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The efficiency of maize production under the conditions of climate change in Ukraine: the use of highly productive hybrids and scientific technologies with elements of biologization

Petro Boiko[1], Nataliia Kovalenko[2*], Yevgen Yurkevych[3], Serhii Albul[3] and Nataliia Valentiuk[4]

[1] *National Scientific Center "Institute of Agriculture NAAS", 08162 Kyiv region, Ukraine*
[2] *Institute of Plant Physiology and Genetics of the NAS of Ukraine, 03022 Kyiv, Ukraine*
[3] *Odessa State Agrarian University of the Ministry of Education and Science of Ukraine, 65039 Odesa, Ukraine*
[4] *Institute of Climate-Smart Agriculture of the NAAS, 67667Odesa region, Ukraine*
[*] *Corresponding author:* BoikoNP@ukr.net

Abstract

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Cultivation of varieties and hybrids of grain crops with the use of scientific technologies with elements of biologization helps to preserve biodiversity and reduce the negative impact on the environment, while simultaneously solving the grain-food problem and providing consumers of the world market with high-quality grain products, especially in conditions of climate change. The article examines Ukraine's prospects on the world market of corn grain and outlines ways to increase the efficiency of its production, taking into account the global challenges and threats of today.

The purpose of the article is to establish the long-term dynamics of sown areas, production and yield of maize in Ukraine, ways to increase the export potential of Ukrainian maize based on the complex implementation of high-yielding hybrids and scientific technologies with elements of biologization in the conditions of the negative impact of climate change and other stress factors. The methodological approach takes into account the general concepts of the development and features of agrarian production based on the use of data of the Food and Agriculture Organization of the United Nations, United States Department of Agriculture, United Nations, Ministry of Agrarian Policy and Food of Ukraine and State Statistics Service of Ukraine. Statistical data on the world production and export of maize grain, the dynamics of sown areas, production and yield of maize in Ukraine are demonstrated, which directly focus attention on the competitiveness of Ukrainian maize on the world grain market.

These arguments are confirmed by the analytical results, which show that in 2022, despite the negative impact of the climatic factors and a full-scale armed attack by the russian federation, Ukraine entered the top five global producers and the top four global exporters of maize grain. Conceptually identified key problems, the solution of which will ensure further growth of maize productivity in different soil-climatic conditions. For the effective production of grain maize, a number of adaptation measures are proposed to overcome the negative impact of climate change and other stress factors, which consist in the complex application of high-yielding hybrids and environmentally safe technologies, which include: the use of plant residues with the use of modern biodestructors for the maximum use of their natural mass, which along with the implementation of scientifically based crop rotations, the introduction of organic and mineral fertilizers and plant protection products, will contribute to the preservation of biodiversity and the solution of the grain-food problem in the world.

*Keywords***:** maize; hybrids; yield; environmentally safe technologies; crop rotation; plant residues; biodestructors; climate change

Introduction

Growing high-yielding varieties and hybrids with the use of environmentally safe technologies, which 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, is becoming important in the world today (Kovalenko, 2014; Kovalenko & Hloba, 2021). To solve these problems, it is important to apply ecologically safe technologies based on the systematic use of scientifically based measures that contribute to the regeneration of quality components of the environment through self-recovery processes, and also provide a solution to the grain-food problem, especially in connection with climate change (Kovalenko, 2012b; Kovalenko & Bey, 2021; Kovalenko & Yehorova, 2022). The relevance of the study increases due to the full-scale armed attack of the russian federation on Ukraine, when there were risks of increasing world food prices by 22% and causing hunger of tens of millions of people in many countries of the world (Official Website of the FAO, 2022).

The purpose of the article is to establish the long-term dynamics of sown areas, production and yield of maize in Ukraine, ways to increase the export potential of Ukrainian maize based on the complex implementation of high-yielding hybrids and scientific technologies with elements of biologization in the conditions of the negative impact of climate change and other stress factors.

Ukrainian and foreign scientists have proposed a system of environmentally safe technologies based on biologization elements, which ensure the diversification of agrarian production and reduce the riskiness of its management in different soil-climatic conditions. In particular, for adaptation to climate changes and under martial law conditions, the effective use of modern varieties and hybrids of agricultural crops with high genetic potential for productivity and quality, stable resistance to diseases, pests and other adverse environmental factors has been established (Biliavska et al., 2021; Elsayed et al., 2022; Morhun, 2001a; Morhun, 2001b; Morhun et al., 2018). In connection with the fact that during extreme climatic phenomena, the role of crop placement is increasing, taking into account the agrobiological characteristics of crops, the structure of sown areas and crop rotation become one of the main elements of biologization, which contribute to the accumulation, preservation and rational use of soil moisture, as well as the regulation of the nutritional regime soil (Demidenko et al., 2020; Demydenko et al., 2018; Demydenko et al., 2019; Kovalenko, 2014; Mitova, 2021). To solve the problem of reproduction of soil fertility, which is aggravated by the growing deficiency of basic nutrients, attention is focused on the importance of optimal application of organic and mineral fertilizers (Berezyuk et al., 2021; Georgieva et al., 2022). In order to effectively provide the soil with organic matter, which is the basis of soil formation processes and an important source of nutrients for agricultural crops, maximum attention is paid to the use of the natural mass of plant residues – straw of grain crops, tops and stalks of maize and sunflower, husks of root crops, as well as siderates (Boiko & Kovalenko, 2017; Kovalenko, 2012a).

