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DEVELOPMENT OF OPTIMAL CROP PRODUCTION MODEL CONSIDERING EXISTING NATURAL-CLIMATIC RISKS INCREASING CROP YIELDS

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SUMMARY

Contemporary agriculture is a fertile ground for the effective use of economic and mathematical models, which can be evaluated to unwind several problems with characteristic optimization features: multiple solution opportunities and freedom of choice, limited production resources, and efficiency valuation. The presented study aims to develop a model of optimal crop production structure under the existing weather risks in the agricultural management system. The article reviews the basic theoretical concepts in optimizing the production structure of agricultural enterprises, examines the specific features of crop production, proves the influence of weather and climate conditions on forming the production structure, demonstrates the use of correlation and regression analysis for trend modeling and forecasting of crop yields, and offers suggestions for determining the optimal production structure. The study concludes that multivariate forecasting helps optimize management in economic organizations and ensure their development under the variability of natural conditions. Natural and climatic conditions significantly impact the development of production structures in agricultural enterprises, along with nature acting as an innate participant in the game.

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Keywords: Agricultural enterprise, economic and mathematical models, natural conditions, agricultural production structure, optimization model, weather risks

Key findings: The proposed mathematical model helps maximize the net profit and predicts the maximum possible profit gain under different production structures depending on the existing weather conditions and risks. The presented model enables agricultural enterprise management to build business strategies based on profit maximization. The said model also provides a better justification of the managerial decision-making process for optimal planning to find the reserves to improve agricultural enterprises' production efficiency and marketing activities in times of crisis and dynamic changes in the external environment.

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INTRODUCTION

From the perspective of agricultural enterprises, competition needs to quickly adapt to the changes in the market, carry out innovative activities, and employ advanced technologies and approaches to boost the business. It is a fact that the priority in managing agrarian sector business is considering problem areas, such as seasonality of production (Bryzhko and Pshenichnikov, 2015), the lack of efficient marketing (Magomedov and Overchuk, 2016), internal operational problems (Klimentova and Iarygin, 2021), relying on soil production (Bayram *et al*., 2015) and climate conditions (Njuki *et al*., 2018), staff turnover (Skobliakova and Kniazeva, 2016), poor management automation (Agarkova, 2018), and significant production costs (Bobrova, 2015).

The risk factors on priority include weather conditions (Shivrina and Davydova, 2014), inflation (Razin *et al*., 2018), and product price variations (Gaiduk *et al*., 2011). In further developing production structures and sales strategies for farming enterprises, using mathematical models is a critical condition for efficient scientific and practical work of agricultural management (Krasnovskiy *et al*., 2022). It also serves as a basis for making managerial decisions (Seidakhmetova *et al*., 2022; Tatibekova *et al*., 2022), aimed at risk reduction (Martirosyan *et al*., 2022; Khoruzhy *et al*., 2023) and increasing crop yields (Kulshikova *et al*., 2023).

Therefore, research on economic processes in the operation of agricultural enterprises increasingly utilizes the corresponding mathematical tools (Krasnovskiy *et al*., 2022). Equations are constructed to reflect the relationship between indicators and determine their impact on the variable, in turn, identifies the necessary constraints for basing the decisions to justify future strategies and obtain tangible results (Sedova and Alekseev, 2023). Hence, the mathematical models of agricultural business activities need to reflect the probability ratio of change in the state of the agricultural enterprise, improving business processes' efficiency, lowering the production costs, and identifying the most vulnerable areas (Simonov *et al*., 2019, 2022).

The research problem and the relevance of the study comprise enhancing the competitiveness of agricultural enterprises through developing and using the optimal mathematical business models to improve the farming enterprise for being beneficial. The study's uniqueness comes from the narrative of the opportunity to apply game theory in constructing the model of optimal production under the existing weather risks. This model will provide an occasion to analyze the prospects to reduce weather risks in the economic activities of the agricultural enterprise with minimal efforts and resources on the management part in making appropriate managerial decisions. In Kazakhstan, the operation of agricultural enterprises demonstrates the difficulty of justifying decisions in the face of weather risks (Kargabaeva and Zhaksybaeva, 2016). Lacking well-managed methodological toolkits makes it unrealistic to adapt to adverse weather-climatic conditions, leading to a higher cost of production and reduced profit.

