Influence of agrometeorological factors on wheat yields

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Abstract. The article examines the influence of agrometeorological factors on the yield of spring durum wheat in the Orenburg region. Among the agrometeorological factors, eight indicators were chosen empirically, the linear and nonlinear correlation was estimated, including by constructing single-factor regression models. Analysis of multicollinearity by the method of principal components made it possible to select four factors out of eight factors, and the result of analysis of the preliminary model of multiple linear regression using t-statistics made it possible to exclude one more factor from consideration. The resulting model has a high enough accuracy and significance, and can be used in forecasting yields.

1. Introduction

One of the main agricultural crops of Russia is spring durum wheat, grown, including in the Orenburg region. This agricultural crop has sufficiently high requirements for growing conditions. The main factors limiting the production of durum wheat are the high temperature regime and the lack of moisture in the soil.

The climate of the Orenburg region is sharply continental, which is explained by its considerable distance from the seas and proximity to the semi-deserts of Kazakhstan. The sharply continental climate is characterized by large fluctuations in the average daily and monthly temperatures, small amounts of precipitation and small clouds. These factors significantly affect yields in regions with similar climate.

The increase in the yield of agricultural crops is the main task facing the agrarian science nowadays. With increasing growth of the population, mankind is forced to increase agricultural production, the basis of which is the grain economy.

Wheat is one of the most valuable and high-yield cereal crops. Grain is rich in gluten proteins and other valuable substances, so it is widely used for food purposes, especially in bakery and confectionery industry, as well as for the production of pasta, cereals, vermicelli and other products. To improve the stability of hard wheat production, it is necessary to take into account the weather peculiarities of a given territory, to study its effect on yield, to identify the most optimal parameters of weather factors that contribute to the formation of high yields of a given crop.

The current system of obtaining data on crop yields is currently not sufficiently operational and is based on various subjective information. In this regard, it is very important to develop approaches to forecasting that would allow us to obtain estimates with sufficiently formalized methods.

A.N. Derevyanko developed a method for forecasting the yield and quality of winter wheat in the regions of the chernozem zone of the European part of the country [1]. To assess the climatic conditions...
by the degree of their influence on the quality of wheat, the author examined about 70 agrometeorological factors. The agroclimatic zoning of the European part of the country was developed with the aim of identifying regions favorable for the cultivation of high-quality wheat.

Sufficiently strong dependence of the yield of grain on the average daily air temperature was shown by the studies of R.R. Ismagilov and A.A. Nigmatyanov in the conditions of the Republic of Bashkortostan [2].

Research of Filho S.R. are aimed at identifying the optimal period of maturation and the time of collection of grain, depending on climatic and weather factors [3].

Mrabet, R. and others studied the quality and yield indicators in Morocco, the influence of various agrotechnologies on these indicators was revealed [4].

Munyanyi W. and others investigated the most promising wheat lines in some areas of Iran, in order to identify the most suitable varieties with the highest quality [5].

A number of studies are devoted to the analysis and forecasting of yields, but there is not enough information about the influence of sharply continental climate on wheat yield. In this connection, the goal of this work was to reveal the influence of agrometeorological factors on the yield of spring durum wheat in sharply continental climate.

2. Materials and methods
The study is based on experimental data on yields for the period 1967-2016, obtained in the stationary experience of the Orenburg region, and agrometeorological data of the Orenburg Regional Center for Hydrometeorology and Environmental Monitoring for the same period. The data was collected for the period May-September of each year.

The experiments were carried out on chernozem: southern, carbonate, medium-heavy, heavy loam with humus content in the 0-30 cm layer 3.5-4.2%, total nitrogen 0.22-0.32%, total phosphorus 1.6-2.7 mg and exchange potassium 35-42 mg per 100 g of dry soil. PH of the soil solution is 7.1-8.2, the sum of the absorbed bases is not more than 40.2 mg/eq. per 100 g of dry soil.

Observations were carried out according to the method of state variety testing of agricultural crops. As agrometeorological factors, the following were selected:
- average air temperature (x1);
- minimum air temperature (x2);
- maximum air temperature (x3);
- amount of precipitation (x4);
- average air humidity (x5);
- minimum air humidity (x6);
- moisture deficit (x7);
- hydrothermal coefficient (x8).

Data processing was carried out in accordance with modern statistical recommendations. As methods of statistical analysis, a test was used to verify the compliance with the normal distribution of crop yield data by the Kolmogorov-Smirnov type criterion, correlation (including nonlinear), partial and multiple regression, the main component method in selecting the determining factors using the Excel, AtteStat и Statistica.

