DYNAMICS AND PROSPECTS OF WHEAT, CORN AND BARLEY GRAIN PRODUCTION: IMPLEMENTATION OF INNOVATIVE TECHNOLOGIES FOR EFFECTIVE CULTIVATION OF GRAIN CROPS IN VARIOUS SOIL-CLIMATE CONDITIONS OF UKRAINE

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ABSTRACT

It was established that during 1991–2021, the production of grain crops in Ukraine increased by 69% thanks to an increase in corn production almost 9 times due to an increase in its sown areas by 4.5 times. Due to high competition on the foreign market, wheat sown areas decreased by 6.5%, barley – by 9.2%. It was found that the transformation of the structure of the sown areas led to a violation of the use of optimal predecessors and periods of return of grain crops to the previous place of cultivation in crop rotations. Because of this, during 1991–2021, the yield of grain crops in Ukraine increased only 1.5 times, corn – 2.0 times, wheat – by 29%, barley – by 9%, and is significantly lower than the potential. In 2022, the lowest productivity and grain production of wheat, corn and barley in the last ten years were obtained, which were negatively affected by the reduction of sown areas, the violation of scientific technologies for growing grain crops, along with the negative impact of climate change and other stress factors. For the effective production of grain crops, the introduction of innovative technologies is proposed, which include a number of adaptation measures to overcome the negative impact of climate change and other stress factors. In particular, the use of high-yielding varieties and hybrids of grain crops with high genetic potential for productivity and quality, stable resistance to diseases and pests, as well as adverse environmental factors. Attention is focused on the optimization of the structure of sown areas and the application of scientifically based seed crop rotations with effective saturation, placement and ratio of crops, taking into account soil-climatic conditions. The implementation of innovative technologies for growing grain crops in different soil-climatic conditions of Ukraine and beyond will guarantee the sustainable supply of food grain needs, which is updated in the conditions of climate change and taking into account the global challenges and threats of today.

Keywords: development, grain production, cultivation of grain crops, wheat, corn, barley, sown areas, yield, innovative technologies, Ukraine.

INTRODUCTION

The increase in the global population and the growth of its food needs require a further increase in the yield of grain crops and the quality of grain products (P. Boiko et al., 2023b; P. Boiko & N. Kovalenko, 2024). Therefore, in order to ensure promising grain production, the introduction of innovative technologies for growing grain crops, including strategically important wheat, corn and barley, is of great importance (N. Kovalenko & S. Yehorova, 2023). A decisive role in the fulfillment of this task belongs to the creation of new varieties and hybrids of grain crops with high genetic potential for productivity and quality, stable resistance to diseases and pests, as well as adverse environmental factors, in particular drought (V. V. Morhun, 2001a; V. V. Morhun, 2001b). In addition, the use of scientifically based seed crop rotations with effective saturation, placement and ratio of crops, taking into account soil-climatic conditions and the specialization of farms, is of great importance (Ye. O. Yurkevych et al., 2021). In seed crop rotations, it is necessary to use optimal rates of organic and mineral fertilizers, siderates, post-harvest sowings, as well as apply differentiated tillage (N. P. Kovalenko, 2014). The introduction of grain cultivation technologies to sustainably meet food grain needs is being updated in the context of climate change and taking into account today's global challenges and threats.

An in-depth study of the complex scientific-technological direction, which consists in the combination of selection and seed production of the leading grain crops – wheat, corn and barley with cultivation in scientifically based seed crop rotations for different soil-climatic conditions, has not been comprehensively carried out. At the same time, scientific publications highlight information about individual agrotechnical measures that require optimal coordination. In particular, information on the effective cultivation of grain, technical, fodder, potato and vegetable crops in crop rotations, the use of scientifically based farming systems in different soil-climatic conditions is provided in monographs (O. V. Demydenko et al., 2019; N. P. Kovalenko, 2014; Ye. O. Yurkevych, N. P. Kovalenko & A. V. Bakuma, 2011; Ye. O. Yurkevych et al., 2021). Scientific achievements and innovative developments in the direction of genetic improvement of grain crops are presented in monographs (V. V. Morhun, 2001a; V. V. Morhun, 2001b; V. V. Morhun et al., 2022). However, the analysis of the dynamics and establishment of prospects for grain production of the leading grain crops in Ukraine and the world has been studied in a fragmentary manner. Therefore, the determination of the features of the implementation of innovative technologies for the cultivation of high-yielding varieties and hybrids of wheat, corn and barley in scientifically based seed crop rotations in the conditions of climate change and taking into account the global challenges and threats of today require further research and analysis.

The purpose of the research is to analyze the dynamics and establish the prospects of grain production of the leading grain crops in Ukraine and the world; determination of the features of the implementation of innovative technologies for the cultivation of high-yielding varieties and hybrids of wheat, corn and barley in scientifically based seed crop rotations in different soil-climatic conditions of Ukraine – Steppe, Forest-Steppe and Polissia, taking into account global challenges and threats of today.

MATERIAL AND METODS

The methodological basis is the principles of reliability and objectivity. To achieve the goal, general scientific and interdisciplinary research methods were used. Thanks to the comparative analysis and the calculation-constructive method, the peculiarities of the implementation of innovative technologies for growing high-yielding varieties and hybrids of leading grain crops in scientifically based seed crop rotations, which are in different soil-climatic conditions, have been revealed, which will ensure the needs for food grain, taking into account climate change and other challenges and threats of today. Thanks to the abstract-logical method, conclusions were formulated and a number of adaptation measures were proposed to overcome the negative impact of climate change and other negative factors, to ensure the promising production of leading grain crops – wheat, corn and barley.