The progressive study aimed to develop a model of optimal production structure under the present conditions of the weather risks in the management system of agricultural enterprises. The article attempts to address the following research questions: a) "What optimal production structure model should be applied and how to implement it under different natural and climatic conditions?" and b) "What results to expect and achieve by applying the model to increase the profit under various variants of production in agricultural enterprises?" In light of these research questions, the study employs a qualitative approach based on the case study methodology (Ciasullo *et al*., 2022). Since Kazakhstan is a country that occupies vast territories with diverse climatic conditions (Seidakhmetova *et al*., 2022), the presented study narrowed down to an individual enterprise in East Kazakhstan. An imperative state in the study is to understand the need to account for the weather risks and to raise the efficiency of directorial decision-making power concerning the crop production structure (Dokholyan *et al*., 2022), with this requirement significant for developing the optimized model.

The latest study conclusions revealed the potential of agricultural production model optimization under the existing conditions of weather risks. The findings supplement the prevailing methodology for accounting the weather conditions in agricultural production. In particular, the model of optimal production structure facing weather risk in the agricultural enterprise management system helps to manage the economic layout and ensure their development under natural conditions.

Background

Economic modeling in the agro-industrial sector

The most reasonable consideration of the specific features of agribusiness is the starting point in developing economic and mathematical optimization models (Nardin and Nardina, 2021). Researchers state that the leading method in the economic performance of agricultural enterprises is financial modeling, which combines a set of versatile techniques (Singh *et al*., 2017). Mathematical modeling presents an efficient universal tool for studying the internal patterns of various processes and allowing to examine the quantitative relationship and interrelationships within the model to develop proposals for further improvement in agribusiness (Ivanyo *et al*., 2020).

Efficient modeling of economic processes requires the use of reliable and credible information sources, reproduction of the essence of an object, its quantitative characteristics, the nature of the interaction of its components, and the significance of this phenomenon in the operation of the system (Svetlov *et al*., 2020). In addition to a substantial description, specific schemes need crafting, such as, symbols, graphs, tables, and so on, to better reproduce and polish the properties of the studied objects for tangible results. Furthermore, an adequate economic-mathematical model capable of efficiently solving complex socio-economic tasks, requires combining the methods of artificial intelligence to design the model and statistical analysis to form the training sample effectively (Gazetdinov *et al*., 2017).

The chief problem that delays the practical implementation of economic and mathematical models is the acquisition of specific, complete, and quality information (Zhichkin *et al*., 2021). Insufficient information support leads to unsatisfactory results and does not improve the situation but worsens it more. Application of authentic economic models requires the following characteristics to be considered well in time, i.e., efficiency, stability (Vlasov and Shimko, 2016), maneuverability (Madykh *et al*., 2017), reliability and flexibility (Chernyshev, 2013), adaptability (Gerashchenko and Shulga, 2017), and evaluation of economic risks (Garmash *et al*., 2014; Voskovskaya *et al*., 2022). During management decisions, the manager should be mindful of the close association between the qualitative parameters of the system and their solutions (Svetlov *et al*., 2013).

Modern modeling approaches

In recent years, the interest in developing models for optimal production structures in agriculture, accounting for natural-climatic risk factors, continually increases. These models aim to multiply crop yields while minimizing the negative impacts of natural disasters, such as, droughts, floods, and extreme temperatures.

Javadi *et al.* (2023), considering a computable general equilibrium (CGE) model, studied the change in economic effects of climate variables on two essential food products of Iran—wheat and rice—representing food security. Using climate yield response functions for rain-fed and irrigated crops simulated the climate scenarios. The estimated tasks have affirmed a direct correlation of rainfall and an indirect correlation of the standard deviation of temperature with the yield of selected crops.

Another study focused on the impact of climate change on rice production in the Mekong River Delta of Vietnam. This climate-crop study applied the crop simulation model Decision Support System for Agrotechnology Transfer (DSSAT) to assess climate change’s future (2020–2050) impacts on rice production. The results suggest that, under rain-fed conditions, winter rice yield was likely to experience a nearly 24% reduction, while summer rice yield could decrease to about 49% (Jiang *et al*., 2019).

The study conducted in Brazil aimed to project the impact of climate change on common bean cropping systems using an upscaling climate approach and crop modeling to represent the Brazilian production regions. Researchers used a well-calibrated process-based crop model to simulate future crop availability by the mid-century (2040–2070) based on climate scenarios provided by the AgMIP (Agricultural Model Inter-comparison and Improvement Project). Yield projections indicate increases in the average yield of common beans in Brazil, which mostly rely on the projected increases of CO_2 under the climate change scenarios considered in the study (Antolin *et al.*, 2021).

In the management of agribusiness processes, modern modeling approaches need to focus on developing such principles of management as systematic nature, comprehensiveness, and multi-variation of calculations, which is achievable by introducing and employing economic-mathematical models (Skabelkin and Iurochkin, 2016). Current scientific literature presents economic models that contain mathematical modeling with numerous gross violations, leading to erroneous and low-quality results (Simonov, 2019). However, when an economic-mathematical model gets developed from a purely mathematical standpoint, it often fails to fully account for the agribusiness operation (business processes, production structure, production, and economic indicators). Likewise, a model developed exclusively on economics typically contains gross mathematical errors (Fedoseev, 2014). Therefore, the specialist developing a particular model must have substantial knowledge of the agricultural economy and modeling and be proficient in mathematical instruments.

