Monitoring of Spring Wheat Cultivation Under the Climatic Conditions of Kursk Region

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Abstract. With the help of generalization and mathematical processing of statistical data, the author found that in Kursk Region, the yield of spring wheat from 1995 to 2018 increased more than 2.5 times (from 1.58 metric tons / ha in 1995 to 3.97 metric tons / ha in 2018), although in Russia there were no significant changes in crop yield. While conducting a correlation analysis of the associated data of spring wheat yield in Kursk Region for the period studied, a close relationship was established with the application of basic nutrients (0.84) and with the prevailing weather conditions of a particular year of cultivation (0.86). It was found out that spring wheat grew under optimal weather conditions in 50% of cases. Adverse and favorable weather conditions are formed equally in 25% of years. Under optimal weather conditions, a high direct linear relationship between yield and the sum of active temperatures is recorded, which is significant at 99% level. Crop shortage in unfavorable years was associated with high air temperature during the entire growing season of the crop and a lack of humidity from seedlings to grain ripeness and an increase in humidity during the harvest of the crop. A linear regression relationship between yield and moisture coefficient was revealed. Thus, the moisture coefficient is the limiting agro-climatic resource of spring wheat yield under the conditions of Kursk Region.

1. Introduction

Global climate warming significantly changes the growing conditions of all vegetation. This directly affects crop yields, which determine the country's food security. Climate change, for several years now, has limited the production of high and stable yields.

Spring wheat is the most important food crop and occupies a significant place in the agriculture of our country [1, 2]. It is used as a food, technical and forage crop [3, 4, 5]. A shortfall in the spring wheat crop can lead to an increase in grain prices and, as a result, to an increase in the price of bread. All this will dramatically affect the standard of living of the country's population. Therefore, obtaining high and stable yields of spring wheat is a priority in ensuring the country's food security [6].

The issue of the impact of climate change on the yield of spring wheat is studied by many scientists around the world [1-13, 25, etc.]. Climate changes over the past 30-50 years have led to a deterioration of the growing conditions of spring wheat [7].

In Russia, in years close to optimal climatic conditions or in years with higher precipitation, high grain yields are formed [1]. High yield of spring wheat in the Republic of Tuva is formed at the
optimal average monthly air temperature in May and June, and with an increase in precipitation in May and a decrease in August [8]. In an unstable climate in the Central zone of the Orenburg Pre-Urals, the increase in spring wheat yield depends on weather conditions of a particular year [9]. In the Volga region, crop yield decreases with an increase in the average air temperature and with a decrease in the amount of precipitation [10].

The territory of Kursk Region is located on the South-Western slopes of the Central Russian Upland and is characterized by a moderate continental climate. The temperature regime of the territory is slightly lower than in the neighboring regions of the Central Chernozem Area, and the humidification regime of the region is favorable. When growing most crops, this climate is suitable for obtaining high yields [11, 12].

We found that over the past 27 years in the region, the average air temperature increased in all months by 0.8-2.60°C, which exceeds the Russian indicators. The amount of average annual precipitation for this period in the territory increased by 4.3% and at the same time, the amount of precipitation decreased in the important summer months (June, July), when the future harvest is formed [13].

Purpose: to identify the limiting agro-climatic resource of spring wheat yield under the conditions of Kursk Region, to assess the influence of the main weather factors in the formation of crop yield.

2. Objects and methods of research
Monitoring of spring wheat cultivation under the climatic conditions of Kursk Region was carried out using statistical data on crop yield in Kursk Region for 24 years (from 1995 to 2018) [14-17] and associated data on weather conditions in the region [18]. The climate conditions were assessed by the average daily air temperature, the amount of precipitation per year, the amount of active temperatures during the growing season, the amount of precipitation at a temperature of more than 10°C, the hydrothermal coefficient and the moisture coefficient. To compare regional data with national data, we used statistical data for Russia [19-24].

The obtained data were processed by methods of descriptive and variational statistics, correlation and regression analysis.

3. Results and discussion
Looking at the yield of spring wheat in Russia as a whole over the past 24 years, we see that it did not change significantly (Figure 1) and varied from 1.08 to 1.89 tons / ha.

![Figure 1. Dynamics of spring wheat yield in Russia and Kursk Region, metric tons / ha.](image-url)

Naturally, the linear and polynomial trend of yield changes, in this case, were not significant.
In Kursk Region the yield of spring wheat over the same 24 years has increased more than 2.5 times (from 1.58 tons / ha in 1995 to 3.97 tons / ha in 2018). The polynomial trend was almost linear. The maximum yield of spring wheat, both in Russia and in Kursk Region, was observed in 2017 and amounted to 1.89 and 4.71 tons / ha, respectively.

Considering the statistical indicators of spring wheat yield, we can note that during the study period, the yield in the Kursk region increased significantly and varied from 1.21 to 4.71 metric tons / ha (Table 1).

Table 1. Statistical indicators of spring wheat yield.

|                        | max  | min  | Range of variation | Average value ± deviation |
|------------------------|------|------|--------------------|--------------------------|
| in Russia              | 1.89 | 1.08 | 0.81               | 1.44±0.08                |
| in Kursk Region        | 4.71 | 1.21 | 3.50               | 2.36±0.39                |

The scope of yield variation in Kursk Region exceeds the indicator in Russia by more than 4 times. The average yield of spring wheat over the past 24 years in the Kursk region was higher than that in Russia by 0.92 metric tons / ha or 64%.

The general trend of spring wheat yield dynamics over 24 years in Kursk Region is obviously related to the improvement of crop cultivation technologies, the use of new varieties, and other factors.