At the same time, establishing the importance of accelerating recovery processes in the soil based on the destruction of plant residues through the use of biologically active drugs – biodestructors, is of great importance for reducing the negative impact on the environment and satisfying consumers of the national and world market with high-quality agricultural products and requires further study, especially in the conditions of change climate

Material and Methods

The research is based on the use of general scientific principles of complexity and systematicity, objectivity and consistency, multifactoriality and comprehensiveness, which provide a holistic solution to the problem. To achieve the goal of the study, analysis, synthesis, typology, classification, and also comparative-historical, problem-chronological, and retrospective research methods were used. Graphical and statistical methods were used – to analyze the dynamics of production, yield and sown areas of maize; abstract-logical – for generalization and critical analysis of the effectiveness of the application of maize hybrids and biodestructors when using plant residues in crop rotation, and also for the formation of conclusions. The information base includes statistical data of the Food and Agriculture Organization of the United Nations, United States Department of Agriculture, United Nations, Ministry of Agrarian Policy and Food of Ukraine and State Statistics Service of Ukraine. It covers a wide range of published materials, the basis of which are the scientific works of scientists from various areas of research: the cultivation of maize hybrids, the introduction of biologization elements, the optimization of the structure of sown areas and the crop rotation system, the use of plant residues in different soil-climatic conditions.

Results and Discussion

Analyzing the structure of world grain production, it can be proven that maize is the leader among other grain crops. In particular, in 2022, the largest share falls on grain production: maize – 42%, wheat – 28%, rice – 18%, barley – 6%, other grain crops – 6% (Official Website of the FAO, 2022).

After all, maize is a highly productive crop that is widely used in various branches of agriculture and industry around the world. For example, for the production of food products, as a high-energy feed for livestock and poultry farming, as a raw material for the production of biofuel and biogas, in the pharmaceutical, chemical and other industries, as well as nutritious green fertilizers (Boiko, 1990). Thus, the valuable properties of maize ensure its steadily growing demand on the world market.

Another important factor in the increase in the production and export of maize grain is the stable growth of its global consumption due to the increase in the number of the planet's population, which during 1950–2022 increased more than 3 times to 8 billion people, and in 2050, according to UN forecasts, it will increase to 9.7 billion persons (Official Website of the UN, 2022). During the 2011/2012–2021/2022 marketing years, there is a trend towards a 33% increase in world production of maize grain, which in the 2021/2022 marketing year amounted to 1 206 million tonnes. During this period, the world export of maize grain increased by 71% and in 2021/2022 marketing year amounted to 200 million tonnes (Figure 1).

Such a trend in increasing the world production and export of maize grain indicates the ability to satisfy the demand for products of its production even with an annual increase in the population of the planet by 60 million people in the next 30 years. However, the trends caused by negative factors that are capable of restraining the further growth of world production of maize grain have intensified (Kovalenko & Hloba, 2021).

One of them is global climate change, which leads to environmental and phytosanitary destabilization of agrarian production in all countries of the world. For example, during 1990–2020, Ukraine experienced a rapid increase in the average annual air temperature by 1.2°C (Ivaniuta et al., 2020). This causes a reduction in the duration and intensity of winter periods and leads to phytosanitary destabilization

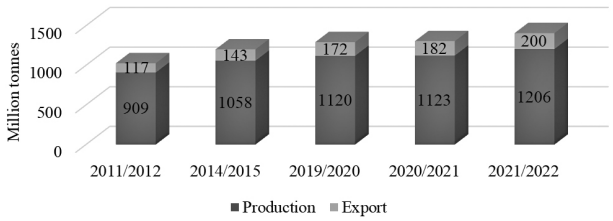

Fig. 1. Dynamics of world production and export of maize for the period 2011/2012–2021/2022 marketing years

Source: Compiled by the authors based on the data from official website of the Food and Agriculture Organization of the United Nations

of agrarian production due to early activation, reproduction and spread of pests and diseases. During this period, the average temperature in Ukraine in January and February increased by 1–2°C, which caused a change in the systematicity of seasonal phenomena – snowfall, spring floods, and the beginning of the flowering of crops. In addition, the number and intensity of dust storms, dry spells and droughts, which occur on average in Ukraine once every three years, have increased. For example, in 2015, Ukraine was hit by a drought, which became the largest in 140 years, starting from 1881 (Yurkevych et al., 2021). At the same time, there is an uneven distribution of precipitation and the intensity of precipitation, which are torrential in nature and cause floods and inundation, which lead to inefficient accumulation of moisture in the soil (Climate Change in Ukraine, 2022). In this context, the growth of maize grain production is possible on the basis of the comprehensive introduction of high-yielding hybrids that are resistant to drought, diseases and pests, as well as scientific technologies with elements of biologization, which ensure the reduction of the negative impact on the environment and the preservation of natural resources, and will also satisfy the consumers of the world market high-quality grain products (Kovalenko, 2019).