The economic-mathematical model with minimized risks

Economic-mathematical methods used in agribusiness in three primary directions:

Development and solution of economic and mathematical problems of internal economic planning and their analysis (Samygin and Keleinikova, 2018).

Development and solution of economic and mathematical problems at the agroindustrial complex (Romanenko and Siptits, 2016).

Development and solution of economic and mathematical problems of industry-specific planning and analysis (Sokolova and Turk, 2016).

In managing agribusiness production and economic activities, when using economic and mathematical methods, it is vital to account for specific factors affecting the operation of said enterprises, such as natural, climatic, biological, economic, and agrotechnical. However, the most crucial problem when choosing the optimality criterion is determining the optimum and most favorable target function (Collins *et al*., 2013). In this respect, Sokolova (2016) suggested that the primary goal of an agricultural enterprise is to maximize profit and minimize costs. In production costs' optimization, researchers specify different optimality criteria, i.e., maximum profit (Afanaseva and Iakimova, 2013) and maximum income from product sales (Sennikov and Sokolova, 2018).

Their properties and the level of information tools and technology define the role of mathematical models in managing agricultural production and sales (Riaman *et al*., 2022). Mathematical models have long served as a means of forecasting and analytical planning of various socio-economic processes, with their analysis (Gataullin *et al*., 2015). Thus, each method has its significance and sphere of application, hence it is expedient to conduct detailed studies of production indicators and agribusiness marketing activities and analyze the influence of environmental factors.

A priority task of an agricultural enterprise is enhancing its economic performance and providing the required material and technical resources. In agribusiness, attaining higher outputs needs compliance with the requirements of seed pre-seeding, agro-technological measures, and good storage of agricultural products. For this purpose, in agriculture, the managers must carry out various measures to update the basic production facilities and provide high-quality and sustainable logistical resources to run the processes on time. An imperative precondition for the sustainable development of agricultural enterprises is optimizing their production structure and economic activities (Mellaku and Sebsibe, 2022). The most efficient way to create optimal parameters for managing agribusiness is the scientific basis of a production program must anchor on economic and mathematical modeling.

Applying mathematical modeling of economic and production processes enables efficient use of available resources in attaining the planned goals of the agricultural enterprise, which allows accounting for the key sources of uncertainty and minimizing the negative economic consequences. Some past studies also classified the economic and mathematical models used in agricultural production with specific parameters (Sokolova, 2020) (Figure 1). With the emergence of new innovative types, the provided classification receives constant revisions. For example, agriculture already has various standard models experimentally assessed and delivered better results.

In such models, the optimization can constitute for the structure of sown area (Volkov, 2007), the use of arable land and fertilizer (Maiorova, 2014; Temreshev *et al.*, 2022), reclamation measures, and combining the agricultural sectors (Orekhova and Bulgarov, 2018). However, if a particular economic problem is hard to address by the existing models, an original model is created, which undergoes all the necessary stages, including practical approbation, then applied in practice (Adilkhankyzy *et al*., 2022; Yessimbek *et al*., 2022). Therefore, it becomes possible to solve the problems of industrial production structure to obtain the optimal solution, discover all unused resources, determine the right direction of their efficient use, optimize the production and formation of the sown areas, and identify structural modifications and prospects for developing the agricultural enterprise.

Apart from optimizing the structure of agricultural production, constructing the optimization models can aim at the following:

Accounting for the requirements for crop rotation and agronomic expediency of various grown crops when optimizing the structure of sown areas (Podkolzin *et al*., 2018).

