Development of a digital model for assessing the influence of agroecological factors on the productivity of wheat grains

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Abstract. The purpose of the study is to build a model of the influence of agro ecological factors on the productivity of wheat grains. In connection with the ongoing climate changes and, as a result, changes in the growing season, it is required to annually adjust the basic parameters that affect the quality and yield of crops. As a rule, the basic parameters include the norms of applied mineral fertilizers, the timing of sowing and the seeding rate. Correct and accurate determination of acceptable values for each of the listed parameters in specific agro-climatic conditions will improve the quality of wheat crops. In the framework of the work, a statistical study of the degree of influence of individual factors on the productivity of seeds of cereal crops was carried out.

1. Introduction
Currently, wheat remains one of the key crops grown worldwide. Worldwide, wheat accounts for 31.7% of the area used to grow all cereals. It should be noted that the Russian Federation is one of the main grain producers in the world along with the USA, India and the EU countries [1]. This is because on the territory of Russia for sowing wheat annually allotted area is not less than 1/3 of the total cultivated land used for growing cereals.

Many factors influence the productivity and productivity of cereal crops [2]. Nevertheless, the agroclimatic features of a particular region, as well as the agrochemical and agrotechnical conditions for growing cereals, remain fundamental. In connection with the ongoing climate changes and, as a result, changes in the growing season, it is required to annually adjust the basic parameters that affect the quality and yield of crops. As a rule, the basic parameters include the norms of applied mineral fertilizers, the timing of sowing and the seeding rate. Correct and accurate determination of acceptable values for each of the listed parameters in specific agro-climatic conditions will improve the quality of wheat crops.

In the Orenburg region, six natural-economic and five zones of varietal zoning are allocated. As applied to the peculiarities of the production of durum and strong wheat, it is advisable to use zones of varietal zoning - North, West, Central, South and East.

The northern (I) zone occupies 1044 thousand hectares of arable land, is part of the Prel-Ural forest-steppe province and is characterized by the following climatic features: the sum of the effective temperatures in the zone 1631–1745 °C; Precipitation averages 380–438 mm per year; frost-free period 111–125 days; the number of days with dry winds is about 22. The prevailing type of soil is typical and ordinary chernozems.
The western (II) zone has 1,440 thousand hectares of arable land, includes the Zavolzhsky wall province and is characterized by the following climatic features: the sum of the effective temperatures in the zone of 1748–1943 °C; precipitation averages 323–353 mm; frost–free period 127 days; the number of days with dry winds is about 30. The soils are ordinary and southern chernozems.

The southern (III) zone has 1097 thousand hectares of arable land, is part of the dry–steppe Zavolzhsky province and is characterized by the following climatic features: the sum of effective temperatures in the zone 2038–2059 °C; precipitation averages 264–363 mm; the frost–free period is 131–133 days, dry days – up to 41. Soils – southern chernozems and chestnut.

The central (IV) zone includes 1289 thousand hectares of arable land, is part of the Zavolzhsky steppe province, characterized by the following climatic features: the sum of effective temperatures is 1844–1999 °C. Precipitation – 333–413 mm; the frost-free period is 118 days, dry days – up to 37. Soils – ordinary and southern chernozems.

The eastern (V) zone occupies 1271 thousand hectares of arable land, the composition of the Kazakhstan steppe and dry steppe provinces is characterized by the following climatic features: the sum of effective temperatures – 1709 °C, precipitation – 285–372 mm; frost–free period – 109–112 days, dry days – up to 31. Soils – southern chernozems and dark chestnut.

From the analysis it is clear that the climate of the Orenburg region has a fairly large variety, which in turn requires the development of a differentiated approach to the management of agricultural technologies. In the framework of this study, it is proposed to focus on establishing the dependence of the quality of the final product, the mass of wheat grains relative to the influence of agroecological factors.

The purpose of the work is to identify the influence of agroecological factors on the formation of the mass of spring wheat grains.

2. Related work
The study of the influence of agroecological factors on the state of crops is carried out by many scientists around the world.