Currently, the production of maize grain has become widespread in 166 countries of the world due to its high level of productivity, as well as adaptability to various soil and climatic conditions. The role of Ukraine in the world market of maize grain production is becoming more significant. If until 1992 Ukraine was not included in the top twenty at all, then in 2010 it was established in the top ten world producers of maize grain, ahead Italy, Canada, Romania and Hungary (Official Website of the USDA, 2022). In the 2021/2022 marketing year, Ukraine entered the top five world leaders in maize grain production, including the USA, China, Brazil and Argentina (Figure 2). After all, the total volume of maize grain production of these countries is 8235 million tonnes or 68% of the global indicator. At the same time, Ukraine overtook maize grain production: India with 32.5 million tonnes, Mexico with 27.6 million tonnes, South Africa with 16.3 million tonnes, France with 15.4 million tonnes. In addition, Ukraine, together with the USA, Brazil and Argentina, entered the group of the world's largest maize grain exporters, which provided 173.0 million tonnes or 84% of exports.

Annually, 75–85% of Ukrainian maize grain is sold on foreign markets, where the leading importing countries are China and the countries of the European Union: Romania, Spain, Poland, Italy, Netherlands and Hungary (Figure 3). The growing demand of the European Union countries for Ukrainian maize is justified by their close location, which greatly facilitates logistics. Turkey, which is geographically

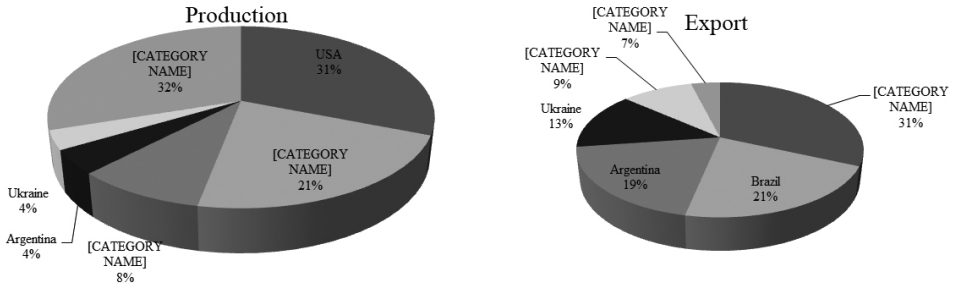

Fig. 2. Production and export of maize by leading countries in the 2021/2022 marketing year

Source: Compiled by the authors based on the data from official website of the United States Department of Agriculture

closest to Ukraine, has become a promising market for maize grain for Ukrainian farmers (Official Website of the FAO, 2022). Thus, today Ukrainian production of maize grain is in great global demand due to relatively low prices and the optimal geographical location of Ukraine relative to the leading importing countries.

We will analyze the dynamics of agrarian production in Ukraine during 1990–2021. During this period, the sown areas of the main groups of agricultural crops were unstable and changed significantly over the years (Figure 4). In particular, the sown area of grain crops increased by 11%: from 14.6 million ha to 15.9 million ha. In this context, an important role was played by the tendency to increase the sown area maize for grain – almost 4.5 times: from 1.23 to 5.48 million ha. In addition, it is possible to state an almost 3-fold increase in the sown area of technical crops, especially sunflower and rapeseed. At the same time, the sown areas of fodder crops decreased by almost 8 times, which caused a decrease in the sowing of maize for silage and green fodder, perennial and annual grasses (Official Website of the State Statistics Service of Ukraine, 2022).

Consequently, significant changes took place in the structure of grain, technical and fodder crops, which led to a violation of the use of optimal predecessors and periods of return of agricultural crops to the previous place of cultivation in crop rotations. Such a violation of the structure of sown areas leads to a decrease in the yield of agricultural crops 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, etc. (Yurkevych et al., 2021).

Thanks to the introduction of high-yielding varieties and hybrids adapted to high temperatures and a limited amount of moisture, as well as scientific technologies for their cultivation, during 1990–2021, Ukrainian farmers increased the national production of grain crops by 69% (Official Website of the State Statistics Service of Ukraine, 2022). In addition, there was progress in increasing the production of maize for

