Assessment of the compliance of biological characteristics of some grain crops to abiotic factors on the example of the steppe zone of Zavolzhye

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Abstract. This article identifies the optimal conditions for the growth of winter, spring durum and spring soft wheat in Zavolzhye. It has been established that the amount of precipitation in September of at least 120 mm at an average temperature of at least 15 °C and a hydrothermic coefficient value of at least 1.2 contributes to the formation of winter wheat yield of 3.5–4.0 t/ha. For spring durum wheat, the best combination of temperature and humidity conditions is at a hydrothermal coefficient of 1.0–1.2. At a hydrothermic coefficient 0.7, it is possible to put a grain yield of spring durum wheat of no more than 0.70 t/ha. Spring soft wheat forms the highest yield at an average temperature of 13 °C in April, 16 °C in May, 24–25 °C in June and 25–26 °C in July. The best combination of temperature and humidity conditions for the growing season of spring soft wheat and the formation of the maximum yield occurs when the hydrothermic coefficient is 1.0 in April; 0.8-1.0 in May; 0.7-0.9 in June; and 1.1-1.2 in July.

1. Introduction
The development of agriculture presupposes the constant improvement of agrotechnical methods, the breeding of new varieties and hybrids, the development of technologies for increasing soil fertility, the expansion of methods of pest control, etc. However, abiotic environmental factors are very important in the formation of elements of productivity of agricultural plants. Of course, in the dry steppe zone of Zavolzhye, atmospheric precipitation is the limiting factor for the growth of agricultural crops [1-3]. However, the amount of precipitation does not yet determine the conditions for wetting the territory. One should always consider the possibility of evaporation, which is determined by the temperature factor. Trans-Volga and Saratov regions, in particular, are characterized by a high degree of climate aridity [4-6]. This article is supposed to consider the effect of the moisture degree on the formation of the yield of grain crops - winter, spring hard and spring soft wheat. It should be noted that a similar work [7] was carried out by a team of authors for the Right Bank of the Saratov Region, which significantly differs from the Left Bank in climatic indicators - annual and daily temperature ranges, the height and duration of snow cover, the amount of precipitation, a lesser degree of continentality, etc.

2. Materials and methods
In this study, the degree of the territory moistening was estimated using the Selyaninov hydrothermal coefficient (HTC):
HTC = \frac{r}{0.1 \sum t_{t \geq 10}},

(1)

Where \( r \) is a precipitation amount for the period with temperature above 10 °C, mm; \( \sum t_{t \geq 10} \) is a sum of active temperatures for the same period.

Data on average daily temperatures and daily precipitation for the stations of the Left Bank of the Saratov region were taken from the site “Weather and Climate”. The data on the yield of considered crops were obtained by the Krasnokutskaya Breeding Experimental Station Research Institute of Agriculture for the South-East Region.

Analysis of the yield dependence on abiotic factors (hydrothermal coefficient) was carried out using polynomial regression. Based on the experience of calculating polynomial dependencies, it has been identified that it is most expedient to use third-degree polynomials [7].

The general form of the polynomial dependence is as follows:

\[ Y = a_0 + a_1 x + a_2 x^2 + a_3 x^3, \]

(2)

Where \( a_0 \) is a constant term; \( a_n \) are polynomial regression coefficients; \( x_k \) is a variable, \( k \) is a polynomial degree.

The time interval of the study was a ten-year time interval – 1999-2008. The results obtained for different regions of the Saratov Trans-Volga region, located in the dry-steppe zone, turned out to be identical; therefore this article presents the results of the Krasnokutskaya Breeding Experimental Station Research Institute of Agriculture for the South-East Region.

3. Results and discussions

Winter crops, in particular, winter wheat are the most important crops for the Volga region. The main period in its cultivation technology is the autumn season. In Zavolzhye, the difficulty of obtaining seedlings, rooting and tillering is not only a lack of moisture in the autumn, but also an insufficient heat supply. Consequently, the yield of winter wheat strongly depends on both the moisture and heat supply in August and September.

During the study, in August, monthly precipitation totals varied from 9.9 to 49.9 mm (\( \bar{c}_v = 52.9\% \)). In September, the average monthly precipitation during this period was 37.4 ± 23.46 mm (\( \bar{c}_v = 62.7\% \)). The extreme values for precipitation totals in September were 14.1 and 98.2 mm, respectively. High \( \bar{c}_v \) values indicate a large temporal variability of precipitation in these months.