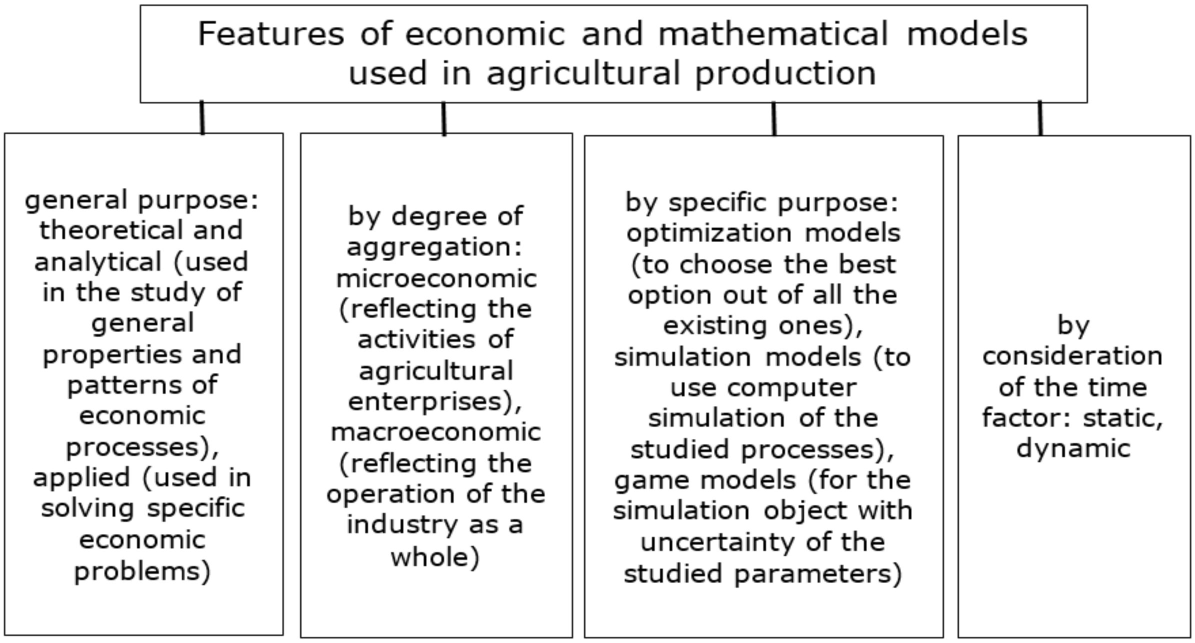

Figure 1. Features of economic and mathematical models of agricultural production.

Consistency of the planned structure of sown areas with the actual schemes of crop rotation in the optimization of various sectors of the agricultural organization (Mikhailenko and Timoshin, 2017).

Selection of the best possible crop sequencing schemes (Gusakova and Ermakov, 2012).

Positioning specified types and varieties of crops in the crop rotation, considering the quality of the soil (Mikhailenko and Timoshin, 2016).

In this study's view, solving economic and managerial problems in managing agricultural enterprises still lacks sufficient addressing. Hence, in modern conditions of economic management, there is a need to acquire more thorough research on the hindrances of informed decision-making by agricultural producers based on mathematical methods, especially managerial decision-making on business processes of agronomic production with the help of optimization models in the aspect of possible natural conditions.

Impact of risks on production and marketing

In many cases, for each respective year, composite meteorological conditions, i.e., weather conditions of production for that isolated critical period, influenced the level of agriculture production (Khosroeva and Sabanova, 2018). In a particular year, the quantitative characterization of weather conditions incorporates indicators of moisture accumulation in soil, precipitation, soil moisture, temperatures in spring and summer, and the period of crop formation and harvesting (Bakucs *et al*., 2020). Although, grouping the conditions of agricultural production may have three categories, i.e., normal - when the average long-term values of weather factors allow for an average yield; favorable - which contributes to a high productivity; and unfavorable - which results in low outputs (Solovyov *et al*., 2015).

Agricultural land and product uses vary depending on natural and climatic conditions in various crop seasons because of uneven crop yields (Dutbayev *et al.*, 2022). The ratio of resource inputs per hectare of crops or head of animals and their output may vary depending on the crop yields and livestock productivity. With higher crop yields, the material and monetary costs of resources and labor per hectare of crops will be higher (Kriuchkov, 2016).

Reduced yields in adverse weather conditions lead to a violation of the balance of agricultural products, ultimately worsening the economic performance of enterprises (Sharko, 2022). Under natural conditions, the volumes of gross and marketable products, and as a consequence, the size of profits may change significantly from year to year (Medvedev *et al.*, 2014). Therefore, farms cannot approach the solution of optimization models purely mechanically, but should also consider both the economic situation and the natural conditions of a particular area and time. The influence of environmental factors necessitates developing various optimal variants of production models in farms, considering yield forecasts for the next year based on the degree of favorability of weather conditions –unfavorable, medium, and favorable.

METHODS

Research approach

In line with the outlined approach on the features of implementation of the optimal production model under weather risks of an agricultural enterprise, the team chose a qualitative-quantitative method to study the complex phenomena under the heterogeneity and uncertainty conditions of the initial information (Nosonov, 2018).