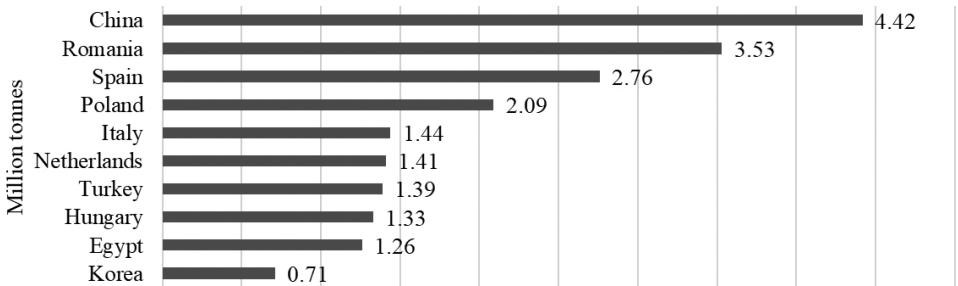

Fig. 3. Leading importers countries of Ukrainian maize in the 2021/2022 marketing year

Source: Compiled by the authors based on the data from official website of the Food and Agriculture Organization of the United Nations

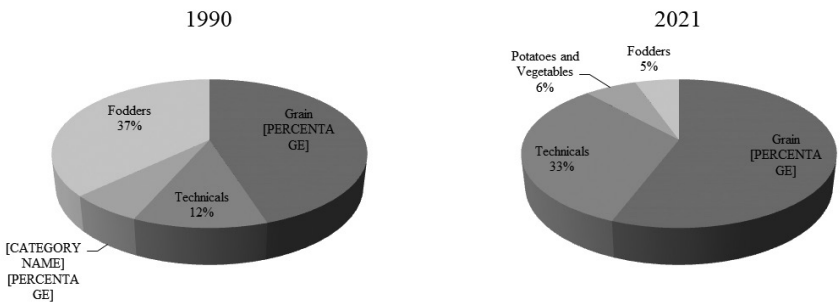

Fig. 4. Dynamics of the structure of sown areas of the main groups of agricultural crops in Ukraine for the period 1990–2021

Source: Compiled by the authors based on the data from official website of the State Statistics Service of Ukraine

grain by almost 9 times, which amounted to 42.1 million tons in 2021. There was also progress in increasing the yield of maize by 2 times – by almost 0.123 t/ha per year, which in 2021 amounted to 7.68 t/ha (Figure 5). However, this is a much lower indicator than the potentially possible level of productivity, which in the countries of the European Union is 10.0 t/ha and more (Official Website of the FAO, 2022).

Annually in Ukraine, 93–98% of the sown areas of grain crops are sown with seeds of high reproduction of the first class. The specific weight of zoned varieties and hybrids is 94–95%, of which Ukrainian selection is 75–78%, which significantly increases the yield of grain crops (Yurkevych et al., 2021). In 1991, 54 maize hybrids were grown in Ukraine, of which 38 or 70% were of Ukrainian selection. In 2021, their number increased more than 20 times, and amounted to 1285 maize hybrids, of which 302 or 24% of Ukrainian selection, which were created at the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine, many scientific-research institutions of the National Academy of Agrarian Sciences of Ukraine and private companies (Morhun et al., 2018). At the same time, during this period, the use of maize hybrids of foreign selection increased from 16 or 30% to 983 or 76%, which were created by foreign companies, including well-known firms: Pioneer, Monsanto, Syngenta and others. The demand for maize seeds of foreign selection is ensured by the fact that foreign companies engaged in its implementation offer a range of services, which includes not only the sale of seeds, but also scientific technologies with the appropriate supply of fertilizers and plant protection products, which collectively contributes to the growth of maize grain yield.

In 2022, the russian federation's full-scale invasion of Ukraine virtually halted Ukrainian maize exports due to port closures and damage to the transport and storage infrastructure, which was partially restored thanks to rail and road transport. In addition, due to lack of fuel, shelling, mining of the territory and problems with logistics, only 75% of arable land in Ukraine was sown. In particular, the sown area of grain crops decreased to 11.7 million ha, maize – to 4.63 million ha, which negatively affected their production. Only 53.1 million tonnes of grain crops were collected with a yield of 4.54 t/ha, including maize grain – 25.6 million tonnes with a yield of 5.53 t/ha (Official Website of the Ministry of Agrarian Policy and Food of Ukraine, 2023). These are the lowest indicators in the last ten years, which were also negatively affected by: the climatic factor – rainy summer and autumn; the inability of some agricultural 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.

At the same time, the use of maize hybrids of Ukrainian selection expanded due to the increase in the cost of imports, which made foreign seeds several times more expensive than Ukrainian ones. After all, Ukrainian hybrids of maize are not inferior to foreign ones in terms of productivity and rates of grain moisture loss in years favorable for the development of maize. In addition, thanks to better adaptability to local soil-climatic conditions, Ukrainian hybrids exceed foreign ones in terms of quality indicators in unfavorable and stressful years, which are increasingly manifested in Ukraine.

In 2023, the situation in the agrarian sector may deteriorate significantly due to the shortage and high prices of seeds, fuel, mineral fertilizers and plant protection products. This will force Ukrainian farmers to reduce the application of fertilizers and plant protection products, which will lead to a decrease in the yield and quality of agricultural crops, in particular maize. To overcome the negative impact of climatic changes and other stress factors, a number of adaptation measures are proposed, which consist in the comprehensive implementation of high-yielding maize hybrids and ecologically safe growing technologies, which include the use of plant residues with the use of modern biodestructors to accelerate the recovery processes in the soil based on their destruction, which, along with the introduction of scientifically based crop rotations, the introduction of organic and mineral fertilizers and plant protection products, will contribute to the preservation of biodiversity and the solution of the grain-food problem in the world.

