Estimation obtaining instrumental means based on nonlinear dynamics methods

A M Kumratova¹

¹ Kuban State Agrarian University, 30, Kalinin str., Krasnodar, 350089, Russia
E-mail: kumratova.a@edu.kubsau.ru

Abstract. This article presents the results of the adapted complex methodology operation for the time series dynamics estimating, its features are in the joint use of both classical and new “nonlinear” statistics. The methods proposed and tested by the author are presented in the form of a pre-estimating and estimating model for assessing the grain yields time series trend stability in the Volgograd region (1930–2019) and obtaining a forecasting. The following methods of nonlinear dynamics were tested: the Hurst normalized range method, phase-plane analysis, and a linear cellular automaton. The results of analysis and forecasting on real yield data are presented in the form of the agro-economic system modeling lower level values, which in turn are input data for models of the upper level - the agro-economic system management level.

1. Introduction
One of the priority areas in the development of agro-industrial production and the fishery complex is to increase the competitiveness of Russian agricultural products in the domestic and foreign markets. When expecting different forecasting for harvests, different technologies of agricultural crops cultivation and growing are applied. In practice, such situations often arise: without a high-quality forecasting, the agro-industrial complex uses intensive technologies to obtain high yields, which are economically more costly (the application of expensive mineral fertilizers and other means of chemicalization) and thereby reduce the quality of soil fertility (to hydroponics), which is categorically unacceptable in the Chernozemje Region. High-quality products are competitive in the world market. In case of the growing such products cost decrease, Russian enterprises will have the opportunity to compete with world prices for agricultural products and thereby oust foreign counterparts from the domestic market. Receiving less costly high-quality products will allow enterprises to monitor prices on the world market for agricultural products and sell surplus products.

The feasibility of the project is consistent:
– with the Federal Scientific and Technical Program for the Development of Agriculture for 2017 - 2025;
– complies with the State Program for the Development of Agriculture and Regulation of Agricultural Products, Raw Materials and Food Markets (https://mcx.gov.ru)

This paper proposes the concept of reducing agroeconomic risk due to the possibility of a more accurate forecast in the next year’s yields, as well as a mathematical model and method for predicting the agricultural crop expected yield in the coming year, considered in the process of solving land use problems for a particular farm, district, region, etc.
Using the analysis, generalized conclusions and the results description, the researcher forms "structured" information about the time series (TS). Namely this structured knowledge allows the analyst to develop reasonable predictive analysis methods [1, 5]. The article uses the values of the grain crops yield in the Volgograd region for the period 1930–2019 as a calculation base. (https://volgastat.gks.ru).

Risk-extreme [5] climatic conditions and the fact that the Volgograd region is one of the five leaders in Russia in the collection of grain crops also determine the relevance of the presented study.

2. Materials and methods
The author developed a software product in the solution of the operation algorithms calculations automation: linear cellular automaton, phase-plane analysis, R/S-analysis, as well as the calculation of statistical indicators with the empirical distribution function construction. One such tool is the “Nonlinear Dynamics Methods” application implemented in the Python 3.7.6 programming language. The simplicity and the ability to load different libraries for performing calculations and graphical representation of data is the rationale for choosing this language. In particular, in the development of the software, the Matplotlib libraries were used, which is designed to visualize the initial data in the form of diagrams and graphs, and NumPy, one of the most popular machine learning libraries in Python for performing several operations on tensors. The program interface is quite simple - the user needs to select the source file in the .xls format with the input data in the form of a time series through the menu.

Distinctive features of the developed product are:
- the possibility of visual analysis, and then the researcher is presented with the opportunity to “play” with the number of “colors” and, accordingly, determine the number of the linear cellular automaton (LCA) toolkit broken lines points. The selection of the number of colors for LCA coloring is a “self-learning” procedure [1], which often arises in practice. The multivariance of this forecasting method makes it possible, at the output, to obtain that forecast model (variant of the time series coloring), which will have the smallest forecast error;
- to identify the time series qualitative characteristics (results of phase-plane analysis, R/S-analysis), which in turn represent quantitative and qualitative pre-forecasting information.

Separately, it should be noted that the study of grain yields volatile time series (the coefficient of variation is 57.7% > 30%) on the basis of the linear cellular automaton provides the decision maker with the forecast information for planning and managing agro-economic processes, including the goals of attracting investment in the development of the region agricultural complex.

3. Approbation of the tool for the grain yields time series
The author's tool allows to carry out a time series comprehensive analysis. Let us present an overview of the consistently obtained results based on the used methods and techniques.

![Figure 1](image1.png)  
**Figure 1.** The result of the "Input data" and "Statistical indicators" tabs operation for the grain crops yield time series in the Volgograd region for the period 1930–2019.
First, the calculation and analysis of grain yields time series statistical indicators, namely the values of the variation coefficient $> 33\%$. The latter means that the degree of data scattering around the value of the mathematical expectation is significant. Figures 1a, 1b show the histogram of the grain yields time series, the empirical distribution function of the studied time series, as well as the calculated statistical indicators.