Researchers Blanche Benzian and Peter W. Lane in their work assess the influence of four weather factors on the interannual dispersion of grain protein using regression analysis [3]. They note the air temperature at the beginning of the grain filling period has a positive effect on the mass of the final product.

In a study by Laidig, F., Piepho, H., Rentel, D. et al. it is noted that the quality of the final product of the grain has a strong environmental dependence, with the ongoing changes at the level of the grain genotype under the influence of these factors being less than 19% of the total changes [4]. In this case, the direct grain yield was strongly negatively associated with the concentration of protein in the grains. Other scientists confirm the same data [5].

In [6], a study was made of spatial gradients in key weather variables and the assessment of meteorological factors affecting wheat productivity and the efficient use of agricultural resources aimed at increasing the yield of grain crops.

In [7], the authors conduct a study to determine the effect of seasonal meteorological data on wheat productivity using methods based on neural networks. At the same time, the following sets of factors are used as parameters, correlated with yield data: maximum and minimum temperatures in a season; minimum temperature and relative humidity; minimum temperatures, solar activity and relative humidity. The authors note that the three-factor model provides a more accurate forecast.

In a study [8], the authors developed an expert system for predicting wheat yields based on daily weather data and average annual agricultural data. The system is based on artificial neural network (ANN) and adaptive neuro-fuzzy output systems (ANFIS) technologies. We note that the authors applied the developed methodology to areas that have different climatic zones. At the same time, the data on the total evaporation, average daily temperature (maximum, minimum and dew point), precipitation, total radiation, and average daily relative humidity for twenty-two years at nine synoptic stations were used as parameters.
In [9], a study was conducted aimed at assessing the yield of winter wheat grains depending on the norm of nitrogen fertilizers introduced annually, depending on meteorological conditions and cultivated crops. The authors evaluate and determine the influence and interaction of research factors on the final product.

In [10], the authors examine the quality of crops relative to the mass of 1000 grains, while the following parameters are used as model parameters: seed sowing rate, environmental data, grain varieties and sowing dates.

Thus, a review of studies showed that most authors use a homogeneous set of factors when constructing basic models, but do not analyze the influence and relationships of factors with each other.

### 3. Materials and methods

The observations were carried out by the method of state variety testing of agricultural crops. As agroecological factors, the following ones were selected:

- average daily air temperature, °C (x1);
- amount of precipitation, mm (x2);
- average relative air humidity, % (x3);
- average moisture deficit, hPa (x4);
- availability of fertilizers, yes / no (x5);
- sowing period, 1-3 (x6);
- seeding rate, kg/ha (x7).

Widespread statistical methods and models were used as a methodological base. Verification of the belonging of the studied data to the normal distribution law was carried out using the Shapiro-Wilk W-test. The relationship between the indicators was evaluated using the non-parametric Spearman correlation coefficient. The regression equations were constructed using the least squares method, and the significance of the obtained regression coefficients was estimated using the Fisher F-test. Processing of statistical data was carried out using the software package MS Excel and Statistika 8.0.

### 4. Results and discussion

Checking the studied indicators for the normal distribution of the Shapiro-Wilk W-test to the law of distribution showed that most of the data do not obey the normal law. This circumstance determines the use of non-parametric procedures for further research.

An important element in assessing the grain mass is the identification of the relationship of this indicator with influencing factors. The relationship was evaluated using correlation coefficients, calculated according to the Spearman method (table 1).

|       | Y1   | X1   | X2    | X3   | X4   | X5   | X6   | X7   |
|-------|------|------|-------|------|------|------|------|------|
| Y1    | 1.000| −0.155| −0.228| −0.383| −0.061| 0.347| −0.236| −0.156|
| X1    | −0.155| 1.000| −0.200| −0.237| 0.862| 0.041| −0.474| −0.003|
| X2    | −0.228| −0.200| 1.000| 0.851| −0.596| −0.124| −0.313| 0.045|
| X3    | −0.383| −0.237| 0.851| 1.000| −0.625| −0.217| −0.068| 0.034|
| X4    | −0.061| 0.862| −0.596| −0.625| 1.000| 0.073| −0.128| −0.017|
| X5    | 0.347| 0.041| −0.124| −0.217| 0.073| 1.000| −0.137| −0.046|
| X6    | −0.236| −0.474| −0.313| −0.068| −0.128| −0.137| 1.000| 0.000|
| X7    | −0.156| −0.003| 0.045| 0.034| −0.017| −0.046| 0.000| 1.000|