RESULTS

One of the global trends that causes a constant increase in food consumption is the dynamic growth of the global population, which during 1950–2022 increased more than 3 times and amounted to 8 billion people (Figure 1) (Official website of the United Nations; Official website of the Food and Agriculture Organization of the United Nations). Therefore, solving the problem of providing the population with food is a priority task and a strategic direction of the economic policy of each country, which is aimed at ensuring its food and national security. At the same time, during this period, the area of land suitable for growing agricultural crops remained almost unchanged, which in 2022 amounted to about 1.6 billion hectares. However, during this period, the world area of arable land per person, which in 1950 was 0.60 hectares, decreased by 67%. In 2050, according to UN forecasts, the global population will increase to 9.7 billion people, which will reduce the population's supply of productive land resources to 0.17 hectares (Official website of the United Nations). Thus, along with the development of soil degradation processes, the area of arable land per person will decrease in the future. This will lead to a significant increase in demand for food products, including grain products. At the same time, to ensure a normal standard of living of the population, at least 0.50 hectares of arable land per person is needed (Official website of the Food and Agriculture Organization of the United Nations). Therefore, with a general decrease in the provision of arable land to the population, the food problem can be solved thanks to the intensification of grain production based on the introduction of innovative technologies that ensure the reduction of the negative impact on the environment and the preservation of natural resources, as well as satisfy the consumers of the world market with high-quality grain products.

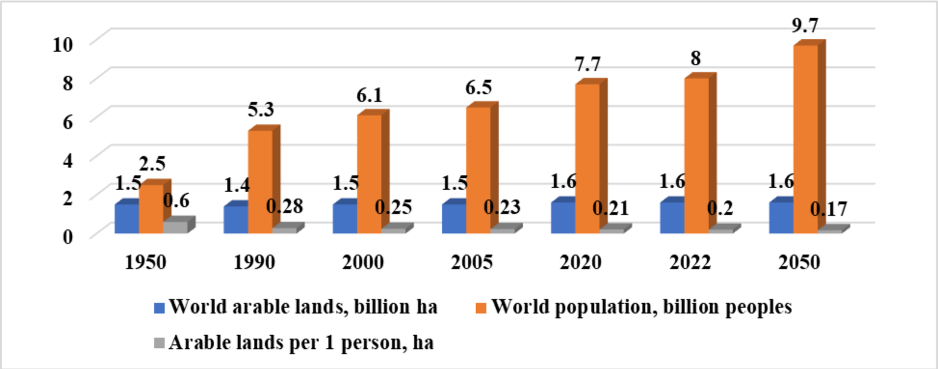

Figure 1. Dynamics of providing the world population with arable land, 1950–2050
Source: Own design based on the data from the Official website of the United Nations and the Official website of the Food and Agriculture Organization of the United Nations

With the increase in the number of the planet's population, the global consumption of grain is steadily growing, which is one of the factors in increasing the volume of its production and export. In particular, during 2008–2022, there is a tendency to increase world grain production by 32% and world grain exports by 76% (Figure 2) (Official website of the Food and Agriculture Organization of the United Nations; Official website of the United States Department of Agriculture). Therefore, such a trend towards increasing world production and export of grain products indicates the ability to satisfy the demand of humanity for its processing products.

At the same time, one of the negative factors capable of restraining the further increase of global grain production is global climate change, which is recognized by the world community as one of the long-term ones, which significantly worsens the cultivation of grain crops and requires coordinated actions of all countries of the world. In particular, the intensity and duration of winter periods are decreasing, droughts and manifestations of other natural elements associated with climate change are becoming more frequent (O. Demidenko et al., 2020; N. Kovalenko, 2022). For example, the intensity and cyclicity of droughts and dust storms, showers and hail, frosts and freezes, floods and flooding are increasing (N. Kovalenko, 2023). Instead, the intensity and duration of winter periods are reduced, the number of frosty days and the depth of soil freezing are reduced, which leads to the early activation, reproduction and spread of diseases and pests (N. Kovalenko & S. Yehorova, 2023). Thus, with the preservation of the existing rates of warming, the probability of phytosanitary destabilization in grain production, accompanied by the appearance of new groups of pests and diseases, increases.

Therefore, the increase in grain production in the face of global climate changes is possible thanks to the introduction of innovative technologies for growing high-yielding varieties and hybrids of grain crops that are resistant to drought, diseases and pests.

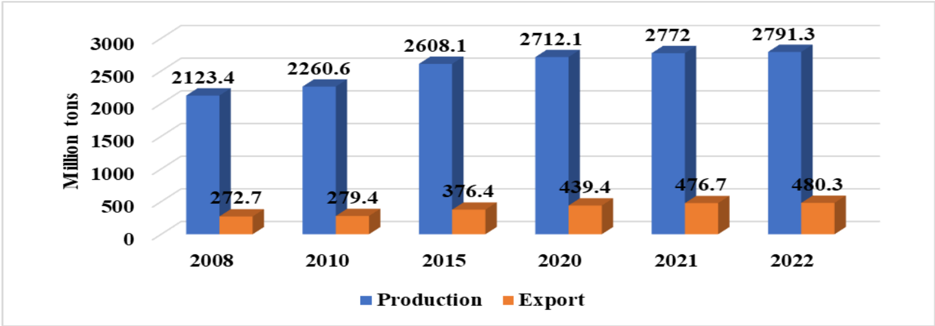

Figure 2. Dynamics of world grain production and export, 2008–2022
Source: Own design based on the data from the Official website of the Food and Agriculture Organization of the United Nations and the Official website of the United States Department of Agriculture

Another negative factor is the COVID-19 pandemic, which, although it did not significantly affect the global grain market, led to a loss of profits due to the application of restrictive measures by countries to contain the spread of the disease, disruption of logistics chains and the global economic downturn. In addition, after several years of the COVID-19 pandemic, the rf's full-scale attack on Ukraine dealt another blow to the world's food security and caused an even greater crisis in the food market. Due to the military actions of the rf, the sown areas of agricultural crops were reduced, the cost of fuel, fertilizers and plant protection products increased, there were problems with logistics, which caused the risks of a 22% increase in world food prices (Official website of the Food and Agriculture Organization of the United Nations).

