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Neural Network System of Grain (Wheat) Yield Forecasting in Risky Agricultural Conditions on the Example of the North Kazakhstan Region

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ABSTRACT

The presented paper is relevant as forecasting of crop yields is one of the main tasks of agricultural planning in any state. The purpose of the study is to assess the practical prospects of using a neural network system for forecasting crop yields in risky agricultural conditions at agricultural enterprises of the Republic of Kazakhstan. The basis of the methodological approach is a combination of quantitative and qualitative methods of investigating the prospects for the development and practical implementation of a neural network system for forecasting grain yield in the activities of agricultural enterprises of the North Kazakhstan region, using the MATLAB software suite that considers a number of key factors from the standpoint of the effectiveness of the described processes. The findings logically reflect the practical value of using a neural network system for forecasting grain yields in risky agricultural conditions and identifying the main factors influencing the accuracy of forecasting grain yields.

1. INTRODUCTION

The use of artificial neural network construction technology to create qualitative forecasts of grain yield is commonly an effective method of solving the issue of crop yields. This method requires a preliminary selection of representative samples of long-term yield indicators, their predictive processing with a qualitative substantiation of the architecture and macroscopic parameters of the projected artificial neural network, specific algorithms for its learning that fully comply with the problem under study [1]. Artificial neural networks for solving forecasting tasks in automated mode fully reproduce the structure and internal patterns of time series of the initial parameters of the entire system. Therewith, it is necessary that the developers of neural network modelling programmes have the necessary information about the state of the structure and specific features of the created time series to substantiate the architecture and macroparameters of the emerging artificial neural network.

Numerous researchers suggest that mathematical modelling performed based on the use of artificial neural networks qualitatively solves numerous tasks, such as technical vision, the ability to recognise images, diagnostics of the current technical condition and forecasts of its subsequent development, including the forecast of dynamic changes in time series parameters, which is essential for agricultural enterprises, since it allows predicting crop yields [2]. The quality and objectivity of forecasting are essential from the standpoint of ensuring the effectiveness of agricultural enterprises in terms of sequencing the planting and harvesting of grain crops in the short and long term [3]. The relative complexity and non-stationarity of the structure of the simulated time series of crop yields necessitate periodic analysis of all possible configurations of the designed artificial neural networks, the quality and final effectiveness of which is ensured by the use of modern software systems that consider the variability of architectures in an automated mode [4].

The task of creating forecasts of different time series levels is one of the special cases of the general regression theory. The existing algorithms for using a family of conditionally generated automatic structures of artificial neural networks to predict time series of yield levels, different in the number and nature of intermediate layers, suggest a preliminary, predictive analysis of time series, performed with the substantiation of the principles of constructing the structure of networks and the automated construction of a complex of artificial neural networks, their adjustment using special samples and a preliminary assessment of the error and quality of forecasting on test samples [5]. Further, it becomes possible to implement the entire forecasting complex for different situations and depths of time horizons. The use of time series of long-term yield levels of grain crops (wheat), the main patterns, the changes of which can be modelled using artificial neural networks, implies the mandatory use of software that allows comprehensively solving all the main tasks [6]. Neural network modelling involves the long-term yield series of grain crops (wheat) as input data using MATLAB (Matrix Laboratory) software so that all the necessary calculations are performed in compliance with the specified parameters of accuracy and timeliness of all operations.

However, the problem of using a neural network system to predict the yield of agricultural crops in risky farming conditions still remains unsolved. This study is an attempt to fill this gap. That is why, the main purpose of this study is to assess the practical prospects regarding the use of a neural network system for forecasting crop yields in risky agricultural conditions on land owned by agricultural enterprises of the North Kazakhstan region. To solve all the tasks of this study, the MATLAB software suite was used, which allows building a neural network system for forecasting grain (wheat) yields in risky agricultural conditions at a qualitatively high technical level. This study was developed in six sections: the introduction shows the description of the artificial neural network construction technology to create qualitative forecasts of grain yield in the global context; the literature review section shows description of the scholarly sources on a chosen topic; the materials and methods section describes the quantitative and qualitative research methods and the disclosed stages of the research; the results section contains the main data; discussion section was stipulated based in the main results; and finally, the conclusions summarize the main results of the study.