According to the data of the correlation analysis shown in Table 1, in most cases, the relationship of agroecological factors to the grain mass index can be estimated as weak (according to the Cheddock scale), which is in the range of 0.1–0.3. Moreover, indicators such as average relative humidity (−0.383) and the presence or absence of fertilizers (0.347) show the greatest correlation.
We note that some of the influencing factors have a fairly high interconnection. For example, the amount of precipitation has a strong direct correlation with the average relative humidity (0.851), and the air temperature is quite strongly associated with the average moisture deficit (0.862). This indicates the presence of partial multicollinearity between influencing factors. Therefore, within the framework of the constructed model, we exclude collinear factors from one another from consideration.

It is known that, regardless of the method of selecting factors, a decrease in their number leads to better conditioning of the correlation matrix, which makes it possible to increase estimates of the model parameters. To exclude multicollinearity, we also exclude the least significant factors from the model. Significance is estimated by the obtained Spearman correlation coefficients.

Obviously, among the pair “air temperature - average moisture deficit”, air temperature is the most significant, since its correlation coefficient with the mass of grains is higher in absolute value than the correlation coefficient of the average moisture deficit with the mass of grains. Similarly, it is obvious that in the pair “rainfall - average relative air humidity”, the average humidity is the most preferable factor, since it has the highest regression coefficient with the mass of grains.

Having adapted the data accordingly, using the least squares method we construct the equation of multiple linear regression, which determines the dependence of the grain mass on the corresponding factors:

\[ y_1 = -1.221x_1 - 0.889x_3 + 1.463x_5 - 2.289x_6 - 0.623x_7 + 128.64. \] (1)

Based on the analysis, we construct the dependence of the contribution of each of the factors to the general model (Figure 1).

![Figure 1. Contribution of each factor to the overall model](image)

Analysis of regression residues using t-statistics showed the significance of all factors. Evaluation of the main parameters of the obtained multiple regression equation allows us to conclude that the presented model has high significance (according to the significance level of the Fisher test F <0.0001); in this case, the multiple correlation coefficient is 0.683, which characterizes the strong relationship of the mass of grains with the initial agroecological factors.

Also, the coefficient of determination of R2 in the percentage ratio is 46.7 %, that is, the factors included in the model describe the variation in the sign of grain mass slightly less than 47 %.
Based on the data obtained, we will construct a model of the influence of agroecological factors on productivity relative to the productivity of wheat grains. In this case, the productivity \( U \) is understood as the total volume of plant products obtained from one unit of area. Then the yield \( U \) can be described by the function \( F \), which depends on agroecological factors \( X = \{x_1, x_2, x_3, x_4, x_5, x_6, x_7\} \). To take into account the degree of influence of each factor on the selected crops, we introduce correction factors \( K = \{k_1, k_2, \ldots, k_7\} \). Then the model of maximizing the yield of the selected crop can be represented in the following form:

\[
U = F(\sum_{i}^{7} k_i x_i) \rightarrow \text{max}.
\]  

Thus, we can conclude that the constructed model allows the model based on data on the agroecological factors of the cultivation region to select the most suitable grain variety to obtain maximum yield. We note that to refine the model, we analyze a number of factors that play a rather significant role in the formation of the mass of grains.

5. Conclusion

In the work, a multiple regression model of the dependence of grain mass on agroecological factors is built. The most significant effect on the resulting model is exerted by the average relative air humidity (20.5 %), the presence of fertilizers (18.6 %) and the sowing period (12.6 %). The contribution of unaccounted factors to the resulting regression equation, which amounted to 31.7 %, is quite significant.

This model with high accuracy allows predicting future yields before the start of the harvesting company.

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