Influence of precipitation variability and temperature conditions on the yield of grain crops in Northern Kazakhstan

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Abstract. The article considers the influence of climate variability (precipitation and air temperature) on the yield of grain crops in Northern Kazakhstan. The paper uses data from some weather stations in the Northern regions of Kazakhstan, located in the main grain-growing zone. Because of the research, the dependence of grain yield on temperature and humidity for specific years of the last decades has been revealed. With an increase in precipitation, there is an increase in productivity in the North Kazakhstan and Kostanay regions, and the decrease in precipitation has a greater impact on the decrease in productivity in the Akmola and Pavlodar regions. Using the regression equation, the dependence of grain yield on the variability of air temperature and precipitation in the Akmola region (for the Esil weather station), a retrospective analysis was performed with the restoration of yield values for 1969-2019. The results of comparing the restored and the true (actual) yield showed a good correlation-0.84, which confirmed the reliability of the values. There are quite close relationships between the decrease in yield at high summer temperatures with reduced humidity, and the increase in yield at low summer temperatures, which is typical for the steppe and forest-steppe regions of Northern Kazakhstan. The yield of grain crops in the Akmola region, in the area of the Esil weather station, was affected by 72% by moisture, and 28% by other factors.

1. Introduction
The Republic of Kazakhstan is one of the largest countries of the Eurasian continent. The territory of Kazakhstan is far removed from the oceans, which has determined the variety of pro-natural climatic conditions. The Republic has a well-developed agro-industrial complex, which mainly specializes in grain production and livestock production. Grain farms are mostly located in the northern part, where the main sown areas of crops are concentrated.

The largest sown areas of grain crops are dispersed in four areas: North Kazakhstan, Kostanay, Akmola, Pavlodar. According to the Statistics Committee of the Ministry of National Economy of the Republic of Kazakhstan for 2019, these regions account for 71% or 15.6 million hectares of the total sown area (22.1 million hectares) of the Republic (table 1) [1].
Table 1. Sowing acreage of the northern areas of Kazakhstan, (thousands of hectares).

| Regions             | Sowing acreages in thousands of hectares | Part from total acreage % |
|---------------------|-----------------------------------------|---------------------------|
| Kostanay            | 5054                                    | 22.8                      |
| Akmola              | 4993                                    | 22.6                      |
| North Kazakhstan    | 4243                                    | 19.2                      |
| Pavlodar            | 1327                                    | 6                         |
| Others              | 6519                                    | 29.4                      |
| Total on Republic   | 22136                                   | 100                       |

This distribution of sown areas determines the main direction of the socio-economic policy of the northern part of the Republic, which consists in the development of the agro-industrial complex and agriculture. Economic activity with the advantage of grain direction is more dependent on natural and climatic factors. In turn, climatic conditions affecting the development of the feed base predeterminates the possibility of placing livestock complexes.

Agricultural yield planning is based on meteorological observations over a multi-year period, taking into account soil conditions that have been developed over previous decades. Climate resilience, with small variations within the mean of the summer, ensures crop yields within the target. However, the climate of our planet is changing. According to the UN the average temperature of the planet can in the nearest future will increase by 1-2 °C in comparison with the level of 1990 [2], the average annual anomaly of temperature of ground air in 2019, on average in the area of land of Earth was 0.74 °C, the greatest contribution to anomalies is observed in the Northern hemisphere 0.82 °C [3].

There is a debate in scientific society about the possible effects of climate change on agricultural production. Due to the complexity of the natural processes associated with climate change, it is difficult to make a qualitative forecast. However, most experts estimate that projected climate change may be accompanied by an increase in the incidence of adverse events to agricultural production, such as the recurrence of droughts [4].

In addition to climate change and the impact on yields in Kazakhstan, there has been another problem in recent years, which is mainly related to human activities. The currently observed intensive methods of farming with the use of heavy agricultural machinery, with the disruption of soil structure, the application of large quantities of chemical fertilizers lead to the reduction of soil fertility with further degradation and destruction of steppe landscapes [5].

In order to identify the possible impact of climate change on forest-steppe and steppe ecosystems of North Kazakhstan, it is necessary to carry out studies on the impact of climate indicators on crop productivity, to establish correlation between these indicators in order to plan measures to increase crop yield.

2. Materials and methods

Observations of several meteorological stations have been used to determine the dependence of crop yields cultivated in the territory of North Kazakhstan on climatic fluctuations observed in recent decades. Observation points are selected so that they cover the typical areas of the area under study and correspond to grain farms (table 2). During the calculation period, the period 1999-2019 was adopted.