Previously it was found that for the climatic conditions of Kursk Region, the yield of cereal crops varies from fertilizers and agricultural machinery by 54%, and weather conditions cause 46% of the variation in yield [25].

The correlation analysis of the associated data of spring wheat yield in Kursk Region for the study period showed that a close relationship was observed with the application of basic nutrients (0.84) and with the prevailing weather conditions of a particular year of cultivation (0.86).

Looking at the graph of changes in the yield of spring wheat in Kursk Region (Figure 1), it becomes clear that the linear trend shows an increase in crop yield under the influence of improved crop cultivation technologies, the use of new varieties, and deviations in yield from the trend line occur under the influence of weather factors.

The deviation from the average linear trend, which was within the range of -10...+10 %, indicates that spring wheat grew under optimal weather conditions. Favorable weather conditions are formed at a deviation of +10 %, and unfavorable conditions at a deviation of < -10 %. Thus, we found that over 24 years, spring wheat grew under optimal weather conditions in 50% of cases (12 years). Adverse and favorable weather conditions are equal in 25 % of cases.

Having distributed the years according to the prevailing weather conditions (optimal, unfavorable and favorable), we analyze the dynamics of the average air temperature (Figure 2).
Analysis of the average air temperature by year allowed us to note that in the unfavorable years of crop cultivation, the average air temperature for the entire growing season of spring wheat (May-August) was higher than in the optimal and favorable years (in May by 1.1 and 0.8°C, in June by 2.7 and 2.6°C, in July by 1.2 and 2.2°C, and in August by 0.5 and 0.4°C, respectively).

After analyzing the amount of precipitation by month (Figure 3), we can note that in optimal and favorable years, the amount of precipitation from sowing to filling of spring wheat grain was higher than in unfavorable years (in May by 14 and 3 mm, in June by 24 and 35 mm, in July by 34 and 16 mm, respectively).

![Figure 3. Dynamics of precipitation by month, mm.](image)

In optimal and favorable years during the laying of the ear and its filling (June and July), precipitation was maximum and decreased by the time of harvesting, which ensured timely harvest, preventing its losses. In unfavorable years, by the time of harvesting, the amount of precipitation increased, which led to difficulties in harvesting and, as a result, to the loss of productivity.

According to the average values of the studied climate indicators, it was determined that in unfavorable years the amount of precipitation per year and precipitation at a temperature of more than 10°C is less than in optimal and favorable years, and the amount of active temperatures was higher by 197.5-142.00°C. Thus, in adverse years, the hydrothermal coefficient and moisture coefficient are slightly lower than in optimal and favorable years.

To determine the limiting climate factor that determines the yield of spring wheat, a correlation analysis of the associated data was performed (Table 2).

| Weather conditions | Precipitation for the year, mm | Sum of active temperatures, °C | Precipitation at more than 10°C | Hydrothermal coefficient | Yield coefficient |
|--------------------|-------------------------------|-------------------------------|-------------------------------|--------------------------|-------------------|
| Adverse            | -0.47                         | 0.21                          | -0.01                         | -0.12                    | -0.46             |
| Optimal            | 0.09                          | 0.72                          | -0.34                         | -0.48                    | -0.12             |
| Favorable          | -0.42                         | 0.47                          | -0.70                         | -0.66                    | -0.44             |

After analyzing the pair correlation coefficients, it can be noted that under optimal weather conditions, a high direct relationship with yield was with the sum of active temperatures. This dependence is described by the following linear regression equation (1), which is significant at 99% level:
y = - 6.34+0.03x_1 \hspace{1cm} (1)

R^2 = 71, where

y is the yield of spring wheat under optimal weather conditions, metric tons / ha;
x_1 is the sum of active temperatures under optimal weather conditions, °C

In favorable years, the yield of spring wheat had a high feedback with the amount of precipitation at an air temperature of more than 10°C (-0.70). This relationship is described by the following linear regression equation (2), which is significant in 90% of cases:

y= 8.14-0.16x_1 \hspace{1cm} (2)

R^2 = 60, where

y is the yield of spring wheat in favorable years, metric tons / ha;
x_1 is the amount of precipitation at an air temperature of more than 10°C, mm.

In addition, in favorable years the average feedback with the hydrothermal coefficient (-0.66) was detected, but no regression relationship was found in this connection.

In years with unfavorable weather conditions, high and medium relationships of pair correlation coefficients were not established, but a linear regression relationship of the yield with the moisture coefficient (3) was found, which is significant at 90% level:

y=11.35-63.7x_1^2 \hspace{1cm} (3)

R^2 =64, where

y is the yield of spring wheat in unfavorable years, metric tons / ha;
x_1 is the moisture coefficient.

4. Conclusion

Thus, it is found out that in Kursk Region, the yield of spring wheat for 24 years increased more than 2.5 times (from 1.58 metric tons / ha in 1995 to 3.97 metric tons / ha in 2018), although in Russia no significant changes were observed.

Conducting a correlation analysis of the associated data of spring wheat yield in Kursk Region for the study period, a close relationship was established with the application of basic nutrients (0.84) and with the prevailing weather conditions of a particular year of cultivation (0.86). It is found out that spring wheat grew in optimal weather conditions in 50% of cases (12 years). Adverse and favorable weather conditions are the same in 25 % of cases. Under optimal weather conditions, a high direct linear relationship between the yield and the sum of active temperatures is recorded, which is significant at 99% level. Crop shortage in adverse years was associated with high air temperature during the entire growing season of the crop and the lack of humidity from seedlings to grain ripeness and an increase in humidity during the harvest of the crop. A linear regression relationship between yield and moisture coefficient was revealed. Thus, the moisture coefficient is the limiting agro-climatic resource of spring wheat yield under the conditions of Kursk Region.

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