3. Results and discussion
The test for compliance with the normal distribution of yield data by the criterion of the Kolmogorov-Smirnov type confirmed the hypothesis of normality of data, which allows us to use parametric procedures in further calculations.

At the next stage of the study, links were established between the agrometeorological data in question and the yield, for which the correlation coefficients
As a result of the correlation analysis, according to the Cheddock scale, the correlation of agrometeorological data with yield is in most cases regarded as weak (0.1-0.3) in one case as moderate (0.3-0.5). Therefore, it is necessary to carry out analysis by the method of nonlinear correlation.

To calculate the coefficients of nonlinear correlation, it is necessary to construct one-factor regression models for each of the agrometeorological factors. For each of the factors, different types of models were selected, the priority was given to the fact that the coefficient of determination of which is the largest. The results are shown in Table 2.

### Table 2. Regression equations and coefficients of non-linear correlation of productivity

| Agrometeorological data                  | The regression equation | Productivity (y) |
|-----------------------------------------|-------------------------|------------------|
| Average air temperature (x1);           | -0.19x2+6.19x-33.51     | 0.334            |
| Minimum air temperature (x2);           | -0.19x2+3.75x-1.95      | 0.273            |
| Maximum air temperature (x3);           | -0.15x2+7.01x-63.8      | 0.362            |
| Amount of precipitation (x4);           | -0.001x2+0.19x+10.11    | 0.322            |
| Average air humidity (x5);              | 1.59e0.033x              | 0.528            |
| Minimum air humidity (x6);              | 0.16x1.2                | 0.46             |
| Moisture deficit (x7);                  | 48.51e-0.13x            | 0.56             |
| Hydrothermal coefficient (x8).          | -5.01x2+11.75x+9.76     | 0.225            |

The resulting nonlinear correlation coefficients are more significant in most cases. A moderate bond (0.3-0.5) is observed in four cases out of eight, for two paired coefficients, the relationship is characterized as "noticeable" (0.5-0.7).

An analysis of the initial factors makes it possible to make an a priori assumption about the presence of multicollinearity among some indicators (the Pearson correlation coefficients for some parameters range from 0.87-0.96). In the light of this circumstance, there is a need to exclude some factors in order to obtain stable estimates of regression parameters.

To assess the yield, we include factors that have a correlation with the sign of 0.3 or higher (we exclude a weak connection, according to the Cheddock scale). This makes it possible to exclude factors X2 and X8 from the model. According to the above requirement of eliminating multicollinear factors, factors X1 and X6 are also excluded, since the factors X3 and X5, which are collinear with them, have lower correlation coefficients, respectively.

The preliminary model of yield is described by the relation:

\[ y_1 = 1.278x_1 + 0.014x_2 - 0.439x_5 - 2.896x_7 + 38.693 \]

Analysis of regression residues using t-statistics showed the insignificance of factor X4. This circumstance makes it possible to exclude the considered factor from the model and to construct a new regression equation:
\[ y_1 = 1.241x_3 - 0.402x_1 - 2.851x_2 + 37.476 \] (2)

Assessment of the parameters of multiple regression allows us to conclude that the model has high significance (according to the significance level of the Fisher test \( F < 0.0001 \)), the multiple correlation coefficient is 0.829, which characterizes the strong dependence of yields to the initial factors, and the determination coefficient \( R^2 \) in the percentage ratio is 68.7%, that is, the factors included in the model describe the variation of the trait by slightly less than 69%.

Judging by these parameters, it can be concluded that the model is chosen correctly, but there is a number of non-significant factors not considered in the study.

The results obtained by us coincide with the studies of J F Zhao et al. [6] devoted to the study of the potential productivity of winter wheat in similar climatic conditions, where the forecast for the year 2050 was compiled based on the regression models constructed. There is also a correspondence to the results of the study of Singh M et al. [7] who studied the productivity of wheat in extreme climatic conditions associated with high temperatures and low humidity. The results also correspond to the studies of Z J Han et al. [8], on the impact of irrigation on long-term forecasting of wheat yield.

In addition to these authors, the results obtained intersect with the works of such researchers as: M L Mann and J M Warner [9]; Yu A Korshikov, T B Shaidulina, E P Kondratenko, L G Pinchuk [10]; S S Nizomov [11], I S Sharapova [12] and others.

4. Conclusion

Thus, the work constructs a multiple regression model of the dependence of yields on weather factors. The most significant effect is caused by moisture deficit (27.1%), average air humidity (24.2%) and maximum air temperature (17.4%). This model with a high enough accuracy allows you to predict the future yield before the start of the harvest campaign.

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