Effect of weather and climatic conditions on the yield of winter wheat cultivated using No-Till technology

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Abstract. The study was conducted between 2018 and 2020 in the arid zone of Stavropol Territory to determine the yields of different varieties of winter wheat cultivated using direct seeding technology, based on weather and climatic changes. The work was carried out on the basis of «Agrokhleboprodukt» JSC agricultural enterprise. The precursors were sunflower, chickpea; soft winter wheat varieties - Zustrich (st.), Bagira and Bagrat. It was found that growth, development and productivity of winter wheat depended on abnormal weather-climatic conditions. It was noted that annual average rainfall tended to decrease while annual average temperature and vegetation index NDVI tended to increase. The average variation of indicators for sprouting of different varieties and precursors was 9 %. The seedlings emerged 19-20 days after sowing. The rates of variation reflected the high heterogeneity in plant development in all phases. The variation of sprouting density was homogeneous in all varieties and precursors. Reduction of the index was observed from the phase of sprouting to earing and for all the precursors. Winter wheat yields were 3.01-4.50 t/ha for sunflowers and 3.26-4.68 t/ha for chickpeas. The variety Bagrat showed the best results for chickpeas and the variety Zustrich for sunflowers.

1. Introduction
One of the main problems in modern crop production is the stabilization of yields under conditions of weather and climate changes. Application of intensification means to some extent allows reducing fluctuations in winter wheat yields from year to year, but the problem is still urgent. The most realistic way to solve it is the cultivation of adaptive varieties of cereal crops in relation to the conditions of the Stavropol Territory [1, 2, 3].

Cultivation of different varieties of winter wheat combining high yield with adaptability is impossible without studying the patterns of variability of basic morpho-biological traits associated with productivity in specific ecological and economic conditions of agricultural enterprises. The introduction with traditional modern technologies of cereal crops cultivation (including No-till technology), the selection of precursors in the crop rotation, etc. are also aimed at increasing the production of high-quality agricultural products [4, 5, 6].

2. Problem statement
The growth and development of winter wheat integrate all physiological functions and interaction of the plant organism with the external environment, which is primarily conditioned by the dynamics of weather and climatic conditions and abnormal phenomena of the study period. In the process of
development, the crop goes through generative phases, which determine the productive capacity of the crop [7]. The peculiarity of its development is getting good sprouts and bushiness [8, 9]. Phenological observations are designed to fix the main phases of development of winter wheat in continuous control, which allows determining the state of the crops, quickly taking measures to reduce losses from unfavourable factors and predict the productivity of the crop [10].

One of the topical fields of scientific research is obtaining additional information about the state of plants in different phases of vegetation by means of Earth remote sensing, by means of spectral reflectivity [11]. Application of plant diagnostics (based on space images and field experiments) makes it possible to control development phases, phytosanitary state, deviation from optimal agrotechnics (especially in unfavorable years), to recommend measures to optimize plant nutrition, etc. and in general to ensure the level of planned yield [12, 13].

3. Research questions
The research was conducted from 2018 to 2020 in a stationary multifactorial experiment on the territory of «Agrokhleboprodukt» JSC. The soil cover of the territory is represented mainly by dark-chestnut carbonate heavy loam soils. The area of the record plot is 500 m².

The climate of the territory is arid. The average annual air temperature was 10.3°C and precipitation 36.1 mm during the research period [14].

The dry autumn of 2019 and the warm snowless winter of 2020 resulted in insufficient reserves of productive moisture for growth and development of winter wheat. Spring frosts occasionally had a negative impact. Rainfall in May 2020 had a positive effect on plant health. However, they were insufficient and untimely.

4. Purpose of the study
The aim of the study was to analyze the impact of weather and climatic conditions on the yield of winter wheat cultivated in the No-till system in the arid zone of Stavropol Territory for the period from 2018 to 2020.

The objectives of the research included:

- determination of the relationship between the hydrothermal index and the vegetation index NDVI under the conditions of production experience based on the application of two-factor analysis of variance;
- determination of field germination of plants by cultivars and precursors, calculation of the average linear deviation;
- phenological observation of winter wheat plant development by varieties, precursors and development phases; calculation of the mean linear deviation;
- determination of yield of winter wheat varieties by mechanized method (direct harvesting) (GOST 28301-2015), calculation of the average linear deviation.

5. Research methods
The scheme of the experiment included study of the following factors: winter wheat varieties - Zustrich (st.), Bagira, Bagrat; precursors - sunflower and chickpea; generative phase of crop development - tillering, heading, and earing. Repetition of the experiment is 3 times.

