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ENVIRONMENTAL FACTORS INFLUENCE ON THE PRODUCTIVITY OF CULTIVATED PLANTS

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SUMMARY

The following study aimed to explore the dependence of crops' yield on soil temperature and humidity. The study focused on the soil saturation with water and solar radiation as key factors affecting crop yields under current climate change conditions. The research employed agroclimatic measurement methods, temperature and phenological calculations, and correlational analysis methods. Based on over 20 years of data obtained from the Uralskaya Agricultural Experimental Station, Kazakhstan, agroclimatic conditions regarding temperature, precipitation, and hydrothermal coefficients reached successful analysis. Crop yield dependency evaluation through temperature and phenological assessments transpired. As a result, an identification of a clear correlation succeeded, with the most stable crop determined as sorghum. The barley crop showed higher yields in the favorable season of 2023, and sorghum, a drought-resistant crop, maintained consistent yields even in adverse seasons in 2021, emphasizing the importance of selecting suitable crops and their optimal sowing time to mitigate climatic challenges. The impact of temperature and productive moisture on crop yields was proven, revealing rising air temperatures (+1.9 °C) during the crop season and varied weather patterns as key drivers of increased drought frequency. Strategies to mitigate drought effects include cultivation of drought-resistant crops, improving agricultural practices, and enhancing meteorological services. Studying such relationships is crucial for ensuring food security in Kazakhstan.

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Key findings: The region's harsh humidification and rising temperatures (+1.9 °C) have negatively affected crop yields. In contrast to barley, the sorghum, being a drought-resistant crop, consistently performed well, even in dry crop seasons, such as in 2021. Optimizing sowing times, cultivating drought-resistant crops, and the ascendancy of agroclimatic data can mitigate the negative impacts of climate variability on agriculture.

INTRODUCTION

Food production for the world's ever-increasing population in the context of its growing number and changing climate is the main concern. Projected crop yields under different agroclimatic conditions are necessary to assess the prospects for food security (Morozov *et al*., 2022; Abdullayev *et al*., 2024; Katherasala *et al.*, 2024). Abiotic stresses, such as drought, salinization, extreme temperatures, chemical toxicity, and oxidative stress, threaten crops and the natural state of the environment (Rivero *et al*., 2022; Zandalinas and Mittler, 2022; Zhyrgalova *et al*., 2024). Therefore, the effects of climate change are currently persistent in physical and ecological systems.

Climate change affects crop production in various regions of Kazakhstan (Rezaiei *et al*., 2023; Bolatova *et al*., 2024; Rafikov *et al*., 2024). Crop yields' variations due to climate change will influence land use, crop production, food prices, and macroeconomic indicators, such as GDP (Fujimori *et al*., 2018, 2022; Afiah *et al.,* 2024). Agrometeorological models built for large areas have linkages with growth and development and crop productivity, which provide information for forecasting yields considering water stress. Monitoring the soil water balance at different stages of crop growth can help assess the risks of reducing final yield associated with scarcity of soil water (Ahmed *et al*., 2022). Other climatic factors also affect productivity, namely, unfavorable air temperature at different stages of crop growth (Kunanbayev *et al*., 2024). Solar radiation and relative humidity also modify various physiological processes (Rosyadi *et al*., 2023) in agricultural plants.

The main factors affecting crop yields are the amount of precipitation and air temperature during the growing season, which falls in June-July for early crops and in July-August for late crops. During these periods, it is easier to determine the amount of crop yield. Furthermore, during these periods, drought usually occurs with insufficient precipitation and high air temperature. The combination of these factors can considerably reduce crop yields even with good spring moisture reserves in the soil (Solovyov *et al*., 2024). Typically, droughts lead to the disruption of the water balance. The persistent type of drought is more harmful since it covers the largest part of the growing season (from early spring through July), where, eventually, all crops suffer (Purwaningrum *et al*., 2024; Sapanov *et al*., 2024).

In various regions of Kazakhstan, droughts often come with dry winds, strong gusts of wind, and high air temperatures. Dry winds occur under the following conditions: when the air temperature is above 25 °C, relative humidity is below 30%, and wind speed is more than 5 m/s. The extent to which dry winds will adversely affect the cultivated plants depends on the degree of soil moisture. If the arable soil layer contains more than 20 mm of productive moisture and the meter layer contains 100 mm, then no damage will happen to plants, except when a strong dry wind blows during the flowering period of cultivated plants (Ualkhanov *et al.,* 2024; Dyussibayeva *et al*., 2024).

Solar radiation is the most crucial climatic factor, with a greater impact on all aspects of plant life, i.e., development, maturation, and crop quality (Sultana *et al*., 2023). Studies found that 90%–95% of the crop's dry mass development occurs during plant photosynthesis due to solar radiation energy. However, if the intensity and productivity of photosynthesis increased, the distribution of absorbed energy between photosynthesis and transpiration would vary, and the proportion of energy going to photosynthesis would also increase (Kyere *et al*., 2024). As a result, an escalation in photosynthetic production and yield exists along with a significant decrease in the water consumption during the formation of each ton of crop dry mass (Grigorieva *et al*., 2023).

