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The influence of climatic changes on the formation of corn productivity in the Western Forest-Steppe of Ukraine

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Abstract. Currently, the trend of actively accelerating the pace of global warming has a negative impact on the current situation in the field of agriculture in many parts of the globe. According to current forecasts, the consequences caused by it will continue to intensify in the coming years. Many facts testify to the predominance of the negative consequences of these influences, including: an increase in temperature regimes, an increase in their variability, an increase in the amount and frequency of precipitation, an increase in periods of drought, and the presence of extreme weather phenomena. In addition, climate changes, increased humidity and CO_2 in the air are making adjustments to crop yields. The main fodder crop in the world is corn, therefore adaptation of agricultural conditions to climatic fluctuations becomes an urgent stage for farmers. Today, corn meets demand not only in the food industry, but also in medicine and energy supply. The purpose of the work is to determine changes in the number of growing seasons and interphase periods of corn, to assess the photosynthetic productivity of crops and to forecast yield indicators. During the research, the method of comparison, monitoring, as well as observation and empirical research was used. The scenario of possible climate changes RCP 6.0 for the period until 2050 was used. The dynamic model of crop productivity, developed by A.M. Polovyi, was used as a research tool. The article presents the results of assessing the impact of climate change on the formation of corn productivity in the Western Forest Steppe of Ukraine. The value of the obtained results lies in their application in the development and improvement of the corn cultivation model in view of the widest list of climatic deviations

Keywords: maize, climate change, crop productivity, RCP 6.0 scenario

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INTRODUCTION

Today, the rapid pace of global warming is already affecting the agricultural sector in many parts of the globe, and its effects will only intensify in the coming years and decades. The predominance of negative results of this impact is indicated by numerous facts: increase in temperature and increase in its variability, change in the amount and frequency of precipitation, increased frequency of dry periods and droughts, increase in the intensity of extreme weather events, salinization of arable land and fresh water.

Reliable supply of the country's population with food is of strategic importance in the conditions of the global world, financial and economic crisis. In connection with the expected increase in air temperature in the Northern Hemisphere, Ukraine's food security will largely depend on how effectively agriculture adapts to future climate changes.

In solving the problem of food security, a special role belongs to corn grain as the most important and socially significant product. Maize is the main fodder crop in the world, as it is considered one of the best types of grain for the production of concentrated fodder for animal feed. The need for corn and its fields of application are not limited only to food purposes, the products of its processing are actively used in industry, animal husbandry and medicine. Today, corn is also the main source of raw material for biogas plants in Europe. This is due to its high yield and the absence of significant problems in cultivation [1; 2]. In the world, in recent decades, corn has been characterized by the highest rates of yield growth among grain crops. In recent years, there has been a tendency to increase the areas devoted to corn cultivation. Adaptation of agriculture to current and future climate changes is of crucial importance today – effective planning and implementation of adaptation measures at various levels of state institutions can help in the implementation of this issue. Therefore, the assessment of future climate changes is very important today, and not only for agriculture.

Today, there is no doubt that the change in climatic conditions leads to significant variability in the yield of many agricultural crops, including corn [3-5]. Up to a certain level, an increase in temperature can contribute to the growth of the yield of some crops in the "cooler" parts of the globe, but if it exceeds the optimal level for this crop or there is a shortage of moisture and nutrients, then the yield can decrease. An increase in the frequency of extreme events, especially floods and droughts, also damages agricultural crops and reduces their yield [6; 7].

An increase in temperature, humidity and the level of carbon dioxide (CO_2) in the atmosphere contributes to the spread of many weeds, pests and diseases. Extreme temperatures combined with reduced precipitation inhibit crop development, but most studies indicate that these effects will change over time and vary depending on where they occu [8; 9].

A special report of the Intergovernmental Panel on Climate Change [10] on emissions scenario issues predicts the possibility of regional differences in global production that could put more than 5 million people at risk of hunger by 2100 [7]. According to [10], the projected increase in global warming to 1.5°C is likely to reduce the yield of major cereal crops, including maize, in sub-Saharan Africa, Southeast Asia, and Central and South America. To ensure today's level of food security and in the coming decades, efforts have been made to create simulation models for corn aimed at predicting the growth, development and yield potential of agricultural crops under certain environmental conditions. According to [3; 11-13], the main problem affecting the growth and development of corn is the change in weather conditions, which lead to intraseasonal yield variability.

