environment Agency (EEA) conducted a study on the change in crop yields in Europe by 2050 (compared to 1961-1990) under the condition of decreasing moisture levels. Therefore, according to the agency (EEA) (Projected changes…, 2022), almost the entire territory of Ukraine falls into the zone of potentially high yield increases (from 5 to 25%) (Fig. 5).

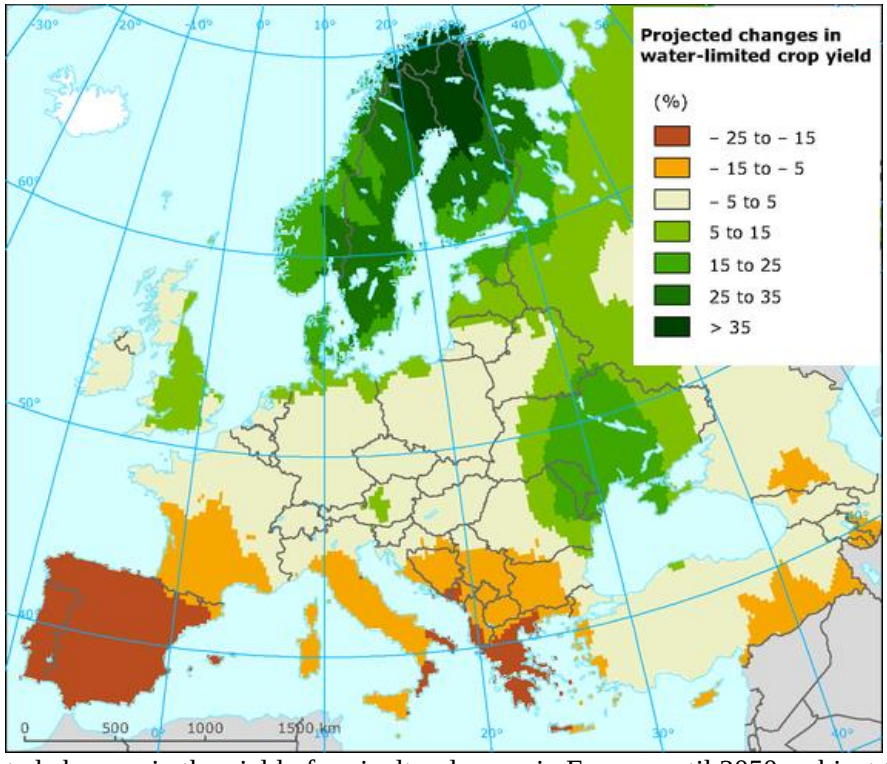

Fig. 5. Projected changes in the yield of agricultural crops in Europe until 2050, subject to a decrease in humidity

It is worth noting that many scientists claim that the increase in the yield of agricultural crops in Ukraine is mainly due to the access of landowners and land users to the latest technologies for the production of crop and livestock products. According to various calculations, the implementation of zonally adapted resource-saving and environmentally safe innovative technologies for the production of agar products will ensure an increase in production efficiency and competitiveness on the domestic and foreign markets due to an increase in the gross production of grain by 10-15 million tons, meat – up to 5.1, and milk – up to 20 million tons, a decrease in specific fuel costs by 26-40%, labor costs by 30-60%, direct operating costs by 22-50%, as well as an increase in the yield of agricultural crops by 30-40% (Yurchenko V., 2017; Tkachuk V., 2014).
It is known that for a comprehensive assessment of the impact of climate changes on agricultural land

use, two main groups of agroclimatic indicators are used – the properties of heat supply and moisture supply, mainly the growing season.
The growth of the heat supply of crops, which is now, is certainly significant factors that contributes to the increase in productivity of agricultural production of Ukraine. However, not only a change in the average annual temperature, but a change in temperature in certain periods of plant life cycle, is important for agriculture. During the period 1991-2019 in the territory of Ukraine, the greatest deviation from the rate of average monthly temperatures of air occurs in winter and in the second half of the summer (Fig. 6).