The model application confirms the assumption about the influence of climate change on crop yields and the expansion of zones in the North (Skrypnyk *et al*., 2021). Investments aimed at improving agriculture adaptation to climate change inevitably give preference to some crops and regions (Dulambayeva *et al*., 2023). The suitability of climate change adaptation strategies depends on the characteristics of the system that needs to adapt (Fahad *et al.,* 2017; Peker *et al.,* 2021; Dossa *et al.,* 2023).

Crop cultivation in West Kazakhstan has existed for over 150 years, and the presented study further focused on the West Kazakhstan Region. A characteristic feature of this region is its aridity, which sits on a zone of risky agriculture (Nasiyev *et al*., 2022). Despite the availability of minerals, West Kazakhstan faces significant problems due to low annual precipitation and temperature fluctuations, which directly affect major crops yield. Therefore, the promising study aimed to assess the impact of climatic factors, such as temperature, precipitation, and soil moisture, on crop yields over 20 years. The study sought to support the development of adaptive agricultural strategies that can mitigate the risks associated with climate change, improving yield stability and ensuring food security.

MATERIALS AND METHODS

The study commenced in the West Kazakhstan Region, with divisions of three zones based on climate (Table 1). In the first zone, crop cultivation is possible, with heat needs of up to 2,400 °C to pass through the entire vegetation. In the second zone, it is up to 2,600 °C, and in the third zone, it is up to 2,800 °C. The first zone comprises the northern part of the region, the second zone is the central strip, and the third zone has the southern part. In the first zone, the agroclimatic conditions meet crops' requirements from groups 1 to 6, while the second zone has groups 1 to 7. However, the southern dry farming border lies in the middle of the second zone, and below this line, farming is impossible without irrigation. In the third zone, the climate is very arid, and agroclimatic conditions do not allow cultivating crops without irrigation. In this zone, the soil cover has low fertility and is mostly unsuitable for agriculture.

The use of traditional agroclimatic indicators helped assess the agroclimatic conditions. These are annual and average monthly air temperatures, active temperatures exceeding 5 °C and 10 °C, dates of steady transition of the average daily air temperature (0 °C, 5 °C, and 10 °C) in spring and fall, duration of an average daily temperature (0 °C, 5 °C, and 10°C), average temperatures of the coldest and warmest months of the calendar year, annual precipitation, and

Table 1. Main climatic indicators of natural and economic zones of West Kazakhstan.

Indicators	Zones		
	First	Second	Third
Annual precipitation (mm)	270-300	240-260	190-230
including the precipitation during the warm period (mm)	125-135	100-130	100-120
Maximum height of snow cover (cm)	25-30	20-25	10-15
Water reserves in the snow (mm)	75-95	60-75	40-50
HTC for the vegetation of grain crops	0.5-0.6	0.3-0.5	0.2-0.3
Sum of the positive average daily air temperatures over 10 °C	2,800	2,800-3,000	3,000-3,400
Period of active vegetation of plants (days)	150-155	155-160	160-165
Frost-free period (days)	130-135	145-155	160-180

Table 2. Average annual air temperature over 20 years.

Indicators	For 20 years (2004–2023)	Deviation from the norm
From May to August	21.3	1.4
From September to April	-0.2	2.1
For the agricultural year	6.9	1.7

Table 3. Average annual productive moisture reserves over 20 years.

Indicators	For 20 years (2004–2023)	Deviation from the norm
From May to August	113.7	-14.4
From September to April	212.2	5.6
For one year	323.4	-11.3

hydrothermal coefficient. For the study, we also received average annual data from over 20 years of reports at the Uralskaya Agricultural Experimental Station in Kazakhstan.

In establishing the correlation between temperature and precipitation data and the obtained yield, the study used temperature and phenological calculation charts, determining the biological curves of crop vegetation.

In the first stage, scientists analyzed the temperature and hydrological indicators for the studied period. In the second stage, they analyzed yield data. The third stage saw them analyzing the dependence of yield on annual temperature and humidity indicators. In the fourth stage, the processing of results and visualization of detected interdependencies used Excel.

RESULTS AND DISCUSSION

The first zone emerged as the most moisture-rich area of the region, and the humidification conditions were extremely harsh. The dynamics of the average annual temperature over 20 years ranged from 5.8 °C to 8.8 °C, and the years 2007 (t 8.0 °C), 2016 (t 8.2 °C), and 2020 (t 8.8 °C) were dry years, with a high average annual temperature. However, the most favorable conditions appeared in 2008 (t 5.8 °C) and 2017 (t 5.9 °C). The average annual weather data for over 20 years underwent analysis. By assessing the air temperature in different years for varied periods of the agricultural year, the greatest deviations were evident from September to April by 2.1 °C (Table 2). In the main growing season (May to August), the deviation was 1.4 °C. The deviation for the entire agricultural year was 1.7 °C, while permissible deviation should not exceed 3 °C. Cherednichenko *et al.* (2024) also mentioned the Northwest Region of Kazakhstan experiences high summer and fairly low winter temperatures, with an expected increase in temperature of about 0.4 °C per decade until 2050.

