APPLICATION OF ECONOMIC-MATHEMATICAL METHODS IN FIELD RESEARCH OF CEREAL CROPS IN THE CONDITIONS OF CLIMATE CHANGES IN UKRAINE IN THE SECOND HALF OF THE 19th – AT THE BEGINNING OF THE 21st CENTURIES

Nataliia Kovalenko[1*]

[1*]*Institute of Plant Physiology and Genetics of the NAS of Ukraine, Ukraine;*

[*]Corresponding Author Nataliia Kovalenko, e-mail: BoikoNP@ukr.net;

Received May 2023; Accepted June 2023; Published July 2023;

DOI: https://doi.org/10.31407/ijees13.302

ABSTRACT

It has been established that the use of effective technologies for growing cereal crops in different soil-climatic conditions of Ukraine is of great importance in the modern conditions of climate change and other stress factors. Such technologies ensure the systematic and comprehensive use of science-based measures affecting the solution of global social problems of humanity, which were caused by climate change and the rf's full-scale war in Ukraine. For this purpose, the wide application of economic-mathematical methods is provided, which ensure the accuracy of obtaining the results of field research, the identification of previously unknown regularities for the favorable growth and development of cereal crops, especially in modern conditions of climate change and other stressful factors. With the use of dispersion analysis, the dynamics of the mutual influence of the main technological factors: varieties and hybrids of cereal crops, crop rotations, tillage, fertilization, plant protection and weather conditions on the productivity of cereal crops in the conditions of climatic changes in Ukraine during the second half of the 19th – the beginning of the 21st centuries were evaluated. The share of mutual influence of the main technological factors and weather conditions on the productivity of the leading cereal, legumes and technical crops in Ukraine is calculated. It was found that the analysis of mathematically verified results of field studies contributes to increasing the reliability of conclusions, better assessment of the essence and solving of scientific-practical problems, establishing new urgent tasks for solving in the future.

Keywords: evolution, economic-mathematical methods, dispersion analysis, cereal crops, productivity, land use, climate changes, Ukraine.

INTRODUCTION

Obtaining a high and stable yield of cereal crops is possible only by creating favorable conditions for their growth and development (P. Boyko et al., 2019; O. Demidenko et al., 2020). This ensures all processes of energy conversion and metabolism in the plant organism at an optimal level, starting from photosynthesis and ending with the formation of the final products of plant life: proteins, fats, carbohydrates, vitamins, trace elements, and others (P. Boiko et al., 2023; V. Orekhivskyi et al., 2022; V. V. Morhun et al., 2022). Ensuring a continuous process of

formation of organic matter, avoiding even short-term interruptions in the photosynthesis of the agroecosystem as a whole, as well as of each individual plant, is a necessary condition for obtaining high and sustainable productivity with better quality indicators (N. Kovalenko et al., 2021; V. V. Morhun, 2001a; V. V. Morhun, 2001b).

It should be noted that at the beginning of the 21st century, climate change was recognized by the world community as one of the long-term factors that require the coordination of actions of all countries of the world (N. Kovalenko & S. Yehorova, 2022; N. Kovalenko, 2022). Ukraine belongs to the number of regions of the planet where climatic changes are becoming quite noticeable. As confirmed by the results of research by scientists from scientific research institutions of the network of the National Academy of Sciences of Ukraine, the National Academy of Agrarian Sciences of Ukraine and higher education institutions of the Ministry of Education and Science of Ukraine, the duration of winter periods has significantly decreased, and winters have become less cold. Droughts and manifestations of other natural elements – droughts, dust storms, downpours, hail, frost, freezing, icing, floods, flooding and inundation, which are associated with climate changes, have become more frequent (Ye. O. Yurkevych et al., 2021). Shortening the duration of the winter period, reducing the number of frosty days and the depth of soil freezing lead to early activation, reproduction and spread of pests. Thus, with the preservation of the existing rates of warming, the probability of phytosanitary destabilization of agroecosystems increases, which will be accompanied by the appearance of new groups of pests. In addition, due to climatic changes, there is an increase in erosion processes and landslides (O. V. Demydenko et al., 2014). Therefore, it can be stated that climatic changes significantly affect the efficiency of growing cereal crops in different soil-climatic conditions of Ukraine: Polissia, Forest-Steppe and Steppe.