The impact of climate change on corn growing conditions in Northeast China was considered by scientists from the Institute of Geographical Sciences and Natural Resources Research of the Chinese Academy of Sciences [13]. The crop-environment synthesis model CERES-Maize v4.5 was used to simulate future maize yields in combination with data for the representative concentration trajectory scenarios (RCP)-RCP 4.5 and RCP 8.5. The results of the study indicate a trend towards a continued decline in maize yields for both climate change scenarios. Thus, when the RCP 4.5 climate scenario is implemented, the average corn yield will decrease by 2.1% by 2020, by 12.9% by 2050, and by 22.7% by 2080. Moreover, reductions of 6.3, 18.4 and 47.5% are expected in the corresponding periods under the RCP 8.5 scenario excluding CO_2. In turn, the impact of CO_2, according to scientists' calculations, will be too small to compensate for the negative effects of climate change.

Parks *et al.* [14] used the GLAM model to assess the impact of climate change on maize cultivation in West Africa. According to the results of the study, a decrease in corn yield by 5.95% is expected when the temperature increases by 2°C, and under the conditions of an increase in temperature by 4°C, a decrease in yield by 37% is expected. It is noted that significant crop failures, which previously occurred only once every 19.7 years, will be observed every 2.5 years.

The study of the influence of the current climate of Ethiopia on the yield of maize was carried out using the APSIM-maize and DSSAT CSM-CERES-maize models [15]. The climatic periods of the near future (2010-2039), the middle (2040-2069) and the end of the 21st century (2070-2099) were considered. Climate simulations were performed using 20 general circulation models (GCMs) and two representative concentration trajectories (RCP 4.5 and RCP 8.5). The results of the study showed that, according to the scenarios, a slight increase in corn yield is expected (by 1.7-4.2%).

For the territory of Ukraine, the influence of climatic changes on the conditions for the formation of corn productivity was studied by T.K. Kostyukevich and T.I. Adamenko [16]. The conducted comparative characteristics based on average long-term data (1986-2005) and climate change scenarios A2 and A1B showed that the best conditions for the formation of corn productivity will be observed in the territory of Polissia, the worst – in the territory of the Southern Steppe. For the Western Forest-Steppe, under the implementation of the A2 climate change scenario, a yield decrease of 4-8% is expected, under the climatic conditions of the A1B scenario, a more significant decrease in yield is expected – up to 20%.

Most of the reviewed works are focused on forecasting the impact of climate change on corn production in comparison with the adaptation and suitability of the territory for corn cultivation. The process-based models used to simulate maize vary in complexity but share common comparable input parameters that include crop phenology, plant cover characteristics, and biomass development. The comparability of the input parameters in the models is relevant for climate change studies, the results of which can be used to make decisions and determine the direction of the policy for the further development of agriculture.

The purpose of the study is to assess the possible impact of climate change on the productivity of corn crops (medium-ripening varieties and hybrids) in the conditions of the Western Forest Steppe of Ukraine.

MATERIALS AND METHODS

One of the simplest methods of displaying possible changes in the climatic regime of any meteorological quantity is a comparison with past data, in particular, average multi-year values for the base period. In this study, the period from 1991 to 2010 is taken as the base. To assess possible climate changes, we used the RCP 6.0 scenario (representative concentration trajectories), which is a stabilization scenario and is currently considered the most realistic possibility [17] and the RCP 6.0+CO_2 scenario, which takes into account a 30% increase in CO_2.

The impact of climate change on corn productivity was assessed based on the dynamic model of crop productivity by A.M. Field [18]. The basis of the model is the system of equations of radiation, heat, water balances and the balance of biomass (carbohydrates and nitrogen) in the plant cover in the "environment – plant" system. The "environment – plant" system is considered as a complex dynamic system that develops under the influence of internal and external factors. In this system, the process of growth, development and formation of plant productivity in their complex interaction are highlighted. Modeling the process of plant growth and development contains a quantitative description of the processes of photosynthesis, respiration, growth and development of plants. The identification of model parameters was carried out on the basis of observation data at the network of hydrometeorological stations of the Hydrometeorological Service of Ukraine of the State Emergency Service of Ukraine [19].