2. LITERATURE REVIEW

Information about the prospects for increasing crop yields for a certain time is one of the main factors in planning agricultural production, forecasting and managing agricultural activity [7, 8]. High-quality information support to effectively solve this problem involves the collection and analysis of statistical information regarding the course of the main agricultural processes and the use of specialised databases that allow storing and processing a large amount of information on the prospects for modelling certain levels of productivity in specific agricultural enterprises [9]. Timely resolution of issues related to ensuring an adequate level of food security requires the creation of new and improvement of existing methods for forecasting an increase in the yield of staple crops at specific enterprises of the agricultural sector. The preliminary development of representative samples of yield levels for specific periods, combined with preliminary processing, ensure high forecasting accuracy, and allow formulating algorithms for its learning that fully comply with the problem under study. All the above determines the scope of requirements for the developer of neural network forecasting systems, considering the main aspects of understanding the structure of such networks and the specific features of modulated time series to describe the macroscopic parameters of the system being created [10]. Specialised agrarian-oriented databases allow clearly systematising information on the main aspects of grain yield forecasting in risky agricultural conditions, provide opportunities for building neural network forecasting systems that consider the available information regarding the state of sown wheat lands. In this regard, the development of the ontology and relational structure of databases contributes to obtaining a clear picture of the prospects for expanding sown areas and increasing the volume of harvested crops, in the context of activities in fuzzy agriculture [11].

Mathematical modelling systems allow performing a qualitative description of forecasting crop yields in any geographical region, considering its characteristic features conditioned by the geological structure of soils and the seasonality of sowing fields and harvesting grain crops. In addition, the creation of mathematical models describing the current state of agriculture in a particular geographical region allows clearly forecasting the prospects for the development of this region, considering the expected forecasts of grain yields and prospects for increasing yields [12]. In any case, mathematical modelling in general and the one performed using neural network systems for forecasting grain (wheat) yields in conditions of risky agriculture allow effectively and competently solving the issues of increasing crop yields in a particular geographical region, considering its characteristic features. In modern economic conditions, the issues of ensuring food security of a single state require the development and practical implementation of a set of measures aimed at optimising the quality control over food production and its safety in accordance with the requirements for quality. From the standpoint of forecasting crop yields, this means monitoring the preservation of a high level of grain yield and ensuring accuracy in forecasts regarding the expected harvest volumes. Mathematical modelling methods based on neural network systems provide high accuracy of forecasts and the ability to collect and analyse large amounts of information about the arable land cultivation, climatic and geological conditions of the area, and a number of other auxiliary factors impact the accuracy of analytical forecasts [13].

An analysis of crop yields at specified time intervals allows making an approximate statistical picture of grain yields for specific years and forecasting the changes in this indicator in accordance with the available statistical data on the climatic and geological conditions of a particular area and the characteristics of sowing and harvesting grain crops in the region. These indicators determine the prospects for performing agricultural activities in a given geographical region related to the planting of grain crops and their harvesting, and, in the context of using the methods of mathematical modelling of the harvested crop, they allow roughly calculating the prospects for increasing or decreasing yields when key conditions change [14]. Methods of forecasting crop yields are applied in conducting modern economic research using computer technology. It is conditioned by the availability of such algorithms and the simplicity of implementing these methods on a modern personal computer. In this context, the main problems lie in choosing the appropriate subject area of a particular method, in the selection of the necessary values of numerical parameters that determine the operating principle of a particular technique [15]. In a number of geographical regions, forecasting of crop yields is associated with the need to conduct agricultural activities in an arid climate, with a small amount of average annual precipitation, which causes difficulties in forecasting the expected harvest, due to the increased influence of endogenous climatic, natural factors [16]. In general, the situation is difficult to model, which necessitates the practical application of methods of fractal analysis, cellular automation, visualisation of phase portraits for making forecasts, and requires the use of complex software, due to the complexity of forecasting and the lack of guarantees in obtaining particularly accurate results.