The relevance of the research is increasing in connection with the full-scale attack of the rf 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 FAO, 2023). Agrarian enterprises of Ukraine, which found themselves in the areas of active hostilities, are forced to stop working altogether due to constant shelling. The impossibility of their activity arose due to the deliberate destruction, theft and damage of: land plots, infrastructure facilities, agricultural machinery, trucks and cars, stocks of resources, equipment and facilities, crop and livestock products. The troops of the rf mine the fields, due to which agrarian producers are forced to reduce the sown areas, which causes a violation of scientifically based crop rotations and leads to a decrease in the productivity of agricultural crops. Some agrarian enterprises, which are located relatively far from the shelling, suffer from problems with logistics, a total shortage of labor, fuel, fertilizers, plant protection products, agricultural machinery, lack of seed material and working capital. Therefore, there is a need for the complex application of technologies for growing agricultural crops in different soil-climatic conditions of Ukraine, which include the systematic use of scientifically based measures that affect the solution of global social problems of humanity, especially in the conditions of environmental, economic, energy and food crises, which caused by climatic changes and military actions of the rf.

For this purpose, at all stages of the implementation of modern scientific research in the agrarian direction, a wide application of economic-mathematical methods is provided, which ensure the establishment of hidden dependencies inherent in many biological phenomena, in particular, in modern conditions of climatic changes and other stress factors (Ye. O. Yurkevych, N. P. Kovalenko & A. V. Bakuma, 2011). The use of economic-mathematical methods in agrarian research ensures accuracy and unambiguity, the degree of probability and reliability of conclusions; contributes to a deeper assessment of the essence of scientific-practical problems; identifying previously unknown regularities and establishing new, relevant tasks for solving in the future.

MATERIAL AND METODS

The research used general scientific methods: systematicity, complexity and objectivity, comprehensiveness and multifactoriality. Special historical methods of scientific knowledge were used: comparative-historical, problem-chronological and retrospective. Such methods provide a holistic and comprehensive analysis of the evolution of economic-mathematical methods in field research of cereal crops in the conditions of climatic changes in Ukraine during the second half of the 19th – the beginning of the 21st centuries. The source base includes published materials, the basis of which are fundamental scientific works based on the results of many years of agrarian research by foreign and Ukrainian scientists.

Modern methods of modern multifactorial field experiments and economic-mathematical processing of research results using the package of application programs for statistical data analysis «Statistica» were used. In order to establish the share of the mutual influence of technological factors and weather conditions on the productivity of

cereal crops in different soil-climatic conditions of the Polissia, Forest-Steppe and Steppe of Ukraine, the method of statistical data analysis in multifactorial experiments was used – dispersion analysis, which is based on determining the action as systematic (controlled) and random of (uncontrolled) factors, as well as their interaction on the variation of the effectiveness of a common trait. The use of dispersion analysis ensured the generalization of the analysis of the obtained results and their verification for reliability according to statistical criteria.

RESULTS

The application of economic-mathematical methods for processing the results of field research led to the emergence and development of appropriate methodological improvements, which later became an integral component of experimental research in the agrarian direction. Their evolution is one of the main ways to increase the effectiveness and quality of field research of cereal crops in the conditions of climatic changes in Ukraine (N. Kovalenko & O. Hloba, 2021).

It should be noted that for the first time, information about the principles of correlation, as the correspondence and interrelationship of various factors, was given in the works of the outstanding Ancient Greece scientist-encyclopedist Aristotle (384–322 BC) (N. P. Kovalenko, 2014). During the 8th – 9th centuries, statistical methods based on the theory of probabilities were first cited in the works of Arab mathematicians. In particular, Al-Khalil applied the method of data permutation and combination, Al-Kindi – the method of deciphering cryptographic messages using statistics and frequency analysis.

During the 18th–19th centuries, correlation and statistical methods in scientific research began to be systematically applied in the countries of Western Europe. In particular, thanks to the discovery in 1783 by the French mathematician and astronomer P. Laplace of the distribution curve of random variables, as well as the method of least squares by the German mathematician, astronomer and surveyor C. Gauss. In 1805, the French mathematician A. Legendre provided a detailed description of number theory and the method of least squares (Ye. O. Yurkevych et al., 2021). In 1889, English statisticians F. Galton and C. Pearson developed methods for analyzing the relationship between two variables, the theory of partial and pure correlation coefficients, as well as the theory of multifactor correlation. Scientists have worked out the theoretical foundations of regression analysis based on the development of regression equations, where the value of one correlated characteristic provides the calculation of the average value of another characteristic.