To characterize the indicators of photosynthetic productivity of corn and agroclimatic growing conditions under different climatic conditions, the following were calculated: the dates of the onset of the phases of corn development, the sum of positive air temperatures and the sum of precipitation for interphase periods, the relative area of corn leaves, net photosynthetic productivity, photosynthetic potential, and the increase in total dry biomass in the period of maximum development. It should be emphasized that the impact of climate change on the formation of the productivity of corn crops was considered under the conditions of modern agricultural technology and modern varieties and hybrids of the culture, assuming that they will not change significantly.

RESULTS AND DISCUSSION

The possibility of using corn as the most important object of agricultural culture in different soil and climatic conditions indicates its high lability, the ability to successfully adapt to significant fluctuations and various combinations of vital factors. However, the conditions necessary for the growth and development of corn cannot be infinitely variable. The parameters of these conditions are determined primarily by the ecological features of plants, which have developed during the long evolution of the species under the influence of natural factors and the conscious activities of many generations of farmers. These features are determined by the reaction of the plant to the influence of such factors as moisture, soil and air temperature, soil acidity and its provision of the necessary reserves of mineral nutrition elements available to the plant, light, interaction between corn plants and other plants in the crop. Corn can develop normally and accumulate a significant amount of organic matter with an optimal combination of all the above factors.

Corn is a monocarpic annual plant of the spring type of development. The duration of the life cycle of corn, depending on the conditions of its growth and varietal characteristics, varies greatly. In corn, the following are the most significant phases of plant formation: seedlings, fifth leaf, seventh-eighth leaf (period of intensive growth), shedding of the panicle, flowering of the panicle and cob, milky, waxy and full ripeness. The occurrence and duration of each of them depends on the complex of agrometeorological conditions.

In the western part of the Forest Steppe, corn is sown at the end of the second decade of April (April 17). Under the influence of climatic changes, the sowing dates are expected five days earlier – on April 12. According to scenario calculations, the emergence of seedlings is expected on May 8, which is three days earlier than according to long-term data (May 11) (Table 1).

Table 1. *Maize development phases based on average multi-year data compared to those expected under the RCP 6.0 climate scenario*

Period, years	Sowing	Seedlings	Ejection of panicles	Milk ripeness	Wax maturity	Duration of the period, days
1991-2010	17.04	11.05	26.06	20.07	16.08	121
2021-2050, RCP 6.0	12.04	8.05	20.06	17.07	2.08	112
Difference	-5	-3	-6	-3	-12	-9

The assessment of agrometeorological conditions for growing corn during the growing season based on average multi-year data in comparison with those expected under the RCP 6.0 climate scenario was carried out in interphase periods. For each period, the average air temperature, the sum of active temperatures, the sum of precipitation and the duration of the period were determined (Table 2).

Table 2. *Evaluation of agro-meteorological conditions for growing corn during the growing season based on average multi-year data compared to those expected under the RCP 6.0 climate scenario*

Period, years	Average air temperature for the period, °C	Sum of active temperatures for the period, °C	Sum of precipitation for the period, %	Duration of the period, days
		Sowing – seedlings		
1991-2010	12.5	300	100	24
2021-2050 – RCP 6.0	12.6	328	141	26
Difference	+0.1	+28	+41	+2
		Seedlings – throwing out panicles		
1991-2010	17.8	820	100	46
2021-2050 – RCP 6.0	19.1	804	98	42
Difference	+1.3	-16	-2	-4
		Ejection of the panicle – milk ripeness		
1991-2010	21.0	505	100	24
2021-2050 – RCP 6.0	22.6	498	88	22
Difference	+1.6	-7	-12	-2
		Milk ripeness – waxy ripeness		
1991-2010	20.9	564	100	27
2021-2050 – RCP 6.0	23.0	483	76	21
Difference	+2.1	-81	-24	-6
		Seedlings – waxy maturity		
1991-2010	18.1	2,189	100	121
2021-2050 – RCP 6.0	19.0	2,113	96	112
Difference	+0.9	-76	-4	-9

The sum of active temperatures accumulated during the sowing-seedling period according to the average long-term data is 300°C, according to the scenario data, it is expected to be a little more – 328°C, but the duration of the period according to the scenario data is also expected to be two days longer. According to scenario data, the average air temperature is expected to be at the multi-year level. Significant changes will be observed in the amount of precipitation – 41% higher than in multi-year conditions (Table 1; Table 2).