Analysis of the structure of world grain production in 2022 shows that the largest share belongs to four leading grain crops: corn – 42%, wheat – 28%, rice – 18%, barley – 6%, other grain crops account for 6% (Figure 3) (Official website of the Food and Agriculture Organization of the United Nations).

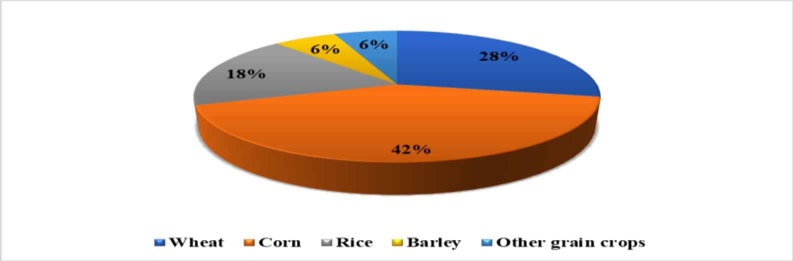

Figure 3. The structure of world grain production, 2022
Source: Own design based on the data from the Official website of the Food and Agriculture Organization of the United Nations

In Ukraine, the largest share of grain production is concentrated on three leading grain crops: corn – 49%, wheat – 38%, barley – 10%, other grain crops account for 3% (Figure 4) (Official website of the State Statistics Service of Ukraine).

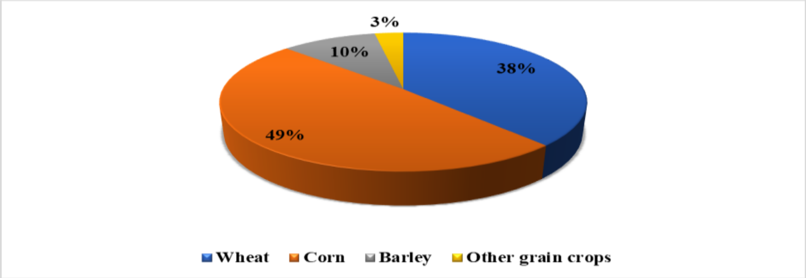

Figure 4. The structure of grain production in Ukraine, 2022
Source: Own design based on the data from the Official website of the State Statistics Service of Ukraine

The Ukraine is the largest country in Europe by area (Figure 5) (Land directory of Ukraine for 2021, 2021). Its land fund is 60.3 million hectares, which occupies 6.0% of the territory of Europe and 0.5% of the globe. The Ukraine guarantees efficient production of grain products, because most of its territory is occupied by humus-rich chernozem soils (P. Boyko et al., 2019; O. V. Demydenko et al., 2019). They provide Ukraine with a leading place in the production of wheat, corn, barley and other grain crops. In general, fertile Ukrainian lands can feed 600 million people, (Chernozems of Ukraine can feed more than half a billion people – expert, 2023), which is 150 million people more than the population of the EU (The EU population has been declining for the second year in a row due to COVID-19, 2022).

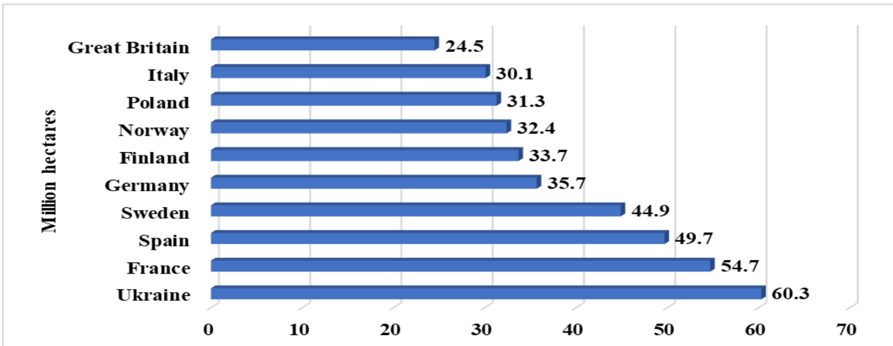

Figure 5. European countries with the largest areas of territory, 2021
Source: Own design based on the data from the National Scientific Center «Institute of Agrarian Economics of the NAAS», 2021

Analyzing the dynamics of sown areas of agricultural crops in Ukraine during 1991–2022, it can be stated that they were extremely unstable and changed significantly over the years. Such a situation was created due to the fact that when choosing an agricultural crop for sowing, farmers are guided by the main levers: profitability, the presence of stable demand and the level of prices on the market. For example, during this period, the sown area of grain crops increased by 8.9% due to the increase in the sowing of corn for grain (Figure 6) (Official website of the State Statistics Service of Ukraine). The sown areas of technical crops increased by 2.5 times due to the expansion of sunflower and rapeseed crops. The sown areas of potatoes and vegetable crops remained almost stable. At the same time, the sown areas of fodder crops decreased by almost 8.0 times due to the reduction of corn sowing for silage and green fodder, perennial and annual grasses. In 2022, the large-scale attack of the rf on Ukraine led to an even greater decrease compared to 2021 in the sown area of all agricultural crops, including grain crops – by 23%, technical crops – by 10%, fodder crops – by 24%, potatoes and vegetable crops – by 19%.