In the first half of the 20th century, the English mathematician, statistician, biologist and geneticist R. A. Fisher made a special contribution to the development of statistical methods of experiment planning, who in 1922 introduced the terms «dispersion» and «statistical parameters» (R. A. Fisher, 1922). In 1925, R. A. Fisher developed a theory of statistical hypothesis testing, namely dispersion analysis, describing its complete classification (R. A. Fisher, 1925). For the first time, the scientist substantiated the expediency of simultaneous variation of all factors as opposed to the widespread one-factor experiment. In 1930, the scientist first used the diffusion equation in population genetics, in 1938 he developed statistical tables for biological, agricultural, and medical research (R. A. Fisher, 1930; R. A. Fisher & F., Yates, 1938). In 1935, R. A. Fisher worked out a detailed method of mathematical planning of the experiment (R. A. Fisher, 1935). The scientist focused the mathematical planning of the experiment on the basis of the analysis of various models in which the differences occurred, which he divided into components due to various factors in the study.

In the second half of the 19th – at the beginning of the 20th centuries, the methods of mathematical statistics for processing the results of agrarian research received wide development in the Ukrainian scientific space. In 1867, methods of statistical processing of the results of agrarian research were first applied by D. I. Mendelieiev, improved: in 1929 by M. F. Derevytskyi (N. F. Derevytskyi, 1930; N. F. Derevytskyi, 1962), in 1931 by V. M. Perehudov (V. N. Perehudov, 1948; V. N. Perehudov, 1978). Ukrainian scientists emphasized the need for their use to solve the accuracy of field research of cereal crops: O. H. Doiarenko (A. H. Doiarenko, 1908), M. A. Yehorov (M. A. Yehorov, 1908; M. A. Yehrov, 1909). They developed a methodology for the analysis of experimental data with the mandatory use of mathematical statistics methods.

In 1911, agronomist M. M. Wolff was one of the first to introduce economic-mathematical methods – the theory of probabilities and mathematical statistics for the analysis of observations in agrarian experiments. In the special section «Mathematical signs of a series of results predetermined by the overwhelming influence of constant factors» in the work «Proceedings of the network of collective experiments with mineral fertilizers in the Yekaterinoslav province», the scientist claimed that with the use of mathematical analysis it is possible to obtain more accurate

mathematical equalities of the values that characterize the obtained series (M. M. Wolff, 1911). He proposed to use the table of distribution of deviations according to C. Gauss for the analysis of statistical series. The above-mentioned work was highly appreciated by scientists of the agrarian industry, especially the development and presentation of the technique of accounting for the yield of cereal crops according to average values. For the first time in agrarian practice, M. M. Wolff applied economic-mathematical methods to evaluate the results of field studies of cereal crops at the Kharkiv Regional Agricultural Research Station. A significant contribution to the development of mathematical and statistical research was made by the Ukrainian economist, statistician and mathematician, a teacher at the Kyiv Commercial Institute Ye. Ye. Slutskyi. In 1912, in the textbook on mathematical statistics «Correlation theory and elements of the doctrine of distribution curves», he presented the methodology of rational decisions under various combinations of conditions (Ye. Ye. Slutskyi, 1912).

In the first half of the 20th century, the analysis of the development of the application of economic-mathematical methods in the direction of the accuracy of the obtained results was carried out by Ukrainian scientists: O. K. Filipovskyi – in the textbook «Agricultural research» (O. K. Filipovskyi, 1927), M. M. Tulaikov – In the handbook «Materials for field technique and laboratory experiments» (N. M. Tulaikov, 1932), A. O. Sapiehin – in the practical guide for researchers «Variational statistics» (A. A. Sapiehin, 1937). They reflected the scientific foundations of agrarian research, emphasized the fact that the main directions of practical application of the methods of mathematical statistics and the theory of probabilities have already been developed. Scientists have developed appropriate methods of analyzing the results and assessing the accuracy of field multifactorial experiments for effective cultivation of cereal crops.