The panicle shedding phase under perennial conditions occurs on average at the end of June (June 26) with the accumulation of the sum of active temperatures around 820°C, under the conditions of climate change, this phase is expected six days earlier, the duration of the period as a whole will decrease by four days, and the sum of active temperatures will be close to 804°C. Under the conditions of climate change, the average air temperature during the interphase period of emergence-ejection of the panicle is expected at the level of 19.1°C, which is 1.3°C higher than under basic conditions. No significant changes are expected in the amounts of precipitation.

After the phase of throwing out the panicle in corn, the phase of milk maturity comes. According to long-term data, it occurs when the sum of active temperatures is around 505°C at the end of July (July 20), under the conditions of climate change, the onset of this phase is expected three days earlier (in general, the duration of the period will decrease by two days) when the sum of active temperatures is around 498°C.

Under the scenario conditions, the average air temperature during the interphase period of panicle ejection – milk ripeness is expected to be 22.6°C, which is 1.6°C higher than under baseline conditions. The amount of precipitation is also expected to differ - according to the scenario, the amount of precipitation decreases by 12% (Table 2). The milk ripeness phase is followed by the wax phase. Under long-term conditions, it occurs with the accumulation of the sum of active temperatures of about 564°C in mid-August (August 16), under the conditions of climate change, it is expected on August 2 with the accumulation of the sum of active temperatures of about 483°C. In general, under the conditions of the scenario, the duration of the period is expected to be reduced by six days. Under the conditions of climatic changes, the average air temperature during the period of milk-wax maturity is expected to be at the level of 23.0°C, which is 2.1°C higher than under basic conditions. A significant difference is also expected in the amount of precipitation – due to climate change, the amount of precipitation during the period will decrease by 24%.

No significant changes are expected during the growing season, but there is redistribution, sometimes very significant. So, for all periods according to the scenario data, except for the period of sowing and planting, a decrease in the amount of precipitation is expected. A similar situation is observed with other indicators. Also, under the conditions of climatic changes, a reduction in the duration of interphase periods is expected, this is due to an increase in the average air temperature, which in turn causes an acceleration of the onset of the phases of culture development.

The study of the influence of certain technological techniques on the growth and development of agricultural crops is usually accompanied by observations of the features of photosynthetic activity in crops. This question is extremely important, because the change in the conditions of plant growth inevitably, directly or indirectly, affects the production process, and accordingly - the formation of the crop. Numerous studies [20; 21] show that plant productivity is closely related to growth and photosynthesis – two cardinal physiological processes. The creation of a photosynthetic apparatus of high activity is the first condition for obtaining significant sowing productivity. The second, no less important condition is the creation of a photosynthetic apparatus of sufficient size, i.e. obtaining the optimal leaf area.

The main indicators characterizing the production process in crops are: relative leaf area, leaf surface index, photosynthetic potential, net productivity of photosynthesis, dry biomass.

The high productivity of corn is also due to the fact that assimilation of carbon dioxide occurs, as in other tropical plants belonging to the C4 plant group. The photosynthetic productivity per unit of leaf surface and per unit of time in corn is 2-3 times higher than in agricultural crops from the temperate climate zone, in which the assimilation of carbon dioxide passes through the C3 cycle.

Let's consider the differences in the intensity of the increase in leaf area in corn according to all options. Thus, the leaf area during the period of maximum development is 3.8 m^2/m^2 on average over a long-term period (Table 3), under the conditions of climate change RCP 6.0, the leaf area is expected to increase to 4.3 m^2/m^2, under the conditions of RCP 6.0+CO_2 , the area of corn leaves is also expected to increase compared to both previous options - up to 4.9 m^2/m^2.