The most appropriate research strategy was a qualitative case study to develop the described mathematical model (Sebera, 2012). The resulting data were more informative and extensive compared with a simple quantitative analysis, as it provided more details, which better helped collect information for model development and feedback from the managers of the agriculture enterprise (Slepov *et al.*, 2022). However, one must recognize that this method does not apply to the entire industry because of several limitations (Zielińska-Chmielewska *et al.*, 2021). In this regard, the study clarifies its main objective is to obtain qualitatively new knowledge about the particular agricultural enterprise. Limited available resources and the desire for additional research on the subject raised the need to publish the results to engage interested researchers and discuss the findings in the scientific community and among interested agro-industrial professionals. The presented study selected a unique case in the agro-industrial sector, described below.

Empirical context and case selection

The research proceeded in the sphere of agro-industrial production of crops. Kazakhstan is a large country with a considerably changing climate (Syzdykbaeva, 2018); the presented study narrowed its focus to agricultural enterprises in Eastern Kazakhstan. The main concentration of agriculture is crop production, which accounts for 55% of total gross output. East Kazakhstan region is implementing a program for developing crop production, diversifying crops, and increasing the area of highly profitable crops.

Following the research goals, websites of agricultural enterprises were randomly selected via the Google.com search engine by keywords (grain production, sunflower production, and corn production). In the obtained samples of various enterprises, choosing a single enterprise for further exploration (Spena and Cristina, 2020) used the following parameters, i.e., a) production and sale of crop products, b) growing of various crops, and c) having at least 10 years of an operating period from the moment of registration. Overall, the 21 agricultural enterprises met the criteria. The management of the enterprises received an e-mail indicating the purpose and program of the research. Thus, the chosen enterprise met the specified criteria, with its management agreeing to participate in the study and providing all the necessary information.

For confidentiality, the study named the selected enterprise following the specified criteria Astyk. The enterprise began in the late 1990s based on a pre-existing agricultural enterprise (state farm). The main activity of the company was plant production. However, at the time of the study, Astyk produced various crops, including wheat (winter and spring), winter rye, millet, buckwheat, sunflower, and corn (for grain and silos).

East Kazakhstan is a chief industrial region of Kazakhstan that contributes significantly to the country's economy. It ranks second in terms of physical investment in fixed assets in agriculture. Despite unfavorable weather conditions, ground grains reached 16.4 million t in 2022, with an average yield of 10.3 c/ha. The initially collected weight was 80.8 t of buckwheat, 76% more than in 2021. Furthermore, the rye harvest was 43% higher than the previous year, the corn yield was 22.6% higher for grain, and legumes were 1.3% higher. The millet yield in the original weight compared with the previous year increased by 15% and maize by 5%. The new harvest grain has better quality characteristics. Of the total volume of soft wheat, 90.5% ascribed to classes 1–3. In the bulk of third-class wheat, the high-quality HI-Pro wheat gained high demand in the market, accounting for about 60% (Nұralina *et al*., 2022).

Unfavorable weather conditions also have a significant effect on the development of the industry in this region. Such type of business marked highly dependent on weather conditions and their consideration in planning the structure of crops. Weather conditions favorable for one culture might also be for some other crops, meaning a positive correlation; however, it may also reduce the yield of a third culture (a negative correlation) (Mukasheva, 2016). Therefore, it is necessary to identify pairwise correlation coefficients of the yield deviation of particular crops from the trend.

As a result, the management of the producer concluded that Astyk would gain the ability to respond better to adverse environmental conditions if it implemented the proposed model of optimal production under the existing weather conditions. The enterprise management thus expressed the desire as the innovation initiator and agreed to provide the information necessary for the research, confirming that the data were suitable for the research's case study. In this way, Astyk became the object of research in the enterprises of the agro-industrial sector in East Kazakhstan that experience difficulties of weather risks.

Data collection

Data collection occurred on 10 August and 10 October 2022 through field and desk research. In the enterprise Astyk, the field study consisted of analyzing the current accounting situation and identifying the natural conditions of agricultural production. It consisted of seven in-depth interviews (the Deputy General Director, Director of Production, and Agronomists). The in-depth interviews provided information about the algorithm of allocation of natural conditions for agrarian production used by the agricultural enterprise.

In the interviews, the obtained data helped to understand the problems and shortcomings that arise at Astyk in accounting for the natural risks faced by agricultural production and finally to create a model for the optimal fabrication of the farming enterprise under the existing weather risk conditions. The interview proceeded with brief introductions explaining the purpose of the study. The interviewees received open-ended questions outlined by the researcher, aimed at establishing views and opinions on the research problem and the existing experience of the enterprise in assessing weather risks, as well as problems associated with harsh weather conditions. The researchers assured the respondents, their answers would remain unpublished and unreleased to other enterprise employees. The average duration of each interview was 25–30 min. The desk research used corporate reports and manuals provided by the company via e-mails.