Achievements in the practical application of methods of mathematical statistics and probability theory contributed to the further improvement of field experiment planning and statistical processing of experimental data. Examples of such studies were the works of scientists: P. N. Konstantynov (P. N. Konstantynov, 1936a; P. N. Konstantynov, 1936b; P. N. Konstantynov, 1952) and O. S. Molostov (A. S. Molostov, 1931; A. S. Molostov, 1966), who improved data evaluation methods to increase the accuracy of field studies of cereal crops. In the second half of the 20th century, the systematic approach in agrarian research based on statistical processing of the results of research on agricultural crops was embodied in the works of B. O. Dospiekhov (B. A. Dospiekhov, 1965; B. A. Dospiekhov, 1985). The specified technique has not lost its relevance until now and has become an integral component of the economic-mathematical processing of the results of field studies of agricultural crops in different soil-climatic conditions of Ukraine: Polissia, Forest-Steppe and Steppe. In particular, at the beginning of the 21st century, in the field studies of agricultural crops, they establish a relationship between a common feature – the yield of agricultural crops, the productivity of crop rotations, the quality of agricultural products and technological factors: the genetic purity of varieties and hybrids, predecessors, the saturation of crop rotations with cereal, technical, fodder and vegetable crops, sowing depth and rate, sowing periods, use of tillage and plant protection, application of organic and mineral fertilizers, preparation of seeds and care of crops, as well as climatic factors: precipitation, air temperature and humidity, number of sunny and cloudy days, wind strength, etc. Such dependencies are revealed using the methods of mathematical statistics – correlation, regression, dispersion, factor and cluster analysis (O. S. Luginin, 2007; T. O. Tarasenko, 2006; Ye. I. Tkach, 2004; V. O. Ushkarenko et al., 2007). When studying several factors in multifactorial field experiments of agricultural crops, it is effective to use dispersion analysis, which provides a simultaneous assessment of all factors and their interaction on the dynamics of the general characteristic. On the basis of long-term studies of the efficiency of growing agricultural crops in stationary multifactorial field experiments of scientific research institutions of the network of the National Academy of Sciences of Ukraine, the National Academy of Agrarian Sciences of Ukraine and higher education institutions of the Ministry of Education and Science of Ukraine, the relationships between the effective cultivation of cereal crops and the main technological and climatic factors are defined and mathematically evaluated (Ye. O. Yurkevych, N. P. Kovalenko & A. V. Bakuma, 2011; N. P. Kovalenko, 2014; O. V. Demydenko et al., 2019; Ye. O. Yurkevych et al., 2021). To determine the share of mutual influence, dispersion analysis was used – a method of statistical data analysis in multivariate experiments (B. A. Dospekhov, 1965; A. S. Molostov, 1966). Dispersion analysis is based on the determination of the action of both systematic (controlled) and random (uncontrolled) factors, as well as their interaction on the variation of the performance of a common feature (N. F. Derevytskyi, 1962; V. N. Perehudov, 1978; B. A. Dospiekhov, 1985). In particular, we assessed the share of mutual influence of the main technological factors: the use of crop rotations, tillage, fertilizer application, plant protection products, other factors – the use of varieties and hybrids, seed preparation, sowing depth and rate, sowing periods, as well as weather conditions on the productivity of cereal crops in conditions of climatic changes in Ukraine during the second half of the 19th – the beginning of the 21st centuries (Fig. 1).

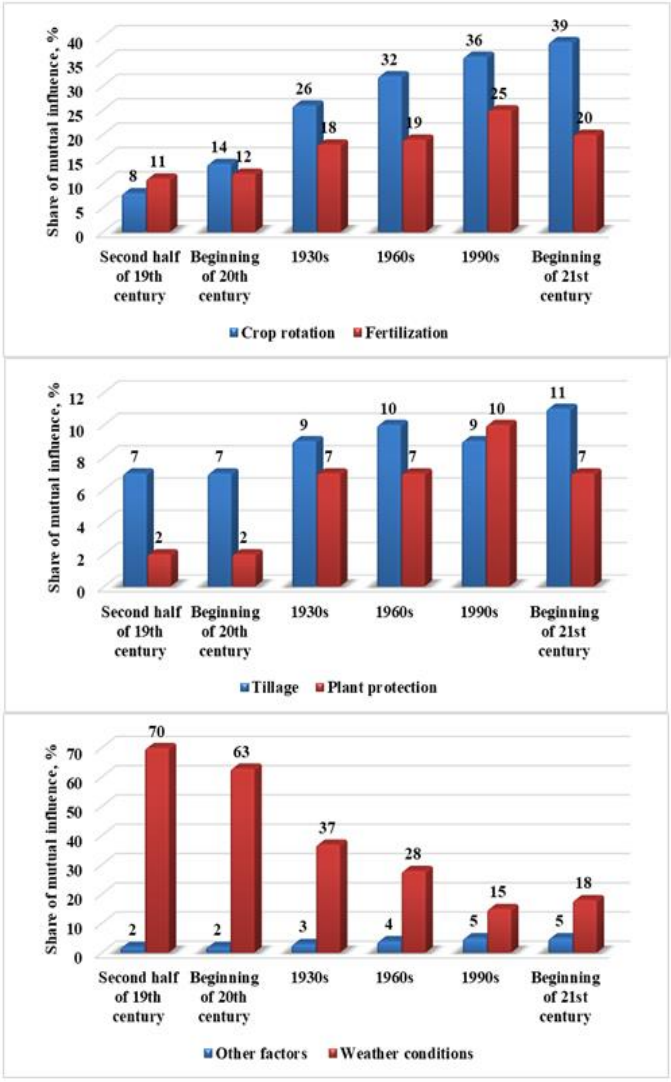

Figure 1. Dynamics of the share of mutual influence of the main technological factors and weather conditions on the productivity of cereal crops in the conditions of climatic changes in Ukraine in the second half of the 19th – at the beginning of the 21st centuries, %

Source: compiled based on the results of the author's long-term scientific research and studies by scientists: Ye. O. Yurkevych, N. P. Kovalenko & A. V. Bakuma, 2011; N. P. Kovalenko, 2014; O. V. Demydenko et al., 2019; Ye. O. Yurkevych et al., 2021.