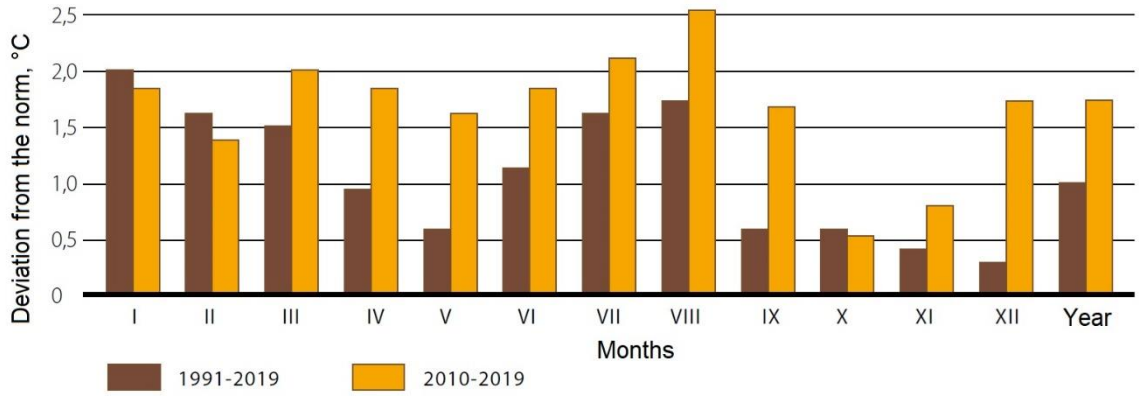

Fig. 6. Deviation from the norm (1961-1990) of average monthly air temperatures for periods of 1991-2019 and 2010-2019 in Ukraine

Climate warming is accompanied by a change in the conditions of moisture of a certain area. Moisture is determined by the ratio of precipitation and evaporation. Soil moisture deficiency in the growing season is a major factor that reduces crop yields. Nowadays, precipitation is characterized by significant spatial heterogeneity, which is caused by various pre -forming processes that prevail in the regions of Ukraine.
It is known that the norm (1961-1990) of the annual rainfall in Ukraine is 578 mm. However, over the last 5 years (2015-2019), on average, rainfall was 569 mm, with their extremely uneven distribution in time and territory-from 500 mm to 659 mm in 2016 (Fig. 7). In Vinnytsia, Donetsk, Zaporizhia, Kyiv, Rivne, Ternopil, Khmelnytsky, Cherkasy and Chernihiv regions, 7-12% fewer than the norm has fallen over these 5 years (Adamenko T., 2019).

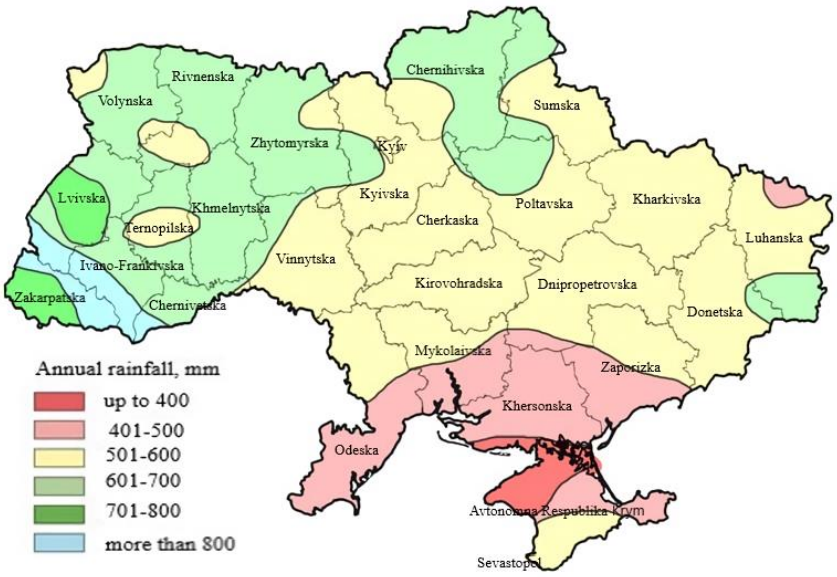

Fig. 7. The average annual rainfall in the territory of Ukraine

It is important that the nature of the rainfall that has become more extreme. In many regions of Ukraine,