In the Cis-Urals Region, the cultivated plants' yield depends on the moisture reserves in the meter layer of the soil during the sowing period of the prevailing weather conditions in May and the first two months of summer. On average, in annual productive moisture reserves in the last 20 years, the deviation from long-term data was -11.3 mm, with a deviation of -14.4 mm over the growing season (Table 3). According to this study's results, precipitation fell below the average annual norm. Together with the productive moisture reserves, it was necessary to consider the dynamics of the annual precipitation (Figure 1). According to Figure 2, the most favorable years for precipitation were 2010 (490 mm) and 2016 (460 mm), with the least favorable conditions recorded in 2014 (220 mm) and 2020 (230 mm). Markin *et al.* (2022) claimed that in the steppe conditions of the European part of Russia, including the Cis-Urals, the soil moisture was a limiting factor for crops, requiring irrigation often.

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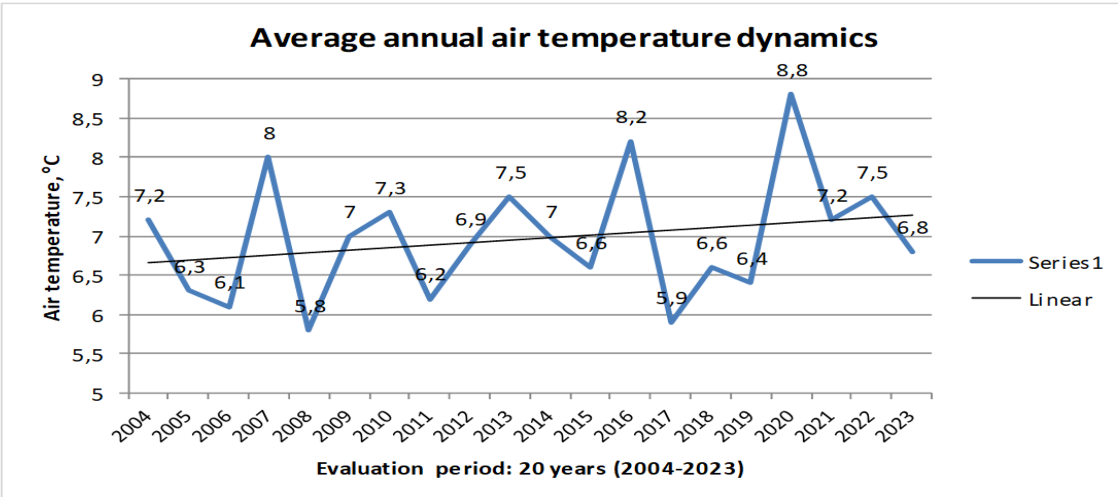


Figure 1. Average annual air temperature over 20 years.

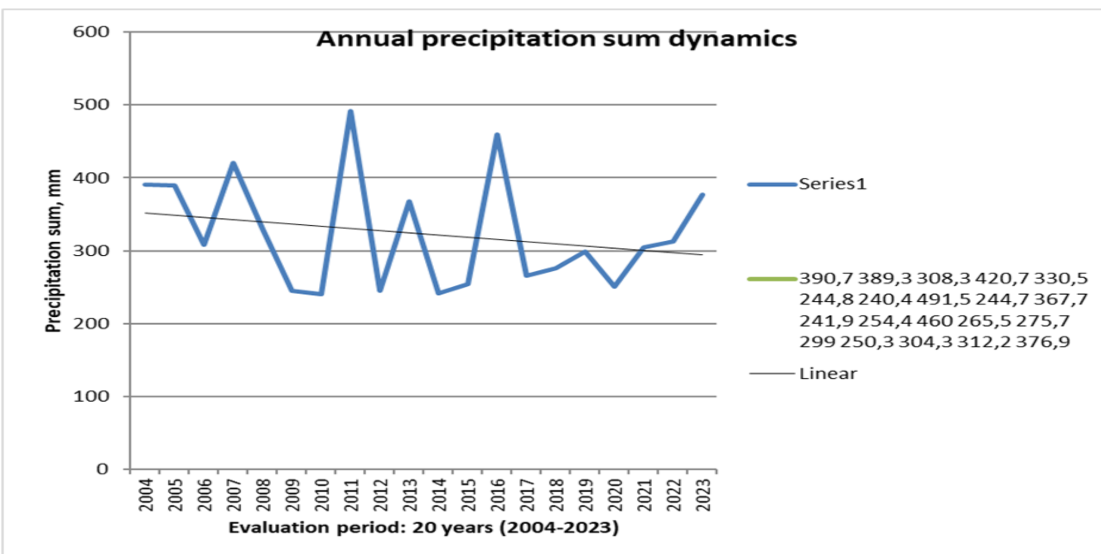