The results of the processing of long-term data on the productivity of agricultural crops by the method of dispersion analysis indicate an increase over the years in the share of mutual influence on the productivity of cereal crops of all technological factors, which ensure a reduction of the negative effect of adverse weather conditions from 70 to 18%. In particular, the share of the mutual influence of the crop rotation factor increased by 31% over more than a century and a half, fertilizer application – by 9%, plant protection products – by 5%, tillage – by 4%, other factors (varieties and hybrids, seed preparation, sowing depth and rates, sowing periods) – by 3%. This confirms the relevance of using scientifically based technologies for growing cereal crops, which have been improved over the years. The share of mutual influence of the main technological factors: the use of crop rotations, fertilizer application, plant protection products, tillage, other factors (varieties and hybrids, seed preparation, sowing depth and rates, sowing periods) and weather conditions on rational land use in Ukraine at the beginning of the 21st century was mathematically estimated (Fig. 2). Each factor with various deviations from the norm, in particular in extreme cases, can become decisive and limit the amount of possible yield of cereal crops in certain soil-climatic conditions. As a result of the processing of long-term data on the productivity of agricultural crops in the Polissia, Forest-Steppe and

Steppe of Ukraine by the method of dispersion analysis, it was established that the largest share of mutual influence on rational land use is the crop rotation factor – 35–42%. The following factors can be placed in descending order: fertilizer application – 18–22%, weather conditions – 17–20%, tillage – 10–12%, plant protection – 6–8%, other factors (varieties and hybrids, seed preparation, sowing depth and rates, sowing periods) – 4–6%. Thus, the effectiveness of the main technological factors on rational land use in the conditions of climatic changes of Ukraine at the beginning of the 21st century has been mathematically confirmed, the share of which is 82%.

The share of mutual influence of the main technological factors (application of crop rotation, fertilization, tillage) and weather conditions on the productivity of the leading cereal, legumes and technical crops in the Forest-Steppe of Ukraine at the beginning of the 21st century was established (Fig. 3). It was established that the largest share of mutual influence on the productivity of winter wheat, barley, corn, peas and sugar beets is the crop rotation factor – 41,3–54,2%. The following factors can be placed in descending order: weather conditions – 18,7–25,3%, fertilization – 16,1–23,5%, tillage – 10,1–16,5%.

The share of the mutual influence of the application of crop rotations and other technological factors – application of fertilizers, tillage, plant protection products on the productivity of the leading cereal, legumes and technical crops in the Forest-Steppe of Ukraine at the beginning of the 21st century was determined (Fig. 4). The largest share of mutual influence on the productivity of all agricultural crops was found in the interaction of the crop rotation factor with the application of fertilizers, which is 6,7–8,3%; the smallest – when the crop rotation factor interacts with the use of plant protection products – 2,8–3,3%; the average place is occupied by the interaction of the crop rotation factor with tillage – 4,0–4,6%.

When growing winter wheat, the percentage of the combined influence of crop rotations and fertilizer application was determined, where the share of the crop rotation factor is 56,4%, fertilizer – 35,3%, and the interaction of these factors – 8,3%. The percentage of the combined effect of crop rotations and tillage was established, where the share of the crop rotation factor is 75,6%, tillage – 19,8%, and the interaction of these factors – 4,6%. The percentage of the combined effect of the use of crop rotation and plant protection products was calculated, where the share of the crop rotation factor is 86,5%, plant protection products – 10,4%, and the interaction of these factors – 3,1%.