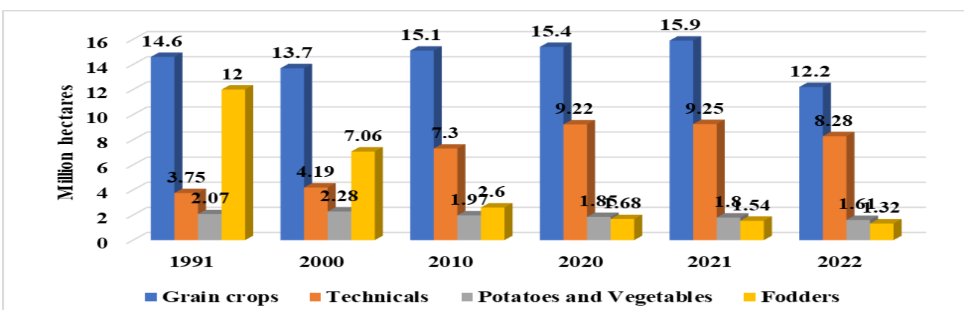

Figure 6. Dynamics of sown areas of agricultural crops in Ukraine, 1991–2022
Source: Own design based on the data from the Official website of the State Statistics Service of Ukraine

During 1991–2021, there were significant changes in the structure of the sown areas of the grain group. In particular, due to high competition on the foreign market, wheat sown areas decreased by 6.5%, barley – by 9.2% (Figure 7) (Official website of the State Statistics Service of Ukraine). At the same time, the increase in sowing of grain crops occurred due to by 4.5 times growth in the sown areas of high-yielding corn for grain. In 2022, the large-scale attack of the rf on Ukraine led to an even greater decrease compared to 2021 in the sown area of grain crops – by 23%, including wheat – by 23%, corn – by 22%, barley – by 28% (Official website of the Ministry of Agrarian Policy and Food of Ukraine). Consequently, during 1991–2022, the structure of grain, technical and fodder crops sown areas underwent significant changes, which caused a violation of the use of better predecessors and periods of crop return to the previous place of cultivation in crop rotations. Such an unjustified transformation led to a reduction in soil moisture reserves, a decrease in its fertility, the spread of weeds, diseases and pests, which caused a decrease in the yield of agricultural crops (N. P. Kovalenko, 2014). During 1991–2021, Ukrainian farmers developed and implemented innovative technologies for growing grain crops, which ensured a 69% increase in national grain production (Figure 8) (Official website of the State Statistics Service of Ukraine). During this period, the production of high-yielding corn for grain increased almost 9 times, but this growth occurred due to a significant expansion of the sown areas of this crop. The production of barley increased by only 4.7 million tons, wheat – by 1.8 million tons, including due to a decrease in the sown areas of these crops by 9.2% and 6.5%, respectively.

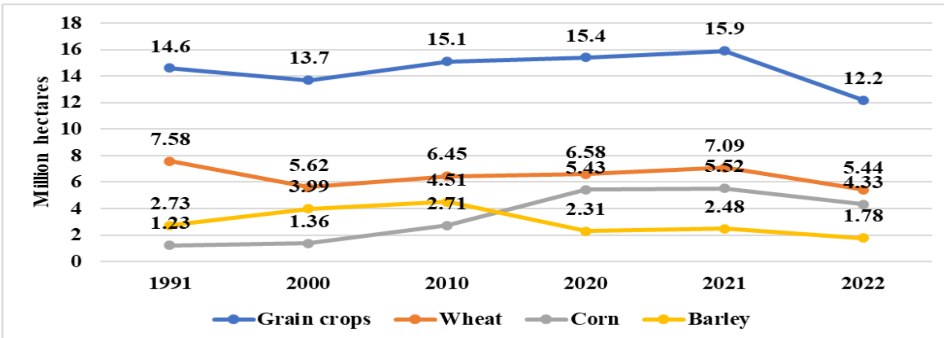

Figure 7. Dynamics of sown areas of leading grain crops in Ukraine, 1991–2022
Source: Own design based on the data from the Official website of the State Statistics Service of Ukraine

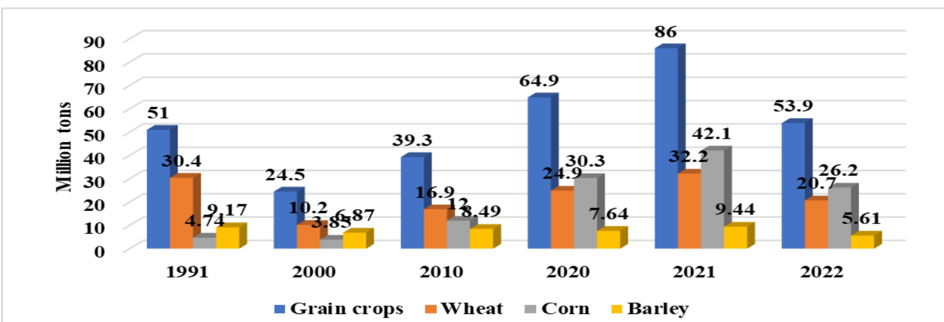

Figure 8. Dynamics of production of leading grain crops in Ukraine, 1991–2022
Source: Own design based on the data from the Official website of the State Statistics Service of Ukraine