Data analysis

During the field study, recordings of the obtained interviews' transcription used the zapisano.org service. Classifying the collected data by uniform topics took place to improve the comparability of information. Data analysis utilized the triangulation method for the validity and reliability of the empirical study results (Kosharnaia and Kosharnyi, 2016). The data analysis employed was thematic analysis, which has the advantage of litheness, including analysis of transcribed conversations, direct quotes, the interviewer's paraphrases of respondents' general ideas, and analysis of enterprise reporting (Braun and Clarke, 2019).

Performing triangulation through researcher triangulation (Denzin, 2009), multiple researchers involved in a project participated in information processing. A discussion for each topic created a venue for all involved researchers to agree on what information in the research process for inclusion in the report. The triangulation method raised the reliability of the interview data, regarding whether they accurately reflected the state of the agricultural enterprise, and improved the quality of the information obtained. The study ensured the recording of all gathered research results is in the report.

The desk study involved the calculation of pairwise correlation coefficients of yield deviations of individual crops from the trend based on past reporting data. Subsequently, all the generated information was summarized in a typical economic-mathematical model in terms of possible results of natural conditions, with the maximum amount of profit taken as the criterion of optimality (Singh *et al*., 2017):

$$\boldsymbol{Z} = \Sigma\, \boldsymbol{c_j}\, \boldsymbol{x_j} - \boldsymbol{x_{jmean}} \rightarrow \max$$

$$j = N$$

A typical model's use, the optimal size of sown areas of crops, the production volume by type of products and sales, costs, profits, and profitability of farming production were determined (Sokolova, 2020). However, the whole totality of the optimal production options for individual weather conditions was impossible to achieve in principle, and it is required to find a solution to best suit all possible situations, i.e., adapted to the entire range of possible weather conditions from the point of maximum average expected effect (Gataullin *et al*., 2015). Although one must note, on average, the optimization does not rule out the risk of getting unexpected results.

In such a situation, choosing the best option for the agricultural enterprise under study was performed by the well-known methods of game theory (game with nature) to decide in the context of partial irresolvability (Krasnovskiy *et al*., 2022). Considering a game situation, one of the parties is a farming enterprise, the object of research, interested in obtaining the highest income, and the other is nature, capable of harming this enterprise as if pursuing the opposite goals. In this case, the second player (nature) acts randomly; however, its possible strategies were obvious.

In the presence of an antagonistic conflict, an agricultural enterprise has three strategies, i.e., optimal production for unfavorable weather conditions (A_1), optimal production for medium weather conditions (A_2), and optimal production for favorable weather conditions (A_3). Nature also has three strategies and variants of natural-climatic conditions, i.e., unfavorable (p_1), medium (p_2), and favorable (p_3), with known probabilities of their occurrence (p_j). Further, based on reporting data according to the typical model with the help of table processors (Sokolova, 2020), calculating the variants, including optimal, had possible combinations of natural and climatic conditions corresponding to the three options for optimal production. Based on these, the team determined the gain of player 1 (agricultural enterprise) a_{ij} (i = 1,2,3; j = 1,2,3), which player 1 receives when choosing the strategy A_i for each state of natural conditions p_j.

In this case, with $\Sigma\, p_j = 1$, j = 1, one can find the value of the mathematical expectation of gain for each strategy A_i:

$$\boldsymbol{M_i} = \Sigma\, \boldsymbol{p_j}\, \boldsymbol{a_{ij}}$$

$$j = 1$$

The optimal strategy was the one for which this value was at its maximum:

$$M^{*} = \max M_i$$

In the study of "game with nature," it was also necessary to determine how much a particular state of weather conditions will affect the results (Krasnovskiy *et al.*, 2022). For this purpose, the study used the risk indicator r_{ij}, defined as the difference between the maximum possible gain β_j under the given weather conditions p_j and gain a_{ij} under the chosen strategy A_i: $r_{ij} = \beta_j - a_{ij}$, where $\beta_j = \max a_{ij}$, i.e., the maximum number in the weather conditions column p_j.

To solve the problem, the team used the mean risk value:

$$r_{imean} = \sum r_{ij} p_j$$

$$j = 1$$

In this case, the optimal strategy was the one with minimal risk:

$$r^{*}_{imean} = \min r_{imean}$$

Financial indicators were in Kazakhstani Tenge at the rate of USD 1 = KZT 461.

RESULTS

The field study results (in-depth interviews) obtained an algorithm for allocating the outcomes of the natural conditions of agriculture production (Table 1). Proceeding from the desk research results (based on data obtained from the agricultural enterprises) helped construct a matrix of pairwise correlation coefficients of deviation of crop yields from the trend (Table 2). The results revealed that the pairwise correlation coefficients of yield deviation of individual crops from the past trends have a positive sign (Table 2). It suggests that extreme weather conditions also have the same effect on crop yield.