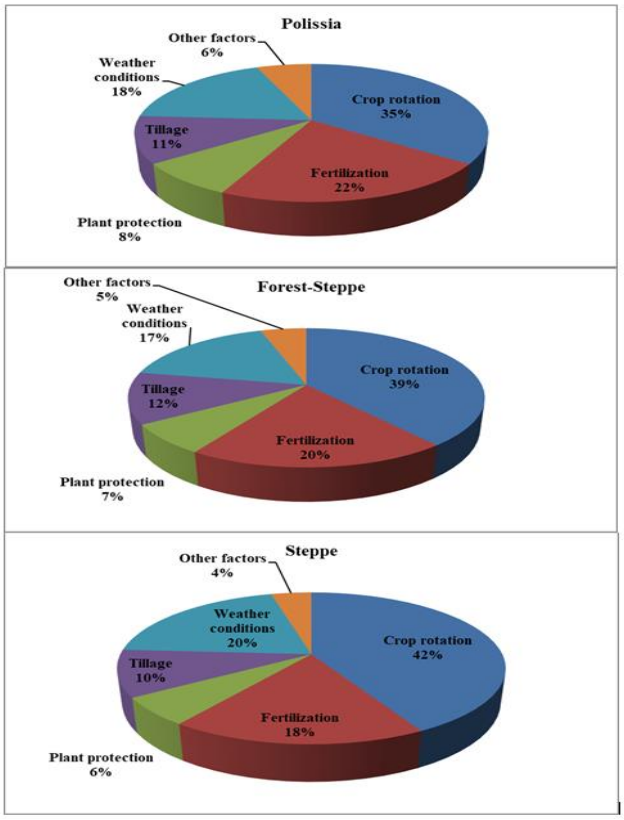

Figure 2. Share of the mutual influence of the main technological factors and weather conditions on rational land use in the conditions of climatic changes in Ukraine at the beginning of the 21st century, %

Source: compiled based on the results of the author's long-term scientific research.

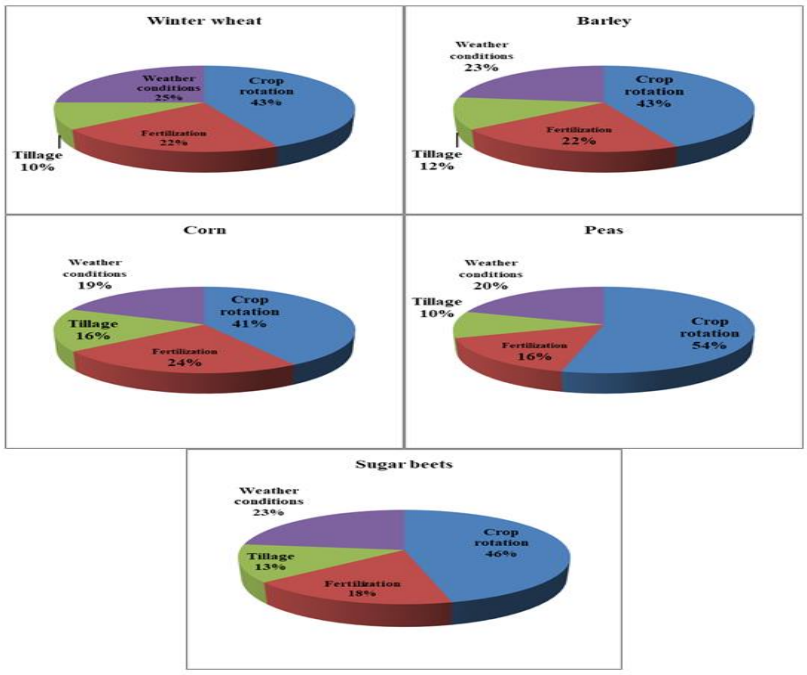

Figure 3. Share of the mutual influence of the main technological factors and weather conditions on the productivity of the leading cereal, legumes and technical crops in the Forest-Steppe of Ukraine at the beginning of the 21st century, %

Source: compiled based on the results of the author's long-term scientific research.