Winter wheat crops and varieties were cultivated using No-till technology according to the following scheme: pre-sowing treatment with herbicide Sprut Ekstra, application rate was 2 l/ha; sowing of winter wheat - 210 kg/ha; application of amososphos (N₁₂P₃₂) - 100 kg/ha; early spring fertilization with ammonium nitrate (N₁₃) - 100 kg/ha; foliar fertilization with KAS (N₃₂) - 100 kg/ha; herbicide treatment with Balerina - 0.4 l/ha; first fungicide treatment with Altosuper - 0.5 l/ha; second fungicide treatment with Kolosal Pro - 0.4 l/ha; harvesting.

Plant samples were taken by the generative growth phases of plants in 3-fold replications.
On the basis of MODIS spectroradiometer data of satellite mapping of vegetation cover was obtained (service «VEGA-Science» IKI RAS - http://sci-vega.ru/). Mathematical processing of the results was carried out by the method of analysis of variance according to the method of fieldwork (B.A. Dospekhov, 1985).

6. Findings

The weather and climatic conditions during the study period were contrasting. In 2018 the hydrothermal coefficient was 0.6, in 2019 0.76 and in 2020 - 0.3 (figure 1). Studies of weather-climatic dynamics showed that precipitation was decreasing and temperature was increasing. In 2018 winter-spring development dynamics of winter crops showed an abnormally early term of their development against the background of lack of soil moisture. In 2020 the resumption of active crop development started 10-12 days earlier. Winter crops practically did not stop growing. In the mid-spring of 2020 there was a plant takeover caused by the drought, amid a lack of soil moisture.

In 2018, the vegetation NDVI averaged 0.456, in 2019 - 0.463 and in 2020 - 0.491 (figure 2). In 2020 NDVI values of winter crops increased by 1.8 times compared to 2018. The NDVI value at the end of March showed that the vegetation index (0.54) exceeded the multi-year «norm» (by 17.0%).

[Figure 1. Dynamics of the hydrothermal coefficient, 2018-2020.]

[Figure 2. Dynamics of the vegetation index NDVI, 2018-2020.]

During this period the average annual linear deviation of the hydrothermal index (d_{HTC}) is 17 times higher than the average annual linear deviation of the vegetation index (d_{NDVI}) (table 1).
Table 1. Dynamics of average linear deviations of HTC and NDVI, (average for 2018-2020).

| Indicators | Month       | Average | Annual |
|------------|-------------|---------|--------|
| d_{HTC}   | January     | 0.11    | 0.17   |
|           | February    | 0.16    |        |
|           | March       | 0.69    |        |
|           | April       | 0.09    |        |
|           | May         | 0.09    |        |
|           | June        | 0.07    |        |
|           | July        | 0.26    |        |
|           | August      | 0.09    |        |
|           | September   | 0.09    |        |
|           | October     | 0.04    |        |
|           | November    | 0.22    |        |
|           | December    | 1.42    |        |
|           |            | 0.08    |        |
|           |            | 0.01    |        |
| d_{NDVI}  | January     | 0.07    |        |
|           | February    | 0.04    |        |
|           | March       | 0.05    |        |
|           | April       | 0.03    |        |
|           | May         | 0.04    |        |
|           | June        | 0.01    |        |
|           | July        | 0.01    |        |
|           | August      | 0.03    |        |
|           | September   | 0.07    |        |
|           | October     | 0.05    |        |
|           | November    | 0.08    |        |
|           | December    | 0.01    |        |
| d_{HTC}/d_{NDVI} | January | 1.6     |        |
|           | February    | 4.0     |        |
|           | March       | 13.8    |        |
|           | April       | 3.0     |        |
|           | May         | 22.5    |        |
|           | June        | 7.0     |        |
|           | July        | 26.0    |        |
|           | August      | 22.5    |        |
|           | September   | 3.0     |        |
|           | October     | 0.6     |        |
|           | November    | 4.4     |        |
|           | December    | 17.8    |        |
|           |            | 17.0    |        |

Note: d_{HTC} – the average linear deviation of the hydrothermal coefficient, d_{NDVI} – the average linear deviation of the vegetation index NDVI.

The results of a two-factor analysis of variance established the reliability of the effect of HTC and NDVI on plant vegetation (significance level 95.0 %). There is no significant statistical significance between the factors considered over the study period (table 2). Prediction level of winter wheat based on the relationship between GTC and vegetation index is low, as the latter reflects only a shift in the vegetation phase of plants to an earlier period.