From the solution of the equations (table 1), it was obtained that to put a high yield of winter wheat in August, at least 35 mm of precipitation at a temperature of no higher than 24 °C should fall. The number of precipitation in September should be 60 mm at a temperature of 15 °C. The average monthly temperature in August is 22.0 ± ± 1.67 °C (\( \bar{c}_v = 7.6\% \)). in September 14.6 ± 1.36 °C (\( \bar{c}_v = 9.3\% \)). For the normal development of winter wheat in autumn, a sum of positive temperatures of at least 450 °C is necessary. The average sum of temperatures for the initial growing season (August-September) is 444.0 ± 36.6 °C. In this period, winter wheat is completely provided with heat, and precipitation is a limiting factor, as the average sum of air temperature during this period is 444.0 ± ± 36.6 °C.

| Table 1. The dependence of winter wheat yield on abiotic factors in the summer-autumn period. |
| --- |
| Month | Factor | Polynomial equation | Interpolation error | Linear dependance. % |
| August | Precipitation | \( y_1 = 0.22 + 0.18x - 0.00192x^2 - 1.729 \times 10^{-3}x^3 \) | 0.5504 | 2.3 |
| September | Precipitation | \( y_2 = 5.32 - 0.19x + 0.00386x^2 - 2.08310 - 5x^3 \) | 0.7953 | 3.2 |
| August | Temperature | \( y_1 = 638.78 - 86.20x + 3.87x^2 - 0.0576x^3 \) | 0.7041 | 4.0 |
| September | Temperature | \( y_2 = -53.81 + 3.39x + 0.36x^2 - 0.0221x^3 \) | 0.5999 | 4.0 |

It is more expedient to describe the humidification conditions by a complex indicator, including both temperature and precipitation. The correlation between winter wheat yield and the hydrothermal
coefficient in autumn is shown in (figures 1). The degree of linear relationship for all equations does not exceed 8.4%. The theoretical curve interpolation error varied from 0.6659 to 0.8857. In August, the best conditions for the development of winter wheat are observed at the hydrothermal coefficient of at least 0.5, and in September at the hydrothermal coefficient of more than 1.0.

![Figure 1. Dependence of winter wheat yield on the hydrothermal coefficient for the autumn period (1 - August, 2 - September, 3 - the average value for the autumn period).](image)

In order to form the maximum winter wheat yield the hydrothermic coefficient should be equal to 1.0 or more. The author revealed that in August, on average over 10 years, the hydrothermic coefficient was $0.70 \pm 0.28$ ($c_v = 42.1\%$). In September it was $0.85 \pm 0.53$. In autumn, the average value of the hydrothermic coefficient was not higher than $0.66 \pm 0.1$ ($c_v = 27.2\%$). The large degree of HTC variation is explained by the large variability of the precipitation regime. It can be concluded that 60–70 mm of precipitation, $15^\circ{C}$ and a HTC of 0.66 are necessary to form 2.5 t/ha of winter wheat in September. In order to obtain more yield (3.5–4.0 t/ha), studied factors should be higher: the necessary precipitation should be at least 120 mm, an average temperature of at least $15^\circ{C}$ and the hydrothermic coefficient of at least 1.2, respectively.

Precipitation in spring and summer (April, May, June) plays an equally important role in the formation of productivity. Table 2 shows the regression dependences of yield on abiotic factors for these months.

| Month | Factor | Polynomial equation | Interpolation error |
|-------|--------|---------------------|---------------------|
| April | Precipitation | $y_1 = 4.14 - 0.25x - 0.00937x^2 - 9.89 \times 10^{-3}x^3$ | 0.6859 |
|       | Temperature  | $y_2 = -30.83 + 12.67x - 1.54x^2 + 0.061x^3$ | 0.5797 |
| May   | Precipitation | $y_3 = 5.46 - 0.37x + 0.0124x^2 - 0.000104x^3$ | 0.63502 |
|       | Temperature  | $y_4 = -58.42 + 13.04x - 0.89x^2 + 0.020x^3$ | 0.6385 |
| June  | Precipitation | $y_5 = -2.94 + 0.43x - 0.0089x^2 + 5.39 \times 10^{-3}x^3$ | 0.64505 |
|       | Temperature  | $y_6 = -123.70 + 19.25x - 0.97x^2 - 0.016x^3$ | 0.5899 |

The solution of the equation 1 (table 2) evidences that winter wheat forms the highest yield when the amount of precipitation in April is more than 40–45. During 10 years, it is averaged $27.9 \pm 16.1$ ($c_v = 57.7\%$). In the steppe zone of Zavolzhye. The precipitation rate in April is estimated at 62.2\%.
From the solution of the equation (2) it is determined that for the formation of the yield of 4–5 t/ha of grain in May, 60–65 mm of precipitation is necessary. In May, \(30.2 \pm 21.2\) mm (\(c_v = 70.2\%\)) falls in this region. The provision of winter wheat with precipitation in May is 75.5%.