Subsequently, based on the developed mathematical model using the 'game theory' and the calculated variants of the possible combinations of natural and climatic conditions, the research team determined the expected values of profits (a_{ij}), together with the probability of their achievement (p_j), presented in the form of a matrix (Table 3). The figures in the diagonal, highlighted in bold, correspond to the optimal variants for the corresponding natural conditions. Formulating first the mathematically expected gain for each version led to choosing the most optimal production structure.

$$M(A_1) = -1{,}683.1 \times 0.4 + 11{,}706.2 \times 0.5 + 22{,}010.7 \times 0.1 = \text{KZT } 73{,}809{,}700 \text{ (USD 160108)};$$

$$M(A_2) = -3{,}308.8 \times 0.4 + 19{,}818.9 \times 0.5 + 35{,}374.7 \times 0.1 = \text{KZT } 12{,}123{,}400 \text{ (USD 26298)};$$

$$M(A_3) = -4{,}482.8 \times 0.4 + 12{,}454.9 \times 0.5 + 40{,}110.5 \times 0.15 = \text{KZT } 8{,}455{,}380 \text{ (USD 18341)}.$$

Then determining the maximum value of this indicator points to the optimal solution:

$$M^{*} = \max M(A_i) = M(A_2) = \text{KZT } 12{,}123{,}400 \text{ (USD 26298)}.$$

Next, according to the developed mathematical model, the team found out all the values of the possible gain (β_j) and created the risk matrix (Table 4).

For each optimal strategy, the mean risk was framed:

$$r_{mean}(A_1) = 0 \times 0.4 + 8{,}103.8 \times 0.5 + 18{,}099.8 \times 0.1 = \text{KZT } 5{,}681{,}880 \text{ (USD 12325)};$$

$$r_{mean}(A_2) = 1{,}625.8 \times 0.4 + 0 \times 0.5 + 4{,}735.8 \times 0.1 = \text{KZT } 1{,}123{,}800 \text{ (USD 2438)};$$

$$r_{mean}(A_3) = 2{,}799.8 \times 0.4 + 7{,}344.0 \times 0.5 + 0 \times 0.1 = \text{KZT } 4{,}791{,}920 \text{ (USD 10395)}.$$

In the long term, the results showed, using the production structure was suitable for medium natural conditions (the second option), giving the farm a profit of KZT 12,123,400

Table 1. Identification of the natural conditions of agricultural production.

Stages	Stage content
I	Analysis of dynamic yield series of a single crop or group of crops that have a high level of yield and
II	Aligning the yield series of a given crop, find the random deviations (positive and negative), and
III	Group the years with the most negative, near-zero, and positive deviations
IV	By the number of deviations that fall into one or another "year group," find the probabilities for each
V	The "year groups" allocated for each crop are the basis for obtaining results for the whole farm. The
VI	Based on the data obtained, yields are predicted for the model by results: negative, average, positive

Table 2. Matrix of pairwise correlation coefficients of deviation of crop yield of the agricultural enterprise in East Kazakhstan region from the trend for 2001–2021.

Culture	Winter wheat	Winter rye	Spring wheat	Millet	Buckwheat	Corn for grain	Sunflower	Corn for silos
Winter wheat	1.000							
Winter rye	0.904	1.000						
Spring wheat	0.676	0.639	1.000					
Millet	0.714	0.742	0.925	1.000				
Buckwheat	0.688	0.681	0.914	0.921	1.000			
Corn for grain	0.288	0.216	0.639	0.498	0.479	1.000		
Sunflower	0.257	0.172	0.416	0.349	0.416	0.368	1.000	
Corn for silos	0.289	0.222	0.369	0.349	0.356	0.411	0.420	1.000

Table 3. Matrix of agricultural production optimization.

Weather conditions	Probability of occurrence	Expected profit margins under different production structure variants (thousands, Kazakhstani Tenge, KZT)		
		A_1	A_2	A_3
Unfavorable	0.4	-1,683.1	-3,308.8	-4,482.8
Medium	0.5	11,706.2	19,818.9	12,474.9
Favorable	0.1	22,010.7	35,374.7	40,110.5

Table 4. Matrix of agricultural production risks.

Weather conditions	Probability of occurrence	Maximum possible profit gain with different variants of the production structure variants (thousands, Kazakhstani Tenge, KZT))		
		A_1	A_2	A_3
Unfavorable	0.4	0	1,625.8	2,799.8
Medium	0.5	8,103.8	0	7,344.0
Favorable	0.1	18,099.8	4,735.8	0

(USD??). In case of the unfavorable influence of environmental factors, when using this production structure variant, the value of losses will be minimal, amounting to KZT 1,123,900 (USD??).