The visualization of Figure 1a allows to conclude that there is a significant increase in yield. In the reporting of the agribusiness expert and analytical center "AB-Center" it is said that due to the introduction of advanced technologies in the growing and harvesting process, there is a tangible increase in the yield of most types of crops. As the result, the volume of crops harvests is nowadays on average more than 2 times higher than in the early 2000s.

Secondly, the availability, the assessment of the noise index and the trend stability property identification are determined for the time series under study. The author uses the indicator of the series values normalized range for the finite period of time, proposed by the hydrologist Hirst. The data standardization procedure is described in detail in [2]. Also, it is proposed to classify the time series trend stability relative to the indicator entered by it.

Third, pre-predictive information by using knowledge about the lengths of time series quasi-cycles based on the phase-plane analysis [3] (in accordance with Figure 2c) was obtained. Each cycle (cyclic formation in accordance with Figure 2b) with its topological, metric and functional characteristics such as: start point, end point, cyclic formation radius and diameter, features of phase quasi-cycles, inertia, act as an elementary macro, the so-called “brick” of natural and economic universe, which is important for a new method of constructing conjunctures [4] and a graphical forecasting algorithm by selecting, moving and combining cyclic constructs (in accordance with Figure 2b). The nature of the yields time series behavior, the calculated indicators of the R/S analysis (Hurst exponent) and the phase-plane analysis allow to conclude that it is possible to use artificial intelligence methods (the theory of cellular automata) to predict the dynamics of these time series.

For the convenience of the analyst's work, in the tool, the time series phase portrait is divided into three periods: beginning, middle and end ones, colored respectively in colors: red, yellow, green. The visualization of the phase trajectory (in accordance with Figure 2b) confirms the upward trend in yield values in accordance with Figure 1a.

One of the pre-predictive characteristics is the quasi-cycles lengths highest frequency, which characterizes the "const" property of the process under study. Grain crops time series has the highest value of this indicator, which means the presence of frequently encountered 4-year quasi-cycles. In
In this context, it can be talked about the presence of the process trend stability property under study. For the investigated time series, the highest frequency is 5, which on average will allow to make a medium-term forecast for 4 years. The value of the Hurst exponent belongs to the "gray" noise zone. The latter means that the data series do not follow random walks and have sufficient trend stability [2].

Fourth, the forecast in the form of a linguistic variable and a numerical value of the forecast were obtained. As the toolkit for the agro-economic indicators time series analysis and forecasting that do not satisfy the conditions of econometric analysis, the work uses a linear cellular automaton model - a model of discrete dynamic systems with distributed control.

**Figure 3.** The "Linear cellular automaton" tab operation result for the grain yields time series in the Volgograd region for the period 1930–2019.

| Pre-forecasting analysis | Phase-plane analysis | Forecasting |
|--------------------------|----------------------|-------------|
| R/S-analysis             |                      | Linear cellular automaton |
| Breakdown point          |                      |              |
| Regression equation      |                      |              |
| Hurst exponent           |                      |              |
| Length of quasi-cycles with the highest frequency | | |
| Frequency of quasi-cycles length | | |
| Forecasting (dt/ha)     |                      |              |
| Memory depth             |                      |              |
| Forecast error (%)       |                      |              |
| Mean Absolute Error (MAE)(%) |              |

To study the grain crops yield time series, a linear cellular automaton was used, the classical coloring in the form of trit was chosen: H - low level of the yield value, C - medium level, B – high level (in accordance with Figure 3a).

**Table 1.** The results of the calculated indicators obtained on the basis of nonlinear dynamics methods for the grain yield time series of in the Volgograd region.

| Grain yields time series | Breakdown point | Regression equation | Hurst exponent | Length of quasi-cycles with the highest frequency | Frequency of quasi-cycles length | Forecasting (dt/ha) | Memory depth | Forecast error (%) | Mean Absolute Error (MAE)(%) |
|--------------------------|-----------------|---------------------|----------------|-------------------------------------------------|--------------------------------|---------------------|--------------|-------------------|-----------------------------|
|                         | 5               | 0.66 · x − 0.44    | 0.66           | 4                                               | 5                              | 22.2                | 6            | 22.6              | 2.214                       |

4. **Conclusion**
According to preliminary data, the grain crops yield value in the Volgograd region for 2020 was 25.7 dt/ha. The forecast error in absolute terms is 3.5 dt/ha.

The aim of the work is to present the developed "Methods of Nonlinear Dynamics" software product approbation results which builds a predictive model based on a linear cellular automaton and issues a forecast in numerical form and in the form of a linguistic variable: H, C, V in most cases it does not exceed 15-20%.

The software product was also tested on the main agricultural crops yields values in the Krasnodar Territory and can be used to obtain a forecast, including spring frosts, which directly affect the economic indicators of the crop production sector.

5. **Acknowledgments**
The reported study was funded by RFBR according to the research project № 19-010-00134 A.

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