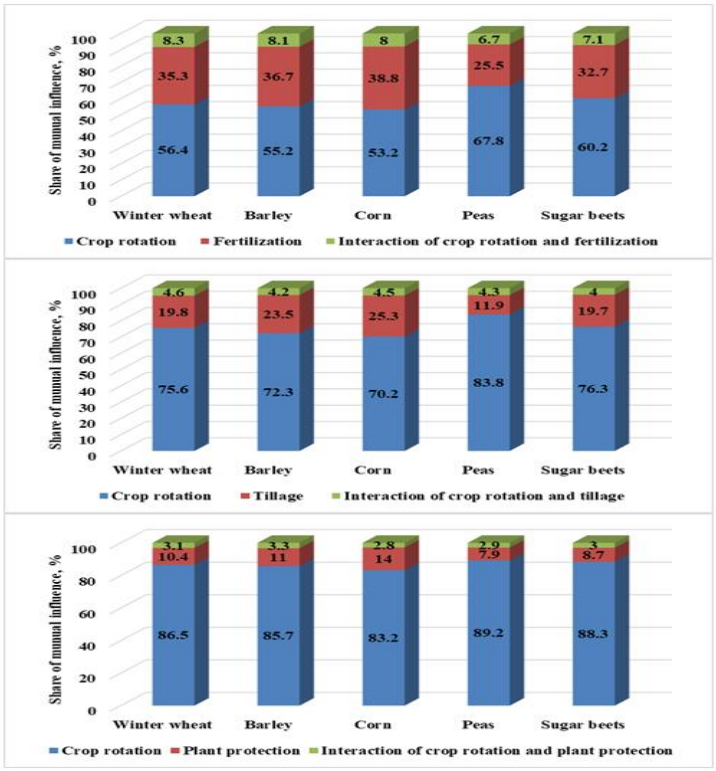

Figure 4. Share of the mutual influence of crop rotation and other technological factors on the productivity of leading cereal, legumes and technical crops in the Forest-Steppe of Ukraine at the beginning of the 21st century, %

Source: compiled based on the results of the author's long-term scientific research.

When growing barley, the percentage of the combined influence of crop rotations and fertilizer application was determined, where the share of the crop rotation factor is 55,2%, fertilizer – 36,7%, and the interaction of these factors – 8,1%. The percentage of the combined effect of crop rotations and tillage was established, where the share of the crop rotation factor is 72,3%, tillage – 23,5%, and the interaction of these factors – 4,2%. The percentage of the combined effect of crop rotations and plant protection products was calculated, where the share of the crop rotation factor is 85,7%, plant protection products – 11,0%, and the interaction of these factors – 3,3%.

CONCLUSIONS

It can be concluded that the emergence of economic-mathematical methods took place in Ancient Greece with the first mention of the principles of correlation in the works of the outstanding scientist-encyclopedist Aristotle. At the beginning of the 20th century, statistical methods for processing the results of agrarian research were developed in the works of Ukrainian scientists. The application of mathematical statistics methods for processing the results of field studies of cereal crops ensured the accuracy and reliability of the obtained results, the identification of previously unknown regularities for their effective growth and development.

As a result of the processing of long-term data on the yield of agricultural crops by the method of dispersion analysis, it was established that during the second half of the 19th – the beginning of the 21st centuries, the share of the mutual influence on the productivity of cereal crops of the main technological factors increased, which restrained the negative impact of adverse weather conditions up to 52%. The effectiveness of the predecessors in crop rotations largely depended on the amount of applied fertilizers and weather conditions. Differentiation of methods of tillage for main crops in crop rotation depending on the predecessor provided increased efficiency of fertilizer application and obtaining high and stable yield of cereal crops. The use of effective varieties and hybrids, plant protection products, seed preparation, depth and rate of sowing, as well as optimal sowing periods of cereal crops were of great importance. The specified technological factors were closely interrelated and determined the yield of all agricultural crops.

Therefore, in the modern conditions of climate change and other stress factors, the application of economic-mathematical methods in field studies of cereal crops in different soil and climatic conditions of Ukraine: Polissia, Forest-Steppe and Steppe is of great importance. They ensure the systematic use of science-based measures affecting the solution of global social problems of humanity, especially in the conditions of ecological, economic, energy and food crises, which were caused by climate change and military actions of the rf.

REFERENCES

1. Boiko, P., Kovalenko, N., Yurkevych, Ye., Valentiuk, N. & Albul, S. (2023). The History, Current State and Prospects for the Implementation of Elements of Biologization for the Efficient Cultivation of Corn in Organic Farming of the Southern Steppe of Ukraine. International Journal of Ecosystems and Ecology Science (IJEES). 13(1): 39–58. doi: https://doi.org/10.31407/ijees13.106;
2. 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;
3. 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;
4. Demydenko, O. V, Boiko, P. I., Blaschuk, M. I., Shapoval, I. S. & Kovalenko, N. P. (2019). Crop rotations and fertility of chernozem of the Left-Bank Forest-Steppe: monograph. Smila: Chornobayivske KPP: 484;
5. Derevytskyi, N. F. (1930). Statistical method in the field experiment. Tashkent. 130;
6. Derevytskyi, N. F. (1962). Experienced in crop production. Kishinev: Shtiintsa. 616;
7. Dospiekhov, B. A. (1965). Field experience methodology (with the basics of statistical processing of research results). Kolos. 424;
8. Dospiekhov, B. A. (1985). Methodology of field experience. Ahropromyzdat. 352;
9. Doiarenko, A. H. (1908). Setting up experiments with mineral fertilizers on peasant lands. 36;