Table 2. Results of a two-factor analysis of variance of the indicator hydrothermal coefficient and NDVI (average for 2018-2020).

| Source of variation | SS   | DF | MS   | F_{fact} | p-value | F_{theor} |
|---------------------|------|----|------|----------|---------|-----------|
| Factor A (HTC)      | 91.5354 | 1  | 91.5354 | 2.5991   | 0.2583  | 4.8443    |
| Factor B (NDVI)     | 472.4470 | 11 | 42.9497 | 1.0348   | 0.4784  | 2.8179    |
| Error rate          | 466.5998 | 11 | 42.4183 |          |         |           |
| Total               | 1030.584 | 23 |        |          |         |           |

Note: HTC - hydrothermal coefficient, NDVI - vegetation index, SS - sum of squares of variance, DF - number of degrees of freedom, MS - variance, F_{fact} - actual value of Fisher's ratio, p-value - Pearson value, F_{theor} - theoretical value of Fisher's ratio.

Sowing of winter wheat in 2017 was carried out on 18-th of August, in 2018 – 21-st of August, and in 2019 – 25-th of August. The area of emerged plants in autumn 2017 and 2018 detected by satellite data was in line with the average annual rate. The dynamics of plant field germination decreased for all winter wheat precursors and varieties (highest for the Zustrich variety - 1.3 times and the Bagrat variety - 1.3 times, the precursor - sunflower; highest for the Zustrich variety - 1.4 times, the precursor - chickpea). The ratio of average linear deviation of germination of 2018 plants to 2020 for sunflower and chickpea is 0.04 and 0.11, respectively (table 3). The highest values of the average linear deviation are in 2020 for sunflower and chickpea 6.44 and 6.89, respectively. On average, the variation in sprouting of the different varieties was 8-11 % for sunflower and 7-8 % for chickpea. The smallest linear deviations were observed in the variety Bagrat with 2.44 and 2.43 for sunflower and chickpea, respectively.

Table 3. Field germination performance of different winter wheat varieties cultivated using No-till technology, % (for the period 2018-2020).

| Predecessor | Variety   | 2018 | 2019 | 2020 | d         |
|-------------|-----------|------|------|------|-----------|
| sunflower   | Zustrich (St.) | 81   | 71   | 61   | 6.67      |
|             | Bagheera  | 79   | 73   | 64   | 5.33      |
|             | Bagrat    | 84   | 81   | 77   | 2.44      |
| d           | 1.78      | 4.00 | 6.44 | -    |           |
Winter wheat sprouted 19-20 days after sowing. On average the density of sprouts was 373-385 pcs/m². The variation of the indicator is practically similar for all varieties and precursors and corresponds to 3.6-3.7 %. For all varieties of winter wheat and phases from sprouting to earing, and precursors decreased plant density (the highest for the variety Zustrich - 7.3 %, the precursor - sunflower; the highest for the variety Zustrich - 10.2 %, the precursor - chickpea).

The highest values of the average linear deviation in the plants growth were in sunflower and chickpea 1.78 and 1.11, respectively during the sprouting phase, and the lowest were in earing (0.89 and 0.67, respectively) (table 4).

**Table 4.** Plant development dynamics of different winter wheat varieties cultivated using No-till technology, days (average for 2018-2020).

| Predecessor | Variety     | Phase | shoots | tillering | exit to the tube | earing |
|-------------|-------------|-------|--------|-----------|------------------|--------|
|             |             |       | autum  | spring    |                  |        |
| sunflower   | Zustrich (st.) | 23    | 21     | 12       | 27               | 7      |
|             | Bagheera    | 20    | 19     | 10       | 25               | 5      |
|             | Bagrat      | 18    | 18     | 10       | 24               | 5      |
|             | d           | 1.78  | 1.11   | 0.89     | 1.11             | 0.89   |
| chickpeas   | Zustrich (st.) | 21    | 20     | 12       | 25               | 6      |
|             | Bagheera    | 19    | 20     | 12       | 24               | 5      |
|             | Bagrat      | 18    | 18     | 11       | 22               | 4      |
|             | d           | 1.11  | 0.89   | 0.44     | 1.11             | 0.67   |

Note: d – the average linear deviation.

The productivity of all winter wheat varieties declined between 2018 and 2020. The largest deviations occurred in 2019 and 2020 (for sunflower and chickpea 0.20 and 0.23; 0.20 and 0.20, respectively) due to weather and climate anomalies (table 5).