the intensity of precipitation has increased, the uneven loss of their fall over certain periods of the year, which has led to an increase in the duration of the inflammation. In general, according to the Ministry of Environmental and Natural Resources of Ukraine in 2020, rainfall fell by 13.6% less than the average long-term amount for 1991-2020. Summer and autumn were the most drying in a large territory of Ukraine. Due to the increase in air temperature and uneven distribution of rainfall, which is of storm, does not ensure the effective accumulation of moisture in the soil, which caused the occurrence of arid phenomena. As a result of the drought that arose in Ukraine in 2020, the amount of material losses caused from the area of dead crops amounted to more than UAH 23.4 billion, of which winter crops are over UAH 17.1 billion (National report…, 2020). In addition, there are no losses of natural disasters, losses from changes in the specialization of enterprise, production cycles of growing crops, costs of adaptation to climate change, etc. According to the British economist Nicholas Stern, if countries do not implement measures to reduce greenhouse gas emissions, then losses from climatic changes can reach about 5-20% of GDP annually (The Economics of Climate Change…, 2007).

Conclusions and proposals

Based on the above data, we can conclude that climate change has an ambiguous impact on both agricultural land use and agriculture as a whole. Thus, the impact of climatic changes on land use in agriculture has both positive and negative consequences.

Therefore, the positive effects of climate change can be attributed:

- Increasing the efficiency of agriculture by increasing the duration and heat supply of the growing season throughout the country;
- Increasing the duration of the vomiting period and improving the conditions of wintering of certain field and garden crops;
- Earlier start of spring field work and the onset of sowing of spring crops, as well as acceleration of ripening of cereals and the terms of their harvesting.;
- The possibility of harvesting several crops during the year;
- Expanding the territory of cultivation of traditional crops (wheat, rye, barley, corn, etc.) and the ability to grow more demanding for warm culture (millet, sorghum, melons, sunflower, soybean, grapes, etc.).

The negative consequences of climatic changes in land use in agriculture of Ukraine belong:

- Weakening of hardening of plants with increasing the likelihood of their damage from freezing, soaking, evaporation due to significant changes in temperature, as well as from various fungal diseases caused by warm and snowless winters;
- Changes in temperature regimes in the spring, which led to a shift in the beginning of the sowing campaign, which in recent years begins on average 2 weeks earlier;
- Reducing yield due to the increase in the frequency and duration of dry periods in some regions and increased recurrence, intensity and duration of extreme precipitation (floods) in others;
- Reducing soil productivity due to humus decomposition in soils at higher air temperatures;
- Development of soil erosion due to intensive leaching of nutrients from the soil during heavy rains;
- The development of wind erosion of soil due to strong wind gusts, which also interfere with the timely introduction of plant protection products;
- The spread of new infectious and parasitic diseases that are not peculiar to certain regions, as well as the increase in the reproduction of many thermophilic species of pests of crops.

Thus, given the dependence of agricultural efficiency on weather conditions, it is now necessary to make timely and adequate solutions for complex problems that are caused by climate changes. In order to effectively use some favorable aspects of climate change (for example, through an increase in thermal resources, it is possible to grow a larger set of crops and their varieties) preparation and implementation of special measures for adaptation (adaptation) to the agricultural sector of the country to new natural conditions at all levels. - from each farm to the country as a whole.

In addition, when analyzing the impact of climatic changes on agricultural land use, it is necessary to clearly separate not only what is happening now, but also what awaits us in the future. This is very important, because most of our country is expected to change the existing poorly positive trend for the negative.

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