10. Filipovskyi, O. K. (1927). Agricultural research work: textbook for higher schools. Kharkiv: Knygospilka. 184;
11. Fisher, R. A. (1922). On the mathematical foundations of theoretical statistics. Edinburgh-London: Oliver & Boyd, 60. https://doi.org/10.1098/rsta.1922.0009;
12. Fisher, R. A. (1925). Statistical methods for research workers. Edinburgh-London: Oliver & Boyd. 354;
13. Fisher, R. A. (1930). The genetical theory of natural selection. Oxford at the Clarendon Press. 270. https://doi.org/10.5962/bhl.title.27468;
14. Fisher, R. A. (1935). The design of experiments. Edinburgh-London: Oliver & Boyd. 258;
15. Fisher, R. A. & F., Yates (1938). Statistical tables for biological, agricultural and medical research. Edinburgh-London: Oliver & Boyd. 146;
16. Konstantynov, P. N. (1936a). Methods of field experiments (with elements of the theory of errors): study guide. Selkhozghyz. 392;
17. Konstantynov, P. N. (1936b). Techniques for improving the accuracy of field experiments. Selkhozghyz. 134;
18. Konstantynov, P. N. (1952). Fundamentals of agricultural experimental work in field farming. Selkhozghyz. 446;
19. Kovalenko, N. P. (2014). Becoming and development of scientifically-organizational bases of application of home crop rotations in the systems of farming (the second half of the 19th – the beginning of the 21th century): monograph. Kyiv: TOV «Nilan-LTD»: 490;
20. 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;
21. 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. doi: https://doi.org/10.31407/ijees11.423;
22. 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. doi: https://doi.org/10.31407/ijees12.110;
23. Kovalenko, N. (2022). Ecologization of agrarian production: efficiency of development and prospects of implementation of innovative technologies in independent Ukraine. Proceedings book essays on ecosystem and environmental research 12th International conference of ecosystems (ICE2022), Chicago, Illinois, USA: 74–84.URL: https://www.ijees.net/journal-87-12th-International-Conference-of-Ecosystems-June-3-5,-2022,-Chicago,-Illinois,-USA-(online).html;
24. Luhinin, O. S. (2007). Statistics: textbook. Kyiv: Center for Educational Literature. 608;
25. Molostov, A. S. (1931). Field experiment data evaluation methods (to the field experiment methodology). Kharkiv: Derzhsilhospvydav. 82;
26. Molostov, A. S. (1966). Field experiment methodology. Kolos. 240;
27. Morhun, V. V. (2001a). Genetics and breeding in Ukraine at the turn of the millennium: in 4 volumes. Kyiv: Logos, 1:664;
28. Morhun, V. V. (2001b). Genetics and breeding in Ukraine at the turn of the millennium: in 4 volumes. Kyiv: Logos, 2:636;
29. Morhun, V. V., Shvartau, V. V., Konovalov, D. V., Mykhalska, L. M., Skryplov, V. O. (2022). Club of 100 centners. Modern varieties and systems of nutrition and protection of winter wheat. Kyiv: Vistka. 11: 106;
30. Official website of the UN Food and Agriculture Organization. (2023). URL: http://www.fao.org/faostat/en/#data/QCL;
31. 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;
32. Perehudov, V. N. (1948). Statistical methods for processing field experience data. Selkhozghyz. 296;
33. Perehudov, V. N. (1978). Planning of multifactorial field experiments with fertilizers and mathematical processing of their results. Kolos. 184;
34. Sapiehin, A. A. (1937). Variational statistics: a practical elementary guide for experienced agronomists and biologists. Selkhozghyz. 86;

35. Slutskyi, Ye. Ye. (1912). Correlation theory and elements of the doctrine of distribution curves. Proceedings of the Kyiv Commercial Institute. Kyiv. 208;
36. Tarasenko, T. O. (2006). Statistics: study guide. Kyiv: Center for Educational Literature. 344;
37. Tkach, Ye. I. (2004). General theory of statistics: a textbook. Ternopil: Leader. 388.
38. Tulaikov, N. M. (1932). Materials on the technique of field and laboratory experiments. 148.
39. Ushkarenko, V. O., Nikishenko, V. L., Holoborodko, S. P. & Kokovihin S. V. (2007). Dispersion and correlation analysis in farming and crop production. Kherson: Ailant, 238;
40. Wolff, M. M. (1911). Proceedings of the network of collective experiments with mineral fertilizers in the Yekaterinoslav province. Kharkov: Pechatnoe delo. 3. Results of collective experiments. 208;
41. Yehorov, M. A. (1908). One way to improve the accuracy of the field experience method. Herald of Agriculture. 51–52: 9–13;
42. Yehorov, M. A. (1909). To the method of field experience. Journal of Experimental Agronomy. Printing house of Altshuler. 10: 502–517;
43. 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;
44. 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;