**Table 5.** Yield dynamics of different winter wheat varieties cultivated using No-till technology, t/ha (for the period 2018-2020).

| Predecessor | Variety     | 2018 | 2019 | 2020 | d    |
|-------------|-------------|------|------|------|------|
| sunflower   | Zustrich (st.) | 4.38 | 4.08 | 2.94 | 0.57 |
|             | Bagheera    | 4.43 | 3.77 | 2.78 | 0.59 |
|             | Bagrat      | 4.71 | 4.36 | 3.31 | 0.54 |
|             | d           | 0.14 | 0.20 | 0.20 | -    |
| chickpeas   | Zustrich (st.) | 4.59 | 4.35 | 3.28 | 0.53 |
|             | Bagheera    | 4.51 | 4.01 | 2.96 | 0.58 |
|             | Bagrat      | 4.95 | 4.69 | 3.54 | 0.57 |
|             | d           | 0.18 | 0.23 | 0.20 | -    |

Note: d – the average linear deviation.

In general, the variation of the indicator is heterogeneous in all varieties and precursors and amounts to 128.1-199.3 %. For all varieties there was a decrease in the index (the highest for the variety Bagira - 2.78 t/ha, the precursor - sunflower; for the variety Bagira - 2.96 t/ha, the precursor - chickpea). Bagrat
variety showed the best results for chickpea (average linear deviation - 0.57), and Zustrich variety for sunflower (average linear deviation - 0.53).

The results of the two-factor analysis of variance showed the reliability of the effect of GTC on the yield (significance level of 95.0 %) (table 6).

Table 6. Results of the two-factor analysis of variance in the indicator hydrothermal coefficient and yields, t/ha (average for 2018-2020).

| Source of variation | SS    | DF | MS          | F_fact. | p-value | F_theor. |
|---------------------|-------|----|-------------|---------|---------|----------|
| Predecessor - sunflower |       |    |             |         |         |          |
| Factor A (HTC)      | 0.3441| 2  | 0.1720      | 16.7124 | 0.0114  | 6.9443   |
| Factor B (Y)        | 3.5543| 2  | 1.7771      | 172.6314| 0.0001  | 6.9443   |
| Error rate          | 0.0412| 4  | 0.0103      |         |         |          |
| Total               | 3.9396| 8  |             |         |         |          |
| Predecessor - chickpeas |     |    |             |         |         |          |
| Factor A (HTC)      | 0.4844| 2  | 0.2422      | 37.9721 | 0.0025  | 6.9443   |
| Factor B (Y)        | 3.3251| 2  | 1.6625      | 260.6777| 5.7971  | 6.9443   |
| Error rate          | 0.0255| 4  | 0.0064      |         |         |          |
| Total               | 3.8350| 8  |             |         |         |          |

Note: HTC - hydrothermal coefficient, Y – yield, t/ha, SS - sum of squares of variance, DF - number of degrees of freedom, MS - variance, F_fact - actual value of Fisher's ratio, p-value - Pearson value, F_theor - theoretical value of Fisher's ratio.

There is significant statistical significance (F_fact > F_theor) between the factors considered over the period under study for all precursors.

7. Conclusion

The growth, development and productivity of winter wheat grown using No-till technology from 2018 to 2020 were affected by the emerging weather and climatic conditions. Rainfall tended to decrease, while temperature and the NDVI vegetation index tended to increase. The average annual linear deviation of the hydrothermal index in relation to the vegetation index is 17 times higher, indicating that they are poorly correlated.

The sowing dates of winter wheat were determined by external conditions and shifted to a later date depending on weather and climatic conditions in 2019 and 2020. Winter wheat emerged 19-20 days after sowing. Plant field germination decreased from year to year for all precursors and varieties (the highest for the Zustrich variety was 74-75 % for all precursors). On average, the variation in germination for different varieties and precursors was 9 % (the lowest for chickpea - 7.5 %). Plant development was highly heterogeneous in all phases with the exception of tillering (8.6-9.0 %). On the contrary, the variation rates of plant density were homogeneous in all varieties and precursors (3.65 %). Decrease in this indicator was observed from the phase of sprouting to earing and for all precursors.

During the period under consideration the decrease of productivity of all varieties of winter wheat was observed. The largest deviations of indicators were in 2019 and 2020, which is due to weather and climatic events. The variety Bagrat showed the best results for chickpea (average linear deviation - 0.57), and the variety Zustrich for sunflower (average linear deviation - 0.53).

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