Due to the violation of the structure of sown areas and scientifically based crop rotations, soil degradation increased, which negatively affected the yield of all grain crops, which during 1991–2021 increased only 1.5 times and amounted to 5.39 t/ha (Figure 9) (Official website of the State Statistics Service of Ukraine). The yield of corn for grain increased by 2 times and amounted to 7.68 t/ha, but this indicator is much lower than the potentially possible level, which is 10.0 t/ha in the countries of the European Union (Official website of the Food and Agriculture Organization of the United Nations). Wheat yield increased by only 29%, barley – by 9%. In 2022, Ukraine harvested only 53.9 million tons of grain crops with a yield of 4.58 t/ha, corn – 26.2 million tons with a yield of 6.35 t/ha, wheat – 20.7 million tons with a yield of 3.93 t/ha, barley – 5.61 million t with a yield of 3.22 t/ha. These are the lowest indicators in the last ten years, which were negatively affected by the decrease in sown areas, the violation of scientific technologies for growing grain crops, along with the negative impact of climate change and other stress factors. In particular, due to the shortage and high prices of fuel, mineral fertilizers and plant protection products caused by the full-scale armed attack of the rf. In general, the damage caused to the environment as a result of the armed aggression of the rf amounts to almost 52 billion dollars USA (Official website of the State Environmental Inspection of Ukraine).

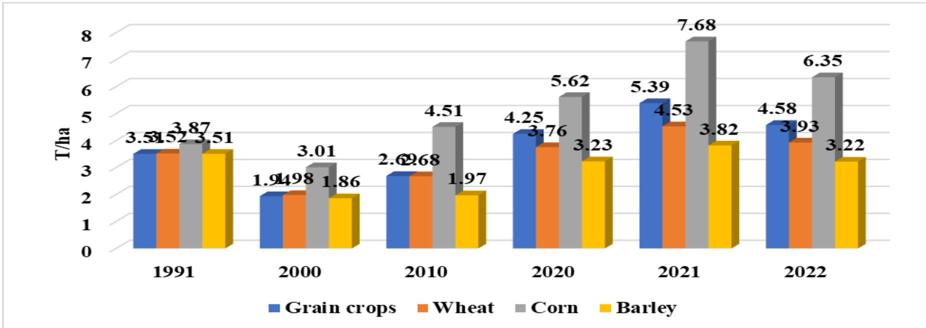

Figure 9. Dynamics of yield of leading grain crops in Ukraine, 1991–2022
Source: Own design based on the data from the Official website of the State Statistics Service of Ukraine

However, the growth of world demand for grain led to an increase in Ukraine's position in the world ranking. According to the results of 2022, despite the military actions of the rf, Ukraine managed to maintain the status of one of the main exporters of grain, entering the top five in the world. In particular, Ukraine took fifth place in the world ranking for the export of wheat, fourth – corn, and third – barley. In addition, Ukraine remained in the top ten producers of grain products in the world and took seventh place in the production of wheat, sixth – in corn, fourth – in barley (Official website of the Food and Agriculture Organization of the United Nations).

Therefore, a strategic task for the further development of the grain industry in Ukraine is the creation of highly productive and competitive grain production using high-quality seed material, which can now be solved thanks to the introduction of innovative technologies for growing grain crops in different soil-climatic conditions. Such technologies should concentrate the latest achievements of science and technique, ensuring the realization of the potential productivity of varieties and hybrids of grain crops in accordance with soil characteristics and weather conditions. Such technologies must include a wide range of adaptation measures, which include (P. Boiko et al., 2023a; P. Boiko et al., 2023b):

– the use of modern varieties and hybrids of grain crops with high genetic potential for yield and quality, stable resistance to weeds, diseases, pests and other negative environmental factors;

– optimization of the structure of sown areas and scientifically based seed crop rotations with the cultivation of traditional and rare crops;

– the use of effective predecessors of agricultural crops and periods of their return to the previous place of cultivation in crop rotations;

– introduction of organic and mineral fertilizers, which ensure regulation of the water and nutrient regime of the soil;

– introduction of biological means of plant protection against weeds, diseases and pests;

– implementation of protective soil tillage, which contributes to the accumulation, preservation and rational use of soil moisture;

– sideration and mulching;

– irrigation systems;

– productive use of the natural mass of plant residues – straw of grain crops, stalks and tops of corn and sunflower, husks of root crops;

– the use of modern biodestructors to transform plant residues into organic matter intended for soil nutrition and increasing its fertility.

One of the main elements of innovative technologies is the use of modern varieties and hybrids of grain crops with high genetic potential for yield and quality, stable resistance to weeds, diseases, pests and other negative environmental factors. The Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine has created and registered more than 200 competitive varieties and hybrids of agricultural crops, which for almost half a century are sown every year in the fields of Ukraine and abroad on an area of up to 5.5 million hectares. According to the level of intensity and direction of use, winter wheat varieties are divided into several groups (V. V. Morhun et al., 2022):

– the first group – short-stemmed varieties of the high-intensity type, which under favorable conditions are capable of forming a yield of 10.0 t/ha and more. Varieties of this group were created by the method of chromosomal engineering and contain rye translocations in their genome. This group includes well-known varieties: Astarta, Zolotokolosa, Perlyna Podillya, Smuglyanka; new varieties: Horodnytsia, Novosmuglyanka, Kyivska 19, Sicheslava, Sofia Kyivska, Stepova krynytsia. The leader of this group is the national standard – Smuglyanka winter wheat variety. In terms of yield, the varieties of this group are the leaders among domestic varieties that were created for innovative growing technologies.