Table 3. *Indicators of photosynthetic productivity of corn crops during the growing season according to average multi-year data compared to those expected under the RCP 6.0 climate scenario*

Period, years	Option, scenario	The period of maximum growth					
		leaf surface area, m^2/m^2	Increase in total dry biomass, g/m^2 per decade	Net productivity of photosynthesis, g/m^2 per day	Dry biomass of the whole plant, g/m^2	Crop capacity, %
1991-2010	Basic	3.7	264.6	8.5	954.8	100
2021-2050	RCP6.0	4.3	249.7	6.8	943.9	89
	RCP 6.0+CO_2	4.9	292.8	7.9	1,099.2	98

In Figure 1 presents the dynamics of accumulation of the relative area of leaves of corn crops under the conditions of climate change RCP 6.0 and RCP 6.0+CO_2 in comparison with the base period. As you can see, during the growing season, the dynamics of the growth of the leaf area both according to climatic changes and according to perennial conditions was almost the same, but its quantitative indicators differ significantly. But in all cases, these values correspond to the interphase period of vegetation of panicle ejection – milk ripeness. Photosynthesis forms the basis of the primary biological productivity of natural ecosystems and determines the formation of crops in agricultural crops. The intensity of the photosynthesis process is affected by illumination, temperature and other environmental factors. Let's consider the graph of the dynamics of the average intensity of photosynthesis of corn crops over a decade under the conditions of climate change

RCP 6.0 and RCP 6.0+CO² in comparison with the base period (Fig. 2). According to the climate scenario RCP 6.0, a slight decrease in the maximum value of the intensity of photosynthesis per decade is expected to 30.1 mgCO_2/(dm²·hour) in comparison with the basic conditions (31.8 mgCO_2/(dm²·hour)). And in the case of the RCP 6.0+CO_2 scenario, on the contrary, the value is expected to increase to 36.2 mgCO_2/(dm²·hour). But in all cases, these values correspond to the interphase period of vegetation of panicle ejection - milk ripeness.

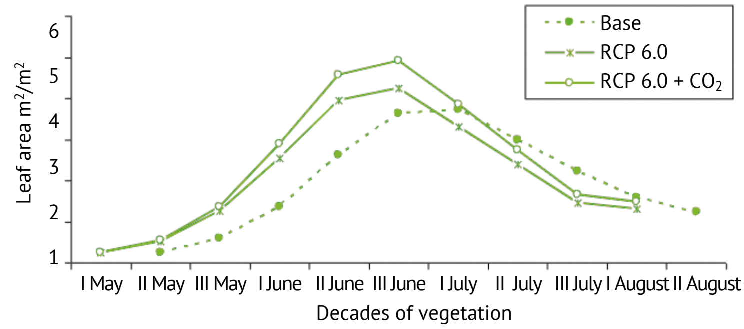

***Figure 1**. Dynamics of the relative area of leaves of corn crops during the growing season according to average multi-year data compared to those expected under the RCP 6.0 climate scenario*

The interrelationship of plants in agrocenoses is unstable, depending on many factors. The main task for obtaining high yields is the creation of such a crop, in which the potential possibilities of photosynthetic activity of plants in agrocenoses would be revealed as much as possible. This can be achieved by creating favorable conditions for the growth and development of plants. The growth of a plant and its biological productivity are primarily the result of photosynthetic activity, during which up to 95% of organic compounds are formed.

One of the indicators characterizing the production process of plants is the net productivity of photosynthesis. The maximum value of the net photosynthetic productivity of corn crops is 8.5 g/m² on average over many years (Table 3). Under the conditions of climate change RCP 6.0, the value of net productivity is expected to be significantly reduced – 6.8 g/m² per day, under the conditions of climate change RCP 6.0+CO_2 the value of net productivity is expected at the level of 7.9 g/m² per day. This is due to the reaction of plants to an increase in CO_2 in the air.

Such a reaction of plants determined the corresponding level of dynamics of the total dry biomass of corn and its growths. The maximum values of the increase in the total dry biomass of corn crops will be 264.6 g/m² per decade on average under long-term conditions (Table 3). According to the climate scenario RCP 6.0+CO_2, the growth values are expected at the level of 292.8 g/m² per decade, and under the conditions of climate change RCP 6.0 – at the level of 249.7 g/m² per decade.

The maximum value of the total dry biomass of corn crops on average according to long-term data is 954.8 g/m² (Table 3). An increase in dry biomass is expected under the implementation of the RCP 6.0+CO_2 climate scenario – up to 1,099.2 g/m², and under the climate change conditions of the RCP 6.0 scenario, it is expected to decrease to the level of 943.9 g/m².

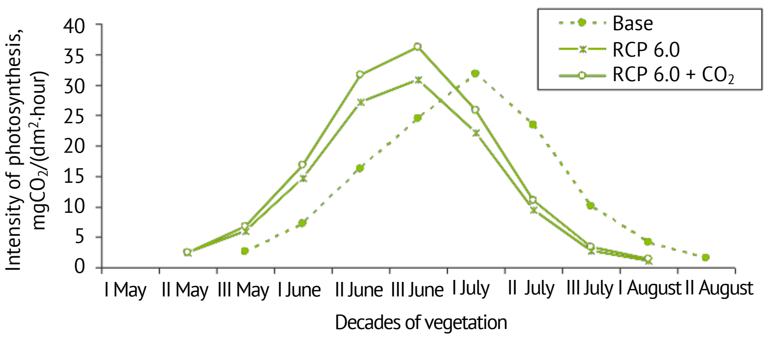

***Figure 2**. Dynamics of the average decade-long photosynthetic intensity of corn crops during the growing season according to average multi-year data in comparison with those expected under the RCP 6.0 scenario*

Thus, under the conditions of implementation of the climate scenarios, a decrease in corn yield is expected: under the RCP 6.0 option – by 11%, and under the RCP 6.0+CO_2 option – by 2%.

CONCLUSIONS

On the basis of the climate change scenario and the dynamic model of the formation of the corn crop, the variability of the expected moisture-temperature regime during the vegetation period of the crop towards an increase in air temperature and a decrease in the amount of precipitation compared to the current climatic period was assessed. A regular reduction of interphase periods and the vegetation period of the crop as a whole has been established. The assessment of the photosynthetic productivity of corn crops under climate change was carried out through its main indicators: the dynamics of the leaf area, the net productivity of photosynthesis, the dry biomass of the plant and the grain yield. Compared to the current climatic conditions, a decrease in corn grain yield by 2-8% is expected, depending on the implementation of one (RCP 6.0) or the other (RCP 6.0+CO_2) version of the scenario.

The perspective of further research is a more detailed consideration of the spatial and temporal variability of possible climate changes, conducting research on the response to climate changes in relation to other groups of varieties and hybrids of corn, as well as developing recommendations regarding the adaptation of agricultural techniques for growing corn in conditions of climate change.

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Вплив кліматичних змін на формування продуктивності кукурудзи в західному Лісостепу України

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Анотація. Наразі тенденція активного пришвидшення темпів глобального потепління негативно позначається на поточній ситуації у сфері сільського господарства у багатьох частинах земної кулі. За актуальними прогнозами, у найближчі роки наслідки, спричинені ним, будуть й надалі посилюватись. Щодо переважання негативних наслідків цих впливів свідчать багато фактів, серед яких: зростання температурних режимів, посилення їх мінливості, зростання кількості та частоти опадів, почастішання періодів засухи, наявність екстремальних погодних феноменів. Крім того, кліматичні зміни, підвищення вологості та CO_2 у повітрі вносять корективи в обсяги врожайності сільськогосподарських культур. Основною фуражною культурою у світі є кукурудза, тому адаптація сільськогосподарських умов до кліматичних коливань стає нагальним етапом для аграріїв. На сьогодні кукурудза задовольняє попит не лише у сфері харчової промисловості, але й медицини та енергетичного забезпечення. Метою роботи є визначення зміни кількості періодів вегетації та міжфазних періодів кукурудзи, оцінка фотосинтетичної продуктивності посівів та прогнозування показників врожайності. В ході дослідження було використано метод порівняння, моніторингу, а також спостереження та емпіричного дослідження. Використано сценарій можливих змін клімату RCP 6.0 на період до 2050 року. Як апарат досліджень використовувалася динамічна модель продуктивності посівів сільськогосподарських культур, розроблена А.М. Польовим. У статті представлено результати оцінки впливу кліматичних змін на формування продуктивності кукурудзи в Західному Лісостепу України. Цінність отриманих результатів полягає у їх застосуванні в розробці і вдосконаленні моделі культивування кукурудзи з огляду на найширший перелік кліматичних відхилень

Ключові слова: кукурудза, зміна клімату, продуктивність посівів, сценарій RCP 6.0