DISCUSSION

The study, conducted at the Astyk enterprise to develop a model of optimal production structure for an agricultural enterprise under weather risks based on game theory, reveals that, at present, implementing this model is a promising direction for farming enterprises. The study team also believes that it is imperative to draw special attention to the results obtained from the presented study.

Previous studies suggested considering weather conditions' impact on crop yields helps increase in productivity in adverse weather years (Kriuchkov, 2016; Saikenova *et al*., 2021; Vesselova *et al*., 2022). In this context, the implemented model will account for weather risks in the long term, providing an opportunity to quickly obtain information about the potential yield for each grown crop in each division of the agricultural enterprise, and ultimately, helping the enterprise management to make managerial decisions concerning the structure of agricultural production.

Moreover, the study also believes that the efficiency of managerial decisions on new projects will improve (Kosharnaia and Kosharnyi, 2016; Dokholyan *et al*., 2022) since the management of an agricultural enterprise will be able to diagnose weather risks at the early stages of decision-making. In addition, the developed model allows forecasting possible profits under different variants of production structure with significantly higher reliability and more accurate calculation of the economic performance of a new project. Thus, the practical application of this model by the management of agrarian enterprises could provide an opportunity to constantly adjust for weather risks to improve the efficiency of agricultural production (Gusev *et al*., 2022), increase crop yields (Matniyazova *et al*., 2022), and consequently, increase the profit of the said enterprise (Kashina *et al*., 2022).

The presented study entails some interesting theoretical and practical conclusions. In particular, the study suggests two theoretical implications, i.e., a) it contributes to the existing literature on developing an optimization model of the production structure for an agricultural enterprise under weather risk conditions. Currently, active research on this problem continues in light of various risks of agro-industrial production; however, further research needs to consider the country-specific features of agribusiness. This study is also one of the first attempts to analyze the accumulated experience in risk modeling, testing it in Kazakhstan's conditions.

This continuing study also leads to the second theoretical contribution, b) according to which the presented model about the influence of weather risks on farming production, substantiates the use of ‘game theory’ for information processing within the agricultural enterprise management system. Proposing the use of game theory since it shows that it can enhance the ability of said enterprises to make reasonable decisions based on available data, increase the profitability of agricultural production, and level out potential weather risks. Therefore, it was possible to work out different weather condition scenarios which, if skillfully performed, will allow for predicting future harvests (Bakucs *et al*., 2020).

As previously mentioned, this study also presents practical conclusions, i.e., a) the researchers believe that the study results should receive attention from both representatives of the agro-industrial sector and government agencies involved in its further development. It confirms what has already resulted in the literature, the need for tools to minimize weather risks considering various analytical methods (Sharko, 2022). Furthermore, b) the study also emphasizes that the multivariate forecast helps optimize management of economic structures and ensure their development under varied natural conditions. Natural and climatic conditions significantly impact the developing production structures in agricultural enterprises, with nature acting as an unconscious participant in the game with the agriculture enterprise.

Therefore, the optimal production model of a farming enterprise under weather risk conditions based on 'game theory' can also benefit other crises of uncertainty.

CONCLUSIONS

The latest study answered the following research questions: a) What optimal production structure model should be applied, and how to implement it under different natural and climatic conditions? and b) What result can be achieved by using the model to enhance the profit under different variants of the production structure in agricultural enterprises? Previous studies demonstrate that the influence of natural factors necessitates the development of various optimal variants of production models in farms, considering the forecast of yield for the next year, based on the degree of favorability of weather conditions, i.e., unfavorable conditions, medium, and favorable conditions. The model proposed in the study is a mathematical product that provides information for maximizing the profit and predicts the maximum possible profit gain under different variants of the production structure depending on the existing weather risk conditions. Applying this model enables agricultural enterprise management to build business strategies based on profit maximization. The said model also provides a better justification of the managerial decision-making process, which is necessary for optimal planning and finding reserves to improve farm enterprises' production efficiency and marketing activities during the crisis and dynamic changes in the external environment. Business costs were also reduced due to better consideration of the natural conditions of agricultural production, reducing the risks of business development, especially found significant for the agro-food industry, where the price of an error is high, and its correction requires time and financial expenses. Despite the theoretical and practical contribution, this study is partly limited to analyzing one particular agricultural enterprise and therefore does not allow for generalizations. Features of application of the model of production structure optimization of an agriculture enterprise under conditions of weather risk require further study, considering a possible increase in the sowing areas available to the said enterprise. For this reason, there is a need for parallel research on this problem. The general results of several studies, including other enterprises in other regions of Kazakhstan, will make it possible to create a generalized model of optimal production structure for agricultural enterprises under conditions of weather risk, as well as to obtain results for the validation and assessment of the model proposed in this study.

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