3. MATERIALS AND METHODS

The basis of the methodological approach is a combination of quantitative and qualitative methods of investigating the prospects for the development and practical implementation of a neural network system for forecasting grain yield in the activities of agricultural enterprises of the North Kazakhstan region, using the MATLAB software suite that considers a number of key factors from the standpoint of the effectiveness of the described processes. The neural network system created based on this software suite considers weather factors, topographic, hydrological, and agro-chemical factors, which together ensures high accuracy of wheat yield forecasts in risky agricultural conditions, typical for the North Kazakhstan region. The theoretical basis of this study is the available publications of a number of authors on the application of forecasting technology using neural network systems to obtain reliable information about the expected yield of grain crops in a particular agricultural region.

This study was conducted in three stages. At the first stage, a theoretical basis was created for subsequent investigation of issues of the development of a neural network system for forecasting grain (wheat) yields in risky agricultural conditions on the example of the North Kazakhstan region. Moreover, at this stage, a quantitative analysis of the processes of building neural network systems for forecasting grain (wheat) yields in risky conditions is performed to obtain reliable information about their construction and principles of use, which is of key importance in the context of the tasks set in this study.

At the second stage, a qualitative analysis of the prospects for the development and practical implementation of a neural network system for forecasting grain yield in agricultural enterprises of the North Kazakhstan region, using the MATLAB software suite, is performed. The study provides statistical information accompanied by graphic illustrations of the main aspects of the operation of a neural network system for forecasting grain yields in risky conditions. The study was conducted on the example of the North Kazakhstan region, considering the risky conditions prevailing in it. In addition, this stage included an analytical comparison of the results obtained with the results and conclusions of other researchers relevant to the issues under study. This contributes to the refinement of the results obtained and improves the quality of research. At the final stage, based on the results obtained, the conclusions are formulated, summarising the entire complex of research activities. The data obtained are of practical value from the standpoint of the prospects for building high-quality neural network systems for forecasting wheat yield in risky agriculture.

4. RESULTS

The following results were obtained in the course of this study. The basis of the economic potential of the North Kazakhstan region of the Republic of Kazakhstan is agriculture, which is the most profitable branch of the country's economy. The total gross output of the agricultural sector is 16% of this indicator nationwide, while about 25% of Kazakhstan's grain crops are grown annually in the region. Since 2011, about a third of all investment inflows into the region's economy has been directed to the development of agriculture, as the most priority area. The North Kazakhstan region has the largest agrarian-climatic potential of all regions of the Republic of Kazakhstan. Agricultural land accounts for 73% of the total area of the North Kazakhstan region. Data on the soil composition of agricultural areas of the region are presented in Figure 1.

According to the data presented in Figure 1, chernozems account for about 68% of the entire territory of the North Kazakhstan region allocated for agricultural activities. 22% of soils are alumina, 8% are silica. However, all other soils combined are allocated no more than 2% of the area of agricultural land. The creation of a high-quality neural network system for forecasting grain (wheat) yields in risky agricultural conditions on the example of the North Kazakhstan region assumes mandatory consideration of the following factors:

1. The quality of the soils allocated for planting grain crops and, particularly, wheat.
2. Cyclicity of climatic changes (precipitation, changes in the average annual air temperature).
3. The influence of agricultural pests on grain cultivation.
4. Topographic conditions of the area.

The practical tasks of creating a neural network system for forecasting grain yields involve the sequential construction of an artificial neural network in the MATLAB software suite. Figure 2 presents, in the structural relationship, the main factors that should be considered when building artificial neural networks using the specified software.