Precipitation in June are also very important in the formation of winter wheat yield. The solution of the equation (3) evidences that 40 mm of precipitation are sufficient to put a yield of the crop of 4 t/ha. In the studied month, over 10 years, the precipitation amount averaged 36 ± 24.5 mm (\(c_v = 68.1\%\)). The provision with precipitation in June reaches 90%.

Table 2 also presents the equations of the correlation between the values of winter wheat yield (y) and the average daily air temperature (x). The degree of linearity does not exceed 32.4%.

Figure 2 presents the correlation of the crop yield (y) with the hydrothermal coefficient (x) in the spring-summer period.

The correlation linearity degree does not exceed 13.1%. The interpolation error ranged from 0.4619 to 0.6854. According to the solution of the equations, in order to put the highest yield of the studied crop, the hydrothermal coefficient in April should be 0.8–0.9; in May it should be not less than 1.2–1.3; in June - 0.6–0.7, respectively.

Spring durum wheat is the most valuable of the cereal crops. It yields a grain with a high protein content and glassiness. In Zavolzhye, its yield is low, since it is a very heavy feeder.

The dependence of the yield (y) on the precipitation amount in summer (x) is presented in (table 3).

**Table 3.** Dependence of spring durum wheat yield on abiotic factors in the spring-summer period.

| Month | Factor     | Polynomial equation | Interpolation error |
|-------|------------|---------------------|---------------------|
| April | Precipitation | \(y_1 = 1.48 - 0.14x + 0.00665x^2 - 8.03 \times 10^{-5}x^3\) | 0.2109 |
|        | Temperature | \(y_2 = 4.088 + 2.44x - 0.367x^2 + 0.0168x^3\) | 0.2053 |
| May   | Precipitation | \(y_2 = 0.77 - 0.0245x + 0.0015x^2 - 1.60 \times 10^{-5}x^3\) | 0.2717 |
|        | Temperature | \(y_2 = 62.25 - 12.43x + 0.83x^2 - 0.0184x^3\) | 0.3284 |
| June  | Precipitation | \(y_3 = 3.12 + 0.30x - 0.00643x^2 + 4.15 \times 10^{-5}x^3\) | 0.2654 |
|        | Temperature | \(y_3 = 64.31 - 10.05x + 0.53x^2 - 0.0093x^3\) | 0.3176 |
| July  | Precipitation | \(y_4 = 0.85 - 0.0195x + 0.00033x^2 - 1.13 \times 10^{-5}x^3\) | 0.2344 |
|        | Temperature | \(y_4 = 27.41 + 3.109x - 0.112x^2 - 0.00132x^3\) | 0.2843 |
On the basis of calculations, it was established that to obtain 1.2 t/ha of spring durum wheat, at least 200 mm of precipitation should fall (21% in April, 30% in May, 18% in June, and 31% in July). It is obvious that spring durum wheat requires the greatest amount of precipitation during stalking and grain filling. Under the actual conditions of moisture supply during the growing season, wheat can form a yield of no more than 0.7 t/ha of grain.

The temperature regime plays an important role in the formation of the grain yield of durum spring wheat in Zavolzhye. Regression dependencies are presented in table 3. The degree of correlation linearity did not exceed 36%. In order to obtain the highest yield of spring durum wheat, the following conditions must be met: in April, the average temperature should not be higher than 5...6 °C, in May – 11...12 °C, in June – 16...17 °C, respectively. In July, the studied crop can withstand temperature up to 23...24 °C without losing yield.

Figures 3 shows the correlation between the yield of spring durum wheat and the hydrothermal coefficient for April and May. The linearity of the equations does not exceed 30.2%. The theoretical curve interpolation error ranges from 0.1750 to 0.3284.

According to figure 3, the best HTC for the growing season of spring durum wheat should be 0.80 in April; 1.20 in May; 0.60 in June and 1.0 in July.

**Figure 3.** Dependence of spring durum wheat yield on the value of the hydrothermal coefficient.

Thus, the best combination of thermal and water conditions for spring durum wheat was at a hydrothermal coefficient of 1.0–1.2.