– the second group – medium-sized varieties of the intensive type of universal use, the genetic potential of productivity of which is more than 10.0 t/ha. This group includes well-known varieties: Bohdana, Boriya, Darynka Kyivska, Zoloto Ukrainy, Malynivka, Podolyanka, Shchedrivka Kyivska; new varieties: Jamala, Zdoba Kyiyska, Kyivska 17, Krasnopilka. The leader of this group is the national standard – Podolyanka winter wheat variety. Varieties of this group have high ecological plasticity. None of the foreign varieties can compete with them in terms of productivity, quality, resistance to frost and drought, as they are not adapted to the soil-climatic conditions of Ukraine.

In the group of varieties of the intensive type of universal use, there is a subgroup of specialized varieties. In addition to the necessary complex of economic and valuable features, varieties have specific properties that provide them with advantages when used to meet certain biological and economic needs. In Ukraine, such varieties were created for the first time. These varieties are characterized by an extended growing season and, with optimal provision of trace elements, these varieties have a high productivity potential. Among the varieties of this subgroup are Donor Kyivskyi, Zymoyarka, whose actual genetic potential for grain productivity is more than 10.0 t/ha. The Zymoyarka variety combines the genes of winter and spring wheat and is dicotyledonous – it can be sown in autumn as winter wheat and in spring as spring wheat. The advantages of using this variety are that it can be sown at the end of the optimal terms for sowing winter crops, during winter thaws and early spring with the first entry into the field; it is possible to sow or re-sow thinned or dead crops of winter crops with the same crop and even variety. The need for this variety is caused by the instability of winter wheat overwintering and the low yield of spring wheat. Therefore, the cultivation of this variety contributes to the stabilization of grain production in different soil-climatic conditions of Ukraine and beyond. The second from this subgroup is the original variety of whole wheat Donor Kyivskyi, which has a unique quality and belongs to extra strong wheats and provides high quality flour.

For promising cultivation in different soil-climatic conditions of Ukraine and beyond, it is recommended to introduce competitive varieties of winter wheat selected by the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine (V. V. Morhun et al., 2022):

– in the Steppe: Astarta, Bohdana, Boriya, Horodnytsia, Jamala, Donor Kyivskyi, Zdoba Kyivska, Zymoyarka, Zoloto Ukrainy, Zolotokolosa, Kyivska 19, Krasnopilka, Malynivka, Novosmuglianka, Podolyanka, Sicheslava, Smuglyanka, Sofia Kyivska, Stepova krynytsia, Shchedrivka Kyivska;

– in the Forest-Steppe: Astarta, Bohdana, Boriya, Horodnytsia, Darynka Kyivska, Jamala, Donor Kyivskyi, Zdoba Kyivska, Zymoyarka, Zoloto Ukrainy, Zolotokolosa, Kyivska 17, Kyivska 19, Krasnopilka, Malynivka, Novosmuglyanka, Perlyna Podillya, Podolyanka, Sicheslava, Smuglyanka, Sofia Kyivska, Stepova krynytsia, Shchedrivka Kyivska;

– in the Polissia: Boriya, Horodnytsia, Darynka Kyivska, Zymoyarka, Kyivska 17, Kyivska 19, Perlyna Podillia, Sofia Kyivska, Stepova krynytsia, Shchedrivka Kyivska.

Optimization of the structure of sown areas and the use of scientifically based seed crop rotations are of great importance in the technologies of cultivation competitive varieties of winter wheat. For this purpose, the optimal saturation and ratio of agricultural crops in scientifically based crop rotations for different soil-climatic conditions of Ukraine have been developed (Table 1) (N. P. Kovalenko, 2014; Ye. O. Yurkevych et al., 2021):

– in the Southern Steppe – 40–82% should be allocated to grain and leguminous crops, 5–35% to technical crops (including rapeseed – 5–10%, sunflower – 12–15%), potatoes and vegetable crops – 5–20%, fodder crops – 10–60% (including perennial grasses – 10–25%), as well as black par – 18–20% of the crop rotation area;

– in the Northern Steppe – 45–80% should be allocated to grain and leguminous crops, 10–30% to technical crops (including rapeseed – 10%, sunflower – 10%), potatoes and vegetable crops – 5–20%, fodder crops – 10–60% (including perennial grasses – 10–16%), as well as black par – 5–14% of the crop rotation area;

– in the Forest-Steppe – 29–95% should be allocated to grain and leguminous crops, 5–30% to technical crops (including rapeseed – 3–5%, sunflower – 5–9%), potatoes and vegetable crops – 3–5%, fodder crops – 10–75% (including perennial grasses – 10–50%) of the crop rotation area;

– in the Polissia –35–80% should be allocated to grain and leguminous crops, 3–25% to technical crops (including rapeseed – 0.5–4.0%, sunflower – 0.5%), potatoes and vegetable crops – 8–25%, fodder crops – 20–60% (including perennial grasses – 5–20%) of the crop rotation area.

Table 1. Optimum saturation and ratio of agricultural crops in scientifically based crop rotations for different soil-climatic conditions of Ukraine

Crops	**Optimum saturation and ratio of cultures, %**			
	Southern Steppe	**Northern Steppe**	**Forest-Steppe**	**Polissia**
Grain and leguminous	40–82	45–80	29–95	35–80
Technical	5–35	10–30	5–30	3–25
including:				
rapeseed	5–10	10	3–5	0,5–4,0
sunflower	12–15	10	5–9	0,5
Potatoes and vegetables	5–20	5–20	3–5	8–25
Fodders	10–60	10–60	10–75	20–60
including:				
perennial grasses	10–25	10–16	10–50	5–20
Black par	18–20	5–14	–	–

Source: Compiled according to the data: N.P. Kovalenko, 2014;
Ye.O. Yurkevych, P.I. Boiko, N.P. Kovalenko & N.O. Valentiuk, 2021

When choosing predecessors in crop rotations for the production of winter wheat seeds, along with the cultivation of seed material with high yield properties, it is necessary to observe a number of scientifically based requirements. In particular, when planting seed crops of winter wheat, it is necessary to take into account the requirements of this crop for fertility, moisture availability, clogging, and mechanical composition of the soil. When drawing up a scheme for alternating crops in crop rotations, it is necessary to take into account that each crop must ensure a high and stable yield and quality of seeds (Ye. O. Yurkevych, N. P. Kovalenko & A. V. Bakuma, 2011). After all, predecessors affect the yield and quality of winter wheat seeds depending on how much they dry the soil and use nutrient reserves.