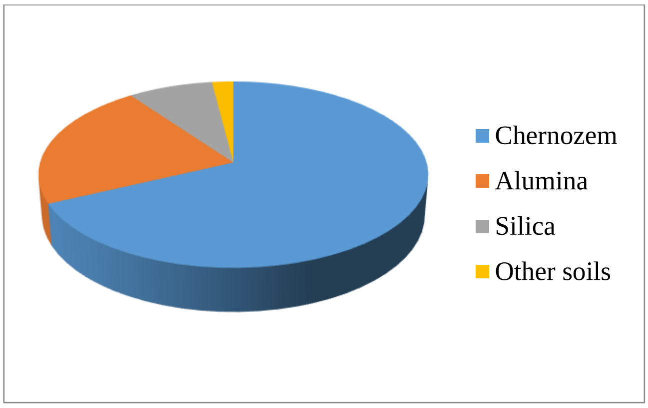

Figure 1. Soil composition of agricultural areas of the North Kazakhstan region

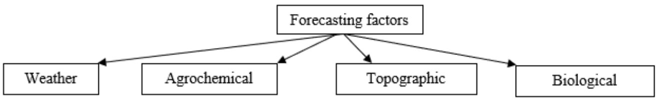

Figure 2. The main factors to consider when building artificial neural networks using the MATLAB software suite

Weather factors include precipitation for five periods: May, June, the beginning of July, the end of July, and August; indicators of average air temperature for the period May-August. The given time period was chosen because these months are the period of wheat growth. Agrochemical factors include control over the content of humus, nitrogen, phosphates in the soil and the pH (*pondus Hydrogenii*) level. Topographic factors assume consideration of the main hydrological indices – the humidity index, elevation changes, and the slope of the terrain. Biological factors suggest the presence of cereal pests and diseases that can damage the growth of cereal crops and their general condition. In this regard, the agrochemical analysis of the state of the chernozems of the North Kazakhstan region is of great interest, according to the main indicators that are crucial in the context of forecasting crop (wheat) yields. The analysis data is presented in Table 1.

According to Table 1, 4 types of chernozem were studied in the territory of the North Kazakhstan region (heavy loamy, sandy loamy, alkaline medium loamy, carbonate heavy loamy). The largest number of fertilizers was found in carbonate heavy loamy, and the smallest in sandy loam.

Table 1. Agrochemical characteristics of the composition of chernozems of the North Kazakhstan region

Type of chernozem	Humus	N	P_2O_5	K_2O
Heavy loamy	296	15.8	11.5	137
Sandy loamy	108	5.6	4.2	64
Alkaline medium loamy	217	14.2	10.7	112.8
Carbonate heavy loamy	315	18.6	13.1	156

To date, the state of the chernozems of the North Kazakhstan region is determined by the system of use of all agricultural land. Therewith, the processes of erosion, wind and water, provoked changes in the state of soils in the region, which contributed to the assignment of the North Kazakhstan region as a zone of risky agriculture. A neural network system for forecasting grain (wheat) yields in risky agricultural conditions, created based on the MATLAB software suite, ensures that these natural factors are considered when making forecasts in specific time series [7]. The sequence of creating a neural network system for forecasting grain (wheat) yields in risky agricultural conditions on the example of the North Kazakhstan region suggests the following stages:

1. A consistent analysis of all factors that have an impact on the change in crop (wheat) yields, considering weather conditions, soil composition, land forms, and biological factors specific to the North Kazakhstan region.
2. Selection of a software mathematical algorithm for making forecasts using various time series.
3. Visualisation of the obtained results in graphical interpretation.

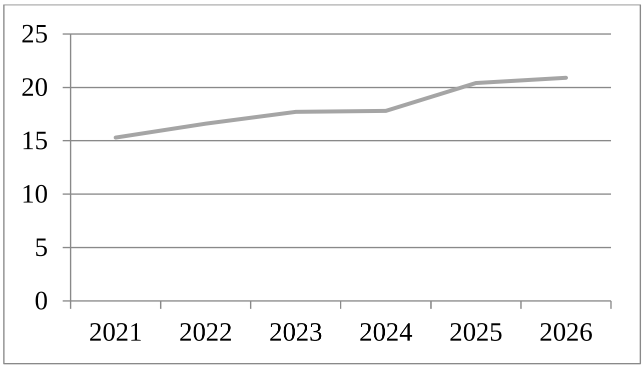

Figure 3. The forecast of crop (wheat) yields by year for the period of 2021-2026, performed using the MATLAB software suite