For the efficient production of maize grain, in different soil-climatic conditions of Ukraine, it is recommended to grow hybrids of certain maturity groups. In particular, in the Steppe

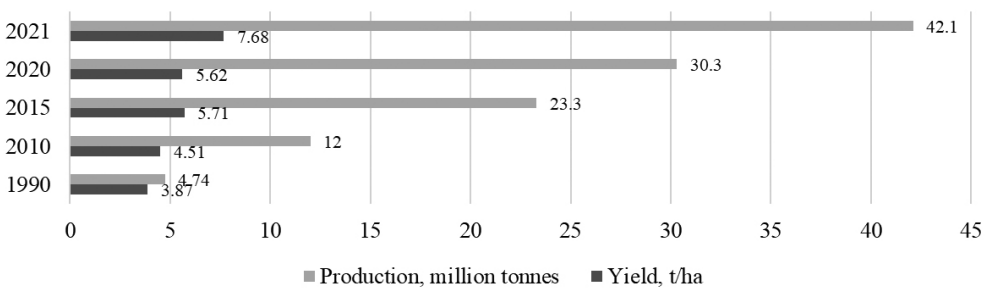

Fig. 5. Dynamics of production and yield of maize in Ukraine for the period 1990–2021

Source: Compiled by the authors based on the data from official website of the State Statistics Service of Ukraine

– mid-late and late-ripening hybrids (FAO 400–599), in the Forest-Steppe – mid-early and mid-ripening (FAO 200–399), in the Polissia – early-ripening and mid-early (FAO 100–299). Highly productive maize hybrids were created at the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine. Their characteristic features are high productivity, heat resistance and drought resistance, cold resistance, rapid moisture release, high resistance to diseases and pests, stem lodging and brittleness, stressful environmental conditions and many valuable properties. In particular, the grain yield of the specified maize hybrids is: in the Steppe, 11.9–17.0 t/ha at a humidity of 12–14%; in the Forest-Steppe – 10.3–16.4 t/ha at a humidity of 15–20%; in the Polissia 11.5–14.3 t/ha at a humidity of 15–20% (Morhun et al., 2018). At the same time, due to global warming, there is a decrease in the cultivation of late-ripening maize hybrids and a transition to early-ripening, mid-early and mid-ripe varieties.

To obtain a high yield of maize for grain in different soil-climatic conditions, it is necessary to observe all components of scientific cultivation technologies: optimal place in crop rotation, sowing rate, sowing date, fertilization and plant protection, tillage, and others (Boyko et al., 2019; Orekhivskyi et al., 2022). An important source of nutrients for maize is the maximum use of the natural mass of plant residues of agricultural crops, which are an effective reserve for providing the soil with organic matter (Boiko & Kovalenko, 2017; Borodai & Kovalenko, 2022; Kovalenko, 2012a). Plant residues improve the microflora of the soil, suppress the growth and development of harmful organisms, protect the soil from erosion, increase the yield of agricultural crops and the quality of products (Kovalenko, 2021; Kovalenko & Boroday, 2021; Terrer, 2019). At the same time, when plant residues are wrapped in the soil, long-term decomposition of fiber occurs, which creates a deficit of mineral nitrogen (Clarkson & Hanson, 1980; Wittgenstein et al., 2014).

The effectiveness of the use of plant residues increases when combined with other agrotechnical measures in crop rotations: the use of siderates, the introduction of organic and mineral fertilizers and plant protection agents (Staniforth, 1979; Yurkevych et al., 2011; Alemu et al., 2020). To accelerate the decomposition of plant residues, modern biodestructors are used, which enrich plant residues with useful and viable microorganisms, fungi and bacteria (Carter & Findlater, 1989; Fowber & Brydon, 1989). Modern biodestructors are distinguished by stability and active action in conditions of low and high temperatures, stability to stress factors – drought and moisture deficit, which is important in conditions of climate change (Stubble Biodestructors, 2014). Thanks to their application, microbiological activity and biochemical processes in the soil are supported (Dar, 2009; Kovalenko et al., 2021; Niranjane et al., 1993); pathogenic microflora is suppressed (Hossain et al., 2017).

Biodestructors are divided into groups: fungal origin, bacterial origin, and others – humates, trace elements, nutrients, biologically active substances, etc. (Stubble Biodestructors, 2014). Modern biodestructors include preparations developed by Ukrainian specialists. In particular, Tselulad of fungal origin was developed by LLC Trading House "Enzym-Agro", Ekostern of bacterial origin was developed by specialists of the "BTU-Center" company, which is characterized by cellulose-destroying and fungicidal properties. Preparations based on humates are used as a nutrient medium for the development of microorganisms in the soil.