Table 2. Location of weather stations of the researched territory.

| Meteorological stations (regions) | Latitude (N) | Longitude (E) | Height above sea level, m |
|----------------------------------|--------------|---------------|--------------------------|
| Iryshsk (Pavlodar)               | 53°20'       | 75°27'        | 94                       |
| Kostanay (Kostanay)              | 53°10'       | 63°35'        | 156                      |
| Ruzavka (North-Kazakhstan)       | 52°49'       | 66°57'        | 227                      |
| Esil (Akmola)                    | 51°95'       | 66°41'        | 221                      |
The initial data used are the average monthly air temperature and average monthly values of atmospheric precipitation for the warm period of the year from April to August. In order to detect the effect on the yield of grain crops, the coefficients of wetting of the territory have been determined.

3. Results and discussion

The analysis of agricultural production yield for the period 1999-2019 showed that the best indicator of agricultural crop production productivity corresponds to North Kazakhstan region (table 3).

Table 3. Average showings of grain crop of Northern Regions of Republic of Kazakhstan for 1999-2019.

| Regions            | Yield, U (c/ha) |
|--------------------|-----------------|
| Pavlodar           | 7.8             |
| Akmola             | 10              |
| Kostanay           | 11.1            |
| North-Kazakhstan   | 13.4            |

The territory of North Kazakhstan is geographically located in the zone of arid climate. The general lack of humidification causes a slowdown in the biological processes occurring in plant communities, which makes it difficult for ecosystems to recover themselves, and therefore has an adverse effect on farmland. Natural complexes developing in such “damaged” conditions have low potential for resistance to external effects and are susceptible to degradation. The soil cover of the studied area changes from north to south having a latitude zonal. The most fertile soils are located in the northern, most moistened part of the territory and are represented by three subtypes of black soil (leached, common and southern), which are replaced in the southern part by subtypes of chestnut soils having less fertility.

The climatic conditions of North Kazakhstan are continental, cold and long winters and hot summers. About 10... 15% of heat energy is spent on cryogenic phenomena (heating and melting snow, ice, soil skeleton and melt water) [6]. The territory is poorly provided with atmospheric precipitation. The largest number - 350... 400 mm is observed in the northern part - decreasing to the south. Low rainfall with sufficient heat is a determinant of risky agriculture.

Depending on climatic conditions crop yield has a great variation - moisturized years, for example, in 2011, in North Kazakhstan and Kostanay regions the yield of cereals reached up to 20.4 and 18.4 c/ha respectively. In dry years in some regions there was a low yield of cultivated cereals, in particular in 2010 in Akmola region (5.2 c/ha), in 2008 and 2012 in Pavlodar region (3.8 and 3.7 c/ha respectively) (figure 1).

![Figure 1. Crop yield in North Kazakhstan for 1999-2019, c/ha.](image)

The interannual dynamics of yields in the regions of North Kazakhstan as a whole is quite synchronous, which makes it possible to apply the dependencies obtained according to the weather stations Iryshsk, Ruzaevka, Kostanay, Yesil with the most correct results of regression equations with yields in North Kazakhstan (table 4).
Table 4. Correlation matrix of yield by region, 1999-2019.

| Region       | North-Kazakhstan | Kostanay | Akmola | Pavlodar |
|--------------|------------------|----------|--------|----------|
| North-Kazakhstan | 1                |          |        |          |
| Kostanay    | 0.64             | 1        |        |          |
| Akmola      | 0.87             | 0.78     | 1      |          |
| Pavlodar    | 0.37             | 0.17     | 0.43   | 1        |

As can be seen from Table 2, the correlation matrix of yield by regions for 1999-2019 shows the presence of a close link between the indicators of North Kazakhstan and Akmola regions (tight link 0.86) and Kostanay and Akmola regions (tight link 0.78). Since there is a weak link between the yield of Pavlodar region and the yield of North Kazakhstan and Akmola regions and the lag of the link with the yield indicators of Kostanay region (0.17), this region should be analyzed separately.

The obtained results of the correlation matrix of grain yield made it possible to select weather stations to perform regression analysis of yield with the most significant heat-generating factors - temperature and amount of atmospheric precipitation during the growing period (table 5).

Table 5. Results of calculations of regression estimation of yield U (c/ha) depending on meteorological elements.

| Meteorological station       | R    | R^2  |
|------------------------------|------|------|
| Ruzaevka (North-Kazakhstan)  | 0.71 | 0.50 |
| Kostanay (Kostanay region)   | 0.77 | 0.60 |
| Esil (Akmola region)         | 0.84 | 0.71 |
| Irtyshsk (Pavlodar region)   | 0.79 | 0.62 |

The close effect of meteorological elements on yield (multiple correlation coefficient R) is greatest in Akmola region (Esil) and Pavlodar region (Irtyshsk), and in Kostanay and North Kazakhstan regions the influence of meteorological factors decreases. As a result of the data obtained, it can be concluded that between 50 and 71% of yield variability occurs due to meteorological factors.