Risky agriculture on the example of the North Kazakhstan region assumes an increased dependence on changes in climatic conditions, which is characteristic of the geographical region under study, located in a zone of heavy continental climate. The maximum temperature drop during the year can reach 60-75℃, which determines the presence of certain problems associated with the risk for agricultural activities. With an average annual precipitation of 350 mm, most of it falls in the warm season. As of 01.09.2021, in the North Kazakhstan region of the Republic of Kazakhstan, the total harvest of grain crops (wheat) was expected at the level of 15.5 million tonnes. Upon using mathematical modelling methods involving the construction of artificial neural networks and the implementation of grain yield forecasts, it is possible to obtain an approximate forecast for almost any period. Figure 3 presents the predicted trends in grain yields in the North Kazakhstan region for the period of 2021-2026.

As follows from the data presented in Figure 3, in the period under study, gradual growth in crop yields is expected in the region under study, which is actively promoted by activities aimed at increasing soil fertility and protecting the soil cover from pollution and early degradation. Also of great importance is the trend that has emerged in recent years towards a decrease in the humus content of the upper soil layers and the gradual elimination of biogenes. The neural network system of grain yield forecasting is highly accurate, provided that data are entered in a timely and accurate manner regarding the main factors that determine the area of the development of agriculture in the geographical region under study and the general structure of agricultural activities [8]. To calculate the yield parameters for a certain period by using a polynomial of the third degree, an approximation of the time series is used according to the formula:

$$Y = 0.0002\ t^3 + 0.0216\ t^2 + 0.767\ t + 3.0955 \qquad (1)$$

where: Y is the parameter of the annual yield in c/ha; t is the year of the calculation.

In the case of unsatisfactory approximation indicators with respect to the convergence of time series, it is necessary to make changes to the calculation structure with the introduction of additional coefficients. The MATLAB software suite provides for such an opportunity, which determines its high effectiveness in solving the issues of practical use of the neural network approach to forecasting time series of grain yields on the example of the North Kazakhstan region. The neural network system for forecasting grain (wheat) yields in risky agricultural conditions on the example of the North Kazakhstan region has shown high effectiveness, which determines the feasibility of its practical application in the future for making predictive analyses of grain yields for various time intervals and under other initial conditions characteristic of different geographical regions. The effectiveness of the system depends on the timeliness of the input of calculation information and the choice of a mathematical prediction algorithm, individual in each case. The MATLAB software suite allows successfully fulfilling this task with any number of initial parameters and any initial conditions, which determines the expediency of its subsequent use to solve problems of this kind.

5. DISCUSSION

Today, in the current economic situation in the world and due to the high intensity of agricultural production in most economically developed countries, the issues of ensuring economic and food security of the country's regions are of particular importance. In this context, increased attention should be paid to the development and practical implementation of effective mathematical models for forecasting crop yields, which is essential for providing agricultural products to entire geographical regions [17]. Therefore, the issues of forecasting the activities of an agricultural enterprise from a distant time perspective, considering the characteristic features of a particular geographical region, should be given increased attention during agricultural planning of a particular economic region and the entire state [18]. The levels of provision of the population with agricultural products and the standard of living in the state depend on the quality of such forecasts. The grain production sector is of great importance in the economic security of any region and state. Qualitative forecasting of the expected level of grain yield in risky agriculture, which can be characterised by high variability and the impossibility of practical application of a number of multifactor models in forecasting the level of grain yield. All these factors combined necessitate the application of nonlinear dynamics techniques to increase the adequacy of actual models and their compliance with the realities of agricultural production in a particular geographical region.