Agricultural crops must not only be placed after the best predecessors, but also adhere to scientifically justified periods of their return to the previous place of cultivation in crop rotations: for winter rye and barley, spring barley, oats, buckwheat – not less than 1 year later; for winter wheat, millet, potatoes – not less than 2 years later; for corn in crop rotation or on a field temporarily removed from crop rotation – the possibility of cultivation for 2–3 years in a row; for perennial legumes grasses, leguminous crops (except lupine), sugar and fodder beets, winter and spring rapeseed – not less than 3 years later; for flax – not less than 5 years later; for lupine, cabbage – not less than 6 years later; for sunflower – not less than 7 years later, for medicinal plants (depending on biological properties) – not less than 1–10 years later (Table 2) (N. P. Kovalenko, 2014; O. V. Demydenko et al., 2019).

Table 2. Scientifically based periods of return of agricultural crops to the previous place of cultivation in crop rotations

Crops	**Return period**
Winter rye and barley, spring barley, oats, buckwheat	not less than 1 year later
Winter wheat, millet, potatoes	not less than 2 years later
Corn in crop rotation or on a field temporarily removed from crop rotation	the possibility of cultivation for 2–3 years in a row
Perennial legumes grasses, leguminous crops (except lupine), sugar and fodder beets, winter and spring rapeseed	not less than 3 years later
Flax	not less than 5 years later
Lupine, cabbage	not less than 6 years later
Sunflower	not less than 7 years later
Medicinal plants (depending on biological properties)	not less than 1–10 years later

Source: Compiled according to the data: N.P. Kovalenko, 2014;
O.V. Demydenko, P.I. Boiko, M.I. Blaschuk, I.S. Shapoval & N.P. Kovalenko, 2019

It is important to preserve winter wheat varieties from biological and mechanical clogging, which is one of the most important tasks of seed production. In order to preserve the purity of seed crops, it is forbidden to place winter wheat after its predecessors, the carrion of which can clog its variety. In addition, it is necessary to exclude the possibility of contamination of seed crops with diseases and pests that are transmitted by wind, water, as well as through soil, seeds, plant residues, etc. (Ye. O. Yurkevych, N. P. Kovalenko & A. V. Bakuma, 2011). It is especially important to take into account the clogging of crops by weeds, the seeds of which are difficult to separate from grain: ryegrass in oat crops, fodder beans in pea crops, wild radish in wheat and barley crops.

The main requirements for the introduction of seed crop rotations have been established: the impossibility of placing winter wheat after winter rye, triticale, barley; spring ears – after winter crops; barley – after wheat and oats, oats – after barley, soft wheat – after durum and vice versa. It is not allowed to replant these crops in the same field within 2 years. Great attention is paid to the creation of spatial isolation between seed and compatible crops and between crops of different varieties and reproductions, because seeds retain their similarity for 1–2 years or more (P. Boiko & N. Kovalenko, 2024; N. P. Kovalenko, 2014).

In different soil-climatic conditions of Ukraine, the best predecessors in crop rotations for the production of seeds of competitive varieties of winter wheat include: black par, perennial grasses, row crops, legumes and other crops. Their choice depends on the soil, climate, length of the growing season, characteristics of the culture and variety, requirements for obtaining pure seed material. A mandatory condition in the Steppe and Forest-Steppe of Ukraine should be a field of black par, in the Polissia – a lupine par, as the best predecessors for growing pure winter wheat seeds.

In order to obtain high-quality seeds of grain crops, it is necessary to implement scientifically based seed crop rotations in different soil-climatic conditions of Ukraine (N. P. Kovalenko, 2014; Ye. O. Yurkevych et al., 2021):

– in the Southern Steppe (non-irrigated lands): 1 – black par, 2 – winter wheat, 3 – winter barley, 4 – peas, 5 – winter wheat; 1 – black par, 2 – winter wheat, 3 – winter rapeseed, 4 – winter wheat, 5 – barley, 6 – sunflower; 1 – black par, 2 – winter wheat, 3 – corn for grain, 4 – barley and corn for green fodder with alfalfa under seeding, 5 – alfalfa, 6 – alfalfa, 7 – winter wheat, 8 – winter and spring crops for green fodder, 9 – winter wheat, 10 – sunflower;

– in the Southern Steppe (irrigated lands): 1 – soybeans, 2 – winter wheat + post-harvest crops, 3 – corn for grain; 1 – safflower, 2 – winter wheat, 3 – winter barley, 4 – soybean, 5 – barley with safflower seeding; 1 – soybean, 2 – winter wheat, 3 – winter rapeseed, 4 – winter wheat;