The analysis of the obtained regression equations for North Kazakhstan showed the greatest contribution to the variance of the yield of the average summer air temperature, in connection with this, a comparison of the restored values of the yield and the average summer temperature calculated according to the data of the true instrumental observations of the Esil weather station was carried out (figure 2).

Figure 2. Comparison of crop yield in Akmola region (Esil weather station) (crop restored) with average summer temperature for 1969-2019.
Judging by the chart presented in Figure 2, it can be seen that in the crop years there is a high air temperature of summer seasons, and in the years with lower summer temperature the yield increases, which is characteristic of the steppe areas of North Kazakhstan.

Along with thermal and power resources, the yield depends on the moisturization of the territory [7]. As moisture supply, consider the effect of the humidification factor on the yield of cereals. In the works of Professor Mezentsev V.S. [8] the structure of relations between heat resources and moisture resources is determined by the level of moistening (natural or anthropogenic); Therefore, the ratio of:

$$B_H = \frac{L(KX)}{T_Z} = \frac{KX}{Z_m}$$  \hspace{1cm} (1)

where, $KX$ - Atmospheric precipitation (corrected for under-accounting of measuring instruments), mm;
$Z_m$ - Water equivalent of thermal and power evaporation resources, mm;
$L$ - specific heat of evaporation of water, equal 2.521 MJ/(m$^2$·mm);
$T_Z$ - TER evaporation in MJ/(m$^2$·year).

As a result of the calculations according to formula (1), humidification factors were determined in the territory of North Kazakhstan for the growing period (May-August) for 1999-2019 years using the sums of air temperatures above 0 °C and the amounts of precipitation corrected for the understatement of measuring instruments of the characteristic weather station Esil (Akmola region), the obtained results were compared with the yield of grain crops (figure 3).

![Figure 3. Comparison of crop yield in Akmola region with humidification factor for the growing period (May-August) for 1999-2019.](image)

As can be seen from the graph (figure 3) in years with low yield there is a decrease in humidification coefficient during vegetation, in crop years - some increase. By analyzing the graph, there are some inconsistencies in the relationship between these indicators, which is due to possible errors in the observation series and the limited amount of meteorological data in these relationships. In general, the correlation coefficient of these dependencies was: $R = 0.72$. In this case, the statistics confirm that these dependencies are partially related, that is, 72% of the impact on the yield of Akmola region in the area of the Esil weather station was from moistening, and other factors accounted for 28%.
In order to study in more detail the effects of atmospheric humidification, which is the main limiting factor in the cultivation of cereals in forest steppe and steppe areas, it is necessary to continue work on expanding the base of weather data in order to improve the quality of regression models.

4. Conclusion
As a result of the joint consideration of yields in recent decades, the temperature regime of the summer season and the time of drought in the territory of North Kazakhstan, it can be concluded that climate variability has a significant impact on agricultural production.

Thus, based on the analysis of the effect of air temperature variability and precipitation on crop yields in North Kazakhstan, the following conclusions can be shown like this:

- According to Committee on statistics of the Ministry of national economy of Republic of Kazakhstan for 2019 71% or 15.6 million hectares from all cultivated area (22.1 million hectares) are the share of a share of 4 areas of Northern Kazakhstan.
- In moisturized years (2011) in North Kazakhstan and Kostanay regions the yield of cereals reached 20.4 and 18.4 c/ha respectively. In dry years in Akmola and Pavlodar regions there was a low yield of cultivated cereals, in particular in 2010 in Akmola region (5.2 c/ha), in 2008, 2012 in Pavlodar region (3.8 and 3.7 c/ha respectively).
- Based on the results of calculations of the regression equation showing the dependence of grain crops in Akmola region on meteorological factors (for the Esil weather station), retrospective estimates have been obtained since 1969, the coefficient of correlation of restored and true (actual) yield values for 1999-2019 years is R = 0.84.
- According to the analysis, a good relationship was found between low-yielding years with a high temperature of summer seasons and reduced moisture, and high-yielding years with a lower temperature of summer seasons, which is typical for the steppe and forest-steppe regions of Northern Kazakhstan.
- The yield of cereals in Akmola region, in the area of the Esil weather station, is affected by 72% by the humidification index.

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