The use of simulation modelling allows analysing various scenarios of the current market situation, in relation to the agricultural products market, the priority role is occupied by mathematical models of neural network forecasting of processes affecting crop and, particularly, wheat yields, in the activities of agricultural enterprises of a specific geographical region [19]. To date, neural networks are actively used in various economic spheres of many countries when the need arises to minimise labour costs and improve the quality of decision-making concerning the effectiveness of managing the forecast of the yield of staple crops. A neural network system for forecasting crop yields in risky agricultural conditions allows obtaining relatively accurate information about the expected grain harvest if optimal and precise data are provided on the current state of the parameters affecting the yield in a given time perspective [20]. The increased attention to mathematical modelling methods, which are based on neural networks, is conditioned by the high results demonstrated in the practical application of such a technique in many economic areas, thus making their use in forecasting the expected level of grain yield logically substantiated. These methods of mathematical modelling allow for sequential modelling of a number of nonlinear processes that take place in various areas of agricultural production [21].

Modelling of economic processes by mathematical methods to acquire reliable forecasts of crop yield indicators should be considered a prerequisite for qualitative planning of agricultural production with substantiation of its main indicators, both technological and economic, obtained due to the modernisation of various spheres of agricultural production and planned investment decisions. Therewith, the influence of various groups of factors (natural, climatic, bio- and technical-technological, organisational-economic) on the effectiveness and consistency of the processes in risky agricultural conditions, as a result, leads to an error exceeding 15-20%. In conditions of risky agriculture, the conventional methods of economic modelling using the capabilities of mathematical apparatus, such as the construction of econometric structural equations and multifactor modelling do not always give optimal results, which determines the feasibility of practical application of a forecasting system using neural networks for the qualitative solution of this kind of problems. To date, neural networks created using the mathematical apparatus of modern computer systems can be considered one of the most optimal methods for the solution of the problems related to forecasting crop yields in risky agriculture. Therewith, a modern operator of a neural network modelling programme must possess an optimal set of heuristic concepts regarding the structure and features of the simulated data, be able to qualitatively substantiate the used variants of the architecture of artificial neural networks, and have skills in interpreting actual results, while the average level of preliminary preparation for the successful implementation of such methods is much narrower than when using classical methods of mathematical statistics.

6. CONCLUSIONS

The following conclusions are based on the findings regarding the prospects for building a neural network system for forecasting grain (wheat) yields in risky agricultural conditions of the North Kazakhstan region. The system for forecasting crop (wheat) yields, created based on artificial neural networks using mathematical modelling methods with the MATLAB software suite, showed high effectiveness in the qualitative introduction of statistical information on the main factors that have a direct impact on crop yields in the conditions of risky agriculture, typical for the North Kazakhstan region of the Republic of Kazakhstan. In general, this software suite enables effective forecasting with almost any source data, provided that the algorithm for compiling a mathematical model is chosen correctly. In addition, an important aspect is the timely and qualitative introduction of information about the changes in natural conditions in a particular geographical region since risky agriculture implies a high probability of frequent changes in natural and weather conditions during the period under study.

Mathematical modelling of a neural network system for forecasting wheat yield should use a multi-year retrospective database of grain harvest in the region under study, which implies a consistent substantiation of the multidirectional structure of vector indicators, including data on weather and climatic conditions, preferential soil types, dynamic series of temperatures and precipitation, which are combined by a number of key indicators. Subsequently, the precise identification of the main patterns in yield indicators for specific years contributes to obtaining objective information about the prospects for planting grain crops in risky agriculture regions and creates the necessary conditions to improve the quality of forecasts of expected yields when a number of basic initial conditions change. MATLAB has shown high effectiveness in forecasting crop yields in a specific geographical region in conditions of risky agriculture, with the compilation of a neural network forecasting system based on mathematical modelling methods of this software suite.

The limitation of the study is that the neural network system for forecasting wheat yield was studied exclusively on the example of the North Kazakhstan region. Prospects for future research are to identify the main regularities in the yield indicators of other grain crops in the territory of the Republic of Kazakhstan and in a comparative aspect with other countries.

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