– in the Central and Northern Steppe: 1 – black par, 2 – winter wheat, 3 – corn for grain, 4 – soybean, 5 – winter wheat, 6 – sunflower; 1 – black par, 2 – winter wheat, 3 – barley with safflower seeding, 4 – safflower, 5 – winter wheat, 6 – sunflower; 1 – black par, 2 – winter wheat, 3 – sugar beets, 4 – corn for grain, 5 – soybeans, 6 – winter wheat, 7 – winter rapeseed, 8 – winter wheat, 9 – sunflower; 1 – black par, 2 – winter wheat, 3 – sugar beets, 4 – peas, annual grasses for green fodder, corn for silage, 5 – winter wheat, 6 – corn for grain or silage, 7 – barley, oats + perennial grasses, 8 – perennial grasses for green fodder, 9 – winter wheat, 10 – sunflower;

– in the Forest-Steppe: 1 – perennial grasses for 1 cutting, annual grasses for green fodder, 2 – winter wheat, 3 – sugar beets, 4 – corn for grain, 5 – peas, vetch, 6 – winter wheat, 7 – sugar beets, potatoes, 8 – corn for grain, silage, 9 – winter wheat, 10 – spring cereals crops with perennial grasses; 1 – peas, 2 – winter wheat, 3 – sugar beets, 4 – corn for grain, 5 – barley; 1 – alfalfa, 2 – winter wheat, 3 – sugar beets, 4 – corn for grain, 5 – corn for silage, 6 – peas, 7 – winter wheat, 8 – corn for silage, 9 – barley, millet with perennial grasses;

– in the Polissia: 1 – clover, 2 – winter wheat, 3 – flax, lupine for grain or silage, 4 – winter rye, 5 – corn for green fodder or silage, 6 – winter wheat, 7 – potatoes, 8 – spring cereals with clover sowing; 1 – winter rapeseed, 2 – winter wheat, 3 – corn for silage, 4 – winter wheat, 5 – soybean; 1 – clover, 2 – winter wheat, 3 – flax + post-harvest crops or annual grasses, 4 – barley or winter rye, 5 – lupine, corn for silage or green fodder, 6 – winter rye + post-harvest crops, 7 – potatoes, 8 – barley with clover seeding.

Growing seeds in seed rotations must be carried out in accordance with scientifically based systems of soil tillage, fertilization, plant protection and varietal agricultural techniques. To prevent mechanical and biological clogging, it is necessary to arrange crops by varieties, categories, generations; observe spatial isolation; documentation; planning the movement routes of sowing units, their thorough cleaning (V. V. Morhun, 2001a; V. V. Morhun, 2001b). It is necessary to perform: varietal, species and phytosanitary weeding; field, granary and laboratory inspection.

CONCLUSIONS

It has been established that with the increase in the number of the planet's population to 8 billion people in 2022, the global consumption of grain is steadily increasing, which is one of the factors in increasing the volume of its production and export. In particular, during 2008–2022, there is a tendency to increase world grain production by 32% and world grain exports by 76%. It was found that despite the military actions of the rf, Ukraine managed to maintain the status of one of the main producers and exporters of grain, entering the top ten and the top five in the world in 2022, respectively.

During 1991–2021, the production of grain crops in Ukraine increased by 69% thanks to an increase in the production of corn for grain by almost 9.0 times due to an increase in its sown area by 4.5 times. Due to high competition on the foreign market, wheat sown areas decreased by 6.5%, barley – by 9.2%. The sown areas of technical crops increased by 2.5 times thanks to the expansion of sunflower and rapeseed crops. The sown areas of fodder crops decreased almost 8.0 times due to the rapid decrease in the sowing of corn for silage and green fodder, perennial and annual grasses.

It was found that the transformation of the structure of sown areas led to a violation of the use of optimal predecessors and periods of return of grain crops to the previous place of cultivation in crop rotations. During 1991–2021, the yield of grain crops in Ukraine increased only 1.5 times, corn – 2.0 times, wheat – by 29%, barley – by 9%, which is significantly lower than the potential.

In 2022, Ukraine harvested only 53.9 million tons of grain crops with a yield of 4.58 t/ha, corn – 26.2 million tons with a yield of 6.35 t/ha, wheat – 20.7 million tons with a yield of 3.93 t/ha, barley – 5.61 million tons with a yield of 3.22 t/ha. These are the lowest indicators in the last ten years, which were negatively affected by the decrease in sown areas, the violation of scientific technologies for growing grain crops, along with the negative impact of climate change and other stress factors.

It was established that in order to ensure promising grain production, the introduction of innovative technologies for growing leading grain crops is of great importance, including strategically important – wheat, corn and barley. For the effective production of grain crops, a number of adaptation measures are proposed to overcome the negative impact of climate change and other stress factors, which consist in the use of high-yielding varieties and hybrids of grain crops with high genetic potential for productivity and quality, stable resistance to diseases and pests, as well as adverse environmental factors, in particular droughts. Great importance is attached to the optimization of the structure of sown areas and the use of scientifically based seed crop rotations with effective saturation, placement and ratio of crops taking into account soil-climatic conditions. Adaptation measures also include: introduction of organic and mineral fertilizers that ensure regulation of the water and nutrient regime of the soil; introduction of biological means of plant protection against weeds, diseases and pests; implementation of soil protective soil tillage, which contributes to the accumulation, preservation and rational use of soil moisture; sideration and mulching; irrigation systems; productive use of the natural mass of plant residues – straw of grain crops, stalks and tops of corn and sunflower, husks of root crops; the use of modern biodestructors to transform plant residues into organic matter designed to nourish the soil and increase its level of fertility.

The introduction of innovative technologies for the cultivation of leading grain crops in different soil-climatic conditions of Ukraine and beyond will guarantee the sustainable supply of food grain needs, which is updated in the conditions of climate change and taking into account the global challenges and threats of today.

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