The use of modern biodestructors Ekostern and Tselulad accelerates the decomposition of straw and ensures an increase in the yield of all crops in crop rotations (Yurkevych et al., 2017). The developed complex of polysaccharides promotes moisture retention and protects microorganisms from ultraviolet rays (Yurkevych & Bierov, 2016; Yurkevych & Alzhaiem, 2016). In arid conditions, the effectiveness of biodestructors increases significantly when irrigation is used, as a result of which the degree of destruction of plant residues by 2.2–2.6 times (Niranjane et al., 1993).

Conclusion

According to the results of the conducted research, it was established that the stable growth of the global consumption of maize grain is due to its valuable properties, as well as due to the increase in the number of the planet's population, which in 2022 has increased to 8 billion people. The comparative analysis showed that during the 2011/2012–2021/2022 marketing years, there is a trend towards an increase in the world production of maize grain by 33%, which in the 2021/2022 marketing year amounted to 1206 million tonnes, and the world export of maize grain by 71%, which amounted to 200 million tonnes. Based on the calculations, it was found that in the 2021/2022 marketing year, despite the full-scale armed aggression of the russian federation, Ukraine entered the top five world leaders of producers and the top four world leaders of exporters of maize grain. It has been proven that due to relatively low prices and optimal geographical location, China and the countries of the European Union: Romania, Spain, Poland, Italy, Netherlands and Hungary became the leading importers of Ukrainian maize.

The comparative analysis showed that during 1990–2021, the production of grain crops in Ukraine increased by 69% thanks to an increase in the production of maize grain almost 9 times – from 4.74 to 42.1 million tonnes due to an increase in its sown area by almost 4.5 times – from 1.23

to 5.48 million ha, and also the comprehensive introduction of high-yielding hybrids and scientific technologies. Due to high competition in the foreign market, the sown areas of technical crops increased by 3 times thanks to the expansion of sunflower and rapeseed. At the same time, the sown areas of fodder crops decreased by almost 8 times due to the rapid decrease in the sowing of maize for silage and green fodder, perennial and annual grasses. Such an unjustified transformation led to a violation of the use of optimal predecessors and periods of returning maize to the previous place of cultivation in crop rotations.

Based on the calculations, it was proved that due to the complex introduction of high-yielding hybrids and scientific technologies, Ukraine has made progress in increasing the production and yield of maize. These arguments are confirmed by analytical results, which show that during the research period, the yield of maize grain increased by 2 times – by almost 0.123 t/ha per year. At the same time, due to the negative impact of climate change and unjustified transformation of the structure of sown areas, it is significantly lower than the potentially possible level. The comparative analysis proved that in 2022, the military actions of the Russian federation in Ukraine caused a sharp decrease in the yield of maize grain to the lowest rate in the last ten years – 5.53 t/ha, which, along with a 15% reduction in the sown area, led to a decrease in the production of maize grain by 1.7 times.

A number of adaptation measures are proposed to overcome the negative impact of climate change and other stress factors, which consist in the comprehensive implementation of high-yielding maize hybrids adapted to local soil-climatic conditions, and scientific technologies with elements of biologization, which include scientifically based crop rotations, the introduction of organic and mineral fertilizers and plant protection products, the use of plant residues with the use of modern biodestroyers to accelerate the regeneration processes in the soil based on their destruction, which will ensure the competitive production of maize grain, taking into account the global challenges and threats of today.

References

Alemu, A., Feyissa, T., Letta, T**. & Abeyo,** B**.** (2020). Genetic diversity and population structure analysis based on the high-density SNP markers in Ethiopian durum wheat. *BMC Genetics, 21,* 98–111. https://www.bmcgenomdata.biomedcentral.com/articles/10.1186/s12863-020-0825-x.

Berezyuk, S., Pryshliak, N. & Zubar, I. (2021). Ecological and economic problems of fertilizers application in crop production. *Bulg. J. Agric. Sci., 27*(1), 29–37.

Biliavska, L., Biliavskiy, Y., Mazur, O. & Mazur, O. (2021). Adaptability and breeding value of soybean varieties of Poltava breeding. *Bulg. J. Agric. Sci., 27*(2), 312–322.

Boiko, P. I. (1990). Corn in intensive crop rotations. Kyiv: *Urozhai,* 142 (Ua).

Boiko, P. I. & Kovalenko, N. P. (2017). How to choose and use green manure. *Propozytsiia, 1,* 104–107 (Ua).

Borodai, I. & Kovalenko, N. (2022). Contribution of scientists of Saint Volodymyr University in the development of physiological science in the second half of the 19th – the beginning of the 20th century. *East European Historical Bulletin,* 25, 92–107. https://doi.org/10.24919/2519-058X.25.269531.

Boyko, P., Litvinov, D., Demidenko, O. & Rasevich, V. (2019). Prediction humus level of black soils of Forest-Steppe Ukraine depending on the application of crop rotation, fertilization and tillage. *International Journal of Ecosystems and Ecology Science (IJEES), 9*(1), 135–162. https://doi.org/10.31407/ijees9118.