The equation for the correlation between the yield of spring soft wheat (y) and the spring reserves of productive moisture in a meter layer of soil (x) is as follows: $y = 19.28 - 0.54x + 0.00507x^2 - 1.505 \times 10^{-5}x^3$. The interpolation error of the theoretical curve relative to the experimental data did not exceed 0.1905. According to the solution of the equation, we can conclude the maximum yield of the studied crop of 1.8–2.0 t/ha can be obtained when productive moisture reserves in the soil are of at least 140 mm.

The dependence of the grain yield of this crop (y) on precipitation during the growing season by months (x) is presented in table 4.

The linearity degree of the dependence of the considered parameters ranged from 2.1 to 15.6%. Therefore, nonlinear equations are quite legitimate. Analysis of the solutions of the equations evidences that 120 mm of precipitation in April, May and June are necessary to obtain the highest yield of spring soft wheat in Zavolzhye.
Table 4. Dependence of spring soft wheat yield on the amount of precipitation.

| Month | Polynomial equation | Interpolation error |
|-------|---------------------|---------------------|
| April | $y_1 = 1.48 - 0.14x + 0.00665x^2 - 8.03 \cdot 10^{-5}x^3 - 8.03 \cdot 10^{-5}x^3 + 0.1932$ | 0.1932 |
| May   | $y_2 = 0.77 - 0.0245x + 0.0015x^2 - 1.60 \cdot 10^{-5}x^3 + 0.2717$ | 0.2717 |
| June  | $y_3 = -3.12 + 0.30x - 0.00643x^2 + 4.15 \cdot 10^{-5}x^3 + 0.2456$ | 0.2456 |
| July  | $y_4 = 0.85 - 0.0195x + 0.00033x^2 - 1.13 \cdot 10^{-8}x^3 + 0.2962$ | 0.2962 |

At an average moisture provision of 60.9% and a grain yield of 0.9 t/ha, the stress coefficient and the coefficient of adaptation to the moisture conditions of the studied crop are 50% and 2.0, respectively. Coefficients value evidences that in terms of the biological characteristics of moisture consumption, spring soft wheat is superior to hard spring wheat, but inferior to winter wheat.

The optimal temperature regime is of great importance in the formation of spring soft wheat yield. The analysis of polynomial dependences of temperature and yield made it possible to conclude that in April spring soft wheat began to grow intensively at temperatures above 8–9 °C, and it forms the highest yield at an average temperature of 13 °C this month. In May, the best temperature regime should be 16 °C, in June - 24–25 °C, in July - 25–26 °C.

Figures 4 shows the dependence of spring soft wheat yield and the value of the hydrothermal coefficient, that is very important in the assessment of the cumulative effect of precipitation and temperature regime on the yield of the studied crop.

![Figure 4](image)

**Figure 4.** Correlation between spring soft wheat yield and the value of the hydrothermal coefficient.

We should conclude that it is necessary to use a nonlinear equation, as the degree of the correlation linearity does not exceed 12.9%. The theoretical curve interpolation error varied from 0.1996 to 0.3037. The solution of the equations showed that the best hydrothermal coefficient should be 1.0 in April; 0.8-1.0 in May; 0.7-0.9 in June, and 1.1–1.2 in July.

On average for 10 years, real hydrothermal coefficient by months were as follows: in April 1.09 ± 0.59; in May - 0.53 ± 0.49; in June - 0.79 ± 0.42; in July - 0.68 ± 0.34, respectively. The coefficients of variation by months were 54.1; 92.4; 53.2 and 50.0%, respectively.

4. Conclusion.

In autumn, winter wheat is mainly provided with warmth, atmospheric precipitation is also a limiting factor in this period.
It is revealed that hydrothermal coefficient of 1.2 ensures the formation of winter wheat yield of 3.5–4.0 t/ha. In September at least 120 mm of precipitation should fall, an average air temperature should be at least 15 °C.

Hydrothermal coefficient of 1.0–1.2 ensures the maximum formation of spring durum wheat yield. At 0.7 hydrothermal coefficient, spring durum wheat yield will be not more than 0.70 t/ha.

Spring soft wheat forms the highest yield at an average temperature of 13 °C in April, 16 °C in May, 24...25 °C in June and 25...26 °C in July. The maximum yield of the crop is ensured at HTC in April 1.0; in May - 0.8-1.0; in June - 0.7-0.9; in July - 1.1-1.2.

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