Carter, D. & Findlater, P. (1989). Erosion potential of Phomopsis resistant lupin stubbles. *West Australian Journal of Agriculture, 30,* 11–14.

Clarkson, D. T. & Hanson, J. B. (1980). The mineral nutrition of higher plants. *Annual Review of Plant Physiology,* 31, 239–298. http://www.dx.doi.org/10.1146/annurev.pp.31.060180.001323.

Climate Change in Ukraine and the World: Causes, Consequences and Solutions for Countermeasures. (2022). *Center for Environmental Initiatives* «*Ecoaction*». https://ecoaction.org.ua/zmina-klimatu-ua-ta-svit.html.

Dar, D. H. (2009). Soil Microbiology and Biochemistry. *New India Publishing Agency,* 513.

Demidenko, O., Boiko, P., Tsimbal, Ya. & Kovalenko, N. (2020). Management of moisture resource potential in agrocenoses of Forest-Steppe of Ukraine. *International Journal of Ecosystems and Ecology Science (IJEES), 10(4), 733*–746. https://doi.org/10.31407/ijees10.423.

Demydenko, O. V., Boyko, P. I. & Velychko, V. A. (2018). Long-term dynamics of humus content under different technologies of soil tillage. *Agricultural Science and Practice, 5*(1), 3–16. https://doi.org/10.15407/agrisp5.01.003.

Demydenko, O. V., Boiko, P. I., Blaschuk, M. I., Shapoval, I. S. & Kovalenko, N. P. (2019). Crop rotation and fertility of chernozem of the Left-Bank Forest-Steppe: monograph. Smila: *Chornobayivske KPP,* 484 (Ua).

Elsayed, H. H. A., Farag, R. M. A. & Ramadan, A. K. E. (2022). Economic impact for the adoption of the recommended improved varieties on wheat production in Egypt. *Bulg. J. Agric. Sci., 28*(3), 369–375.

Fowber, D. & Brydon, J. (1989). No-till winter wheat production on Canadian prairies: placement of urea and ammonium nitrate fertilizers. *Agronomy Journal, 81*(3), 518–524. http://www.10.2134/agronj1989.00021962008100030025x.

Georgieva, N., Nikolova, I., Pavlov, D. & Zhelyazkova, Ts. (2022). Energy efficiency in pea organic production. *Bulg. J. Agric. Sci., 28*(1), 55–60.

Hossain, M., Fragstein, P., Niemsdorff, P. & Heb, J. (2017). Effect of Different Organic Wastes on Soil Properties and Plant Growth and Yield: Review. *Scientia Agriculture Bohemica, 48*(4), 224–237. http://doi.org/10.1515/sab-2017-0030.

Ivaniuta, S. P., Kolomiiets, O. O., Malynovska, O. A. & Yakushenko, L. M. (2020). Climate change: consequences and adaptation

measures: analytical report, Kyiv: NISD, 110 (Ua).

Kovalenko, N. P. (2012a). Historical aspects of the origin and development of scientific knowledge about greenhouse crop rotations. *Rural host, 11–12,* 27–33 (Ua).

Kovalenko N. P. (2012b). Ecologically balanced crop rotations in the system of alternative agriculture: historical aspects. *Agroecological Journal, 4,* 95–99 (Ua).

Kovalenko, N. P. (2014). Becoming and development of scientifically and organizational bases of application of domestic crop rotations in the systems of agriculture (the second half of the 19th – the beginning of the 21st centuries): monograph. Kyiv: *TOV "Nilan-LTD*", 490 (Ua).

Kovalenko, N. P. (2019). Ecologization of agricultural production: development of implementation of innovative technologies in Ukraine at the beginning of the 21st century. *Modern Problems of History of Science and Biographical Study: collective monograph.* Lviv-Torun*: Liha-Pres,* 41–64. https://doi.org/10.36059/978-966-397-148-3/41-64.

Kovalenko, N. (2021). Vasyl Pastushenko's Scientific School in the Development of Soil Protection Technologies in Ukraine. *Acta Baltica Historiae et Philosophiae Scientiarum (ABHPS), 9*(2), 100–115. https://doi.org/10.11590/abhps.2021.2.05.

Kovalenko, N. & Bey, R. (2021). Southern Branch of the VASHNIL (1969–1990) as a model of organization of agrarian science in the Ukrainian and Moldovan SSR. *East European Historical Bulletin, 20,* 162–170. https://doi.org/10.24919/2519-058X.20.240032.

Kovalenko, N. & Boroday, I. (2021). Biomedical engineering in Ukraine: development of computer modeling of biological objects. *2021 IEEE 2nd KhPI Week on Advanced Technology (KhPIWeek),* 234–238. https://doi.org/10.1109/KhPIWeek53812.2021.9570036.

Kovalenko, N. & Hloba, O. (2021). The model of regional development of agrarian science in Ukraine: the relationship between a centenary past and today. *International Journal of Ecosystems and Ecology Science (IJEES), 11(4),* 845–856. https://doi.org/10.31407/ijees11.423.

Kovalenko, N., Borodai, I. & Shchebetiuk, N. (2021). The development of biochemical research to improve the physiology of crop nutrition in Ukraine in the second half of the 20th century. *International Journal of Ecosystems and Ecology Science (IJEES). 11(2),* 299–310. doi: https://doi.org/10.31407/ijees11.214.

Kovalenko, N. & Yehorova, S. (2022). The history of development and the perspectives of implementation of innovative technologies for the environmentally safe use of water and land resources in Ukraine at the beginning of the 21st century. *International Journal of Ecosystems and Ecology Science (IJEES), 12(1),*87–100. https://doi.org/10.31407/ijees12.110.

Mitova, D. (2021). Environmental sustainability of Bulgarian agriculture. *Bulg. J. Agric. Sci., 27*(1), 72–79.

Morhun, V. V. (2001a). Genetics and breeding in Ukraine at the turn of the millennium: in 4 volumes. Kyiv: *Logos, 1,* 664 (Ua).

Morhun, V. V. (2001b). Genetics and breeding in Ukraine at the turn of the millennium: in 4 volumes. Kyiv*: Logos, 2,* 636 (Ua).

Morhun, V. V., Havryliuk, M. M., Shvartau, V. V., Morderer, Ye. Yu., Konovalov, D. V., Havryliuk, V. M. & Skryplov, V. O. (2018). Club of 100 centners. Modern varieties and hybrids and plant nutrition and protection systems: scientific edition. Kyiv: *Lohos, 10,* 111 (Ua).

Niranjane, J., Somani, R. & Puranik, R. (1993). Microbiol population as influenced, by incorporation of wheat straw inatypic usthortent. *Indian Society of Soil Science, 41*, 368–369.

Official Website of the Food and Agriculture Organization of the United Nations, (2022). http://www.fao.org/faostat/en/#data/QCL.

Official Website of the Ministry of Agrarian Policy and Food of Ukraine, (2023). https://minagro.gov.ua/news/vijna-zminyuye-strukturu-posivnih-ploshch-pershi-prognozi-urozhayu-2023-roku.

Official Website of the State Statistics Service of Ukraine, (2022). https://www.ukrstat.gov.ua.

Official Website of the United Nations, (2022). https://www.un.org/en/academic-impact/97-billion-earth-2050-growth-rate-slowing-says-new-un-population-report.

Official Website of the United States Department of Agriculture, (2022). https://usda.library.cornell.edu/concern/publications/zs25x844t?locale=en.

Orekhivskyi, V., Kryvenko, A., Kovalenko, N., Burykina, S., Parlikokoshko, M. & Drobitko, A. (2022). Efficiency of using organo-mineral biopreparations as elements of biologization in chickpea cultivation technologies in the arid Southern Steppe of Ukraine. *International Journal of Ecosystems and Ecology Science (IJEES), 12(4),* 15–26. doi: https://doi.org/10.31407/ijees12.403.

Staniforth, A. R. (1979). Cereal Straw. *Clarendon Press Oxford,* 191.

Stubble Biodestructors Are a Guarantee of Soil Fertility: Recommendations. (2014). BTU Center, 14 (Ua).

Terrer, C. (2019). Nitrogen and phosphorus constrain the CO_2 fertilization of global plant biomass. *Nature Climate Change, 9,* 684–689.

Wittgenstein, V., Neil, J. B., Hawkins, B. J. & Ehlting, J. (2014). Evolutionary classification of ammonium, nitrate, and peptide transporters in land plants. *BMC Ecology and Evolution, 14,* 11. http://www.biomedcentral.com/1471-2148/14/11.

Yurkevych, Ye. O., Kovalenko, N. P. & Bakuma, A. V. (2011). Agrobiological bases of crop rotations of the Steppe of Ukraine: monograph. Odessa: *Odessa Publishing House "VMV",* 240 (Ua).

Yurkevych, Ye. O. & Alzhaiem, Kh. (2016). Influence of different systems of basic tillage on productivity of short-term crop rotations in the conditions of biologization of agriculture. *Agrarian Bulletin of the Black Sea Coast, 79,* 93–102 (Ua).

Yurkevych, Ye. O. & Bierov, Ye. D. (2016). Mineralization of basic pea tillage in organic farming of the Southern Steppe of Ukraine. *Agrarian Bulletin of the Black Sea Coast, 79,* 85–93 (Ua).

Yurkevych, Ye., Mamenko, P. & Bierov, Ye. (2017). Stubble destructors: pros and cons. *The Ukrainian Farmer, 8*(92), 72–73 (Ua).

Yurkevych, Ye. O., Boiko, P. I., Kovalenko, N. P. & Valentiuk, N. O. (2021). Scientific-technological and agrobiological bases of highly productive agroecosystems of Ukraine: monograph. Odessa*: Publishing House LLC "Publishing Center",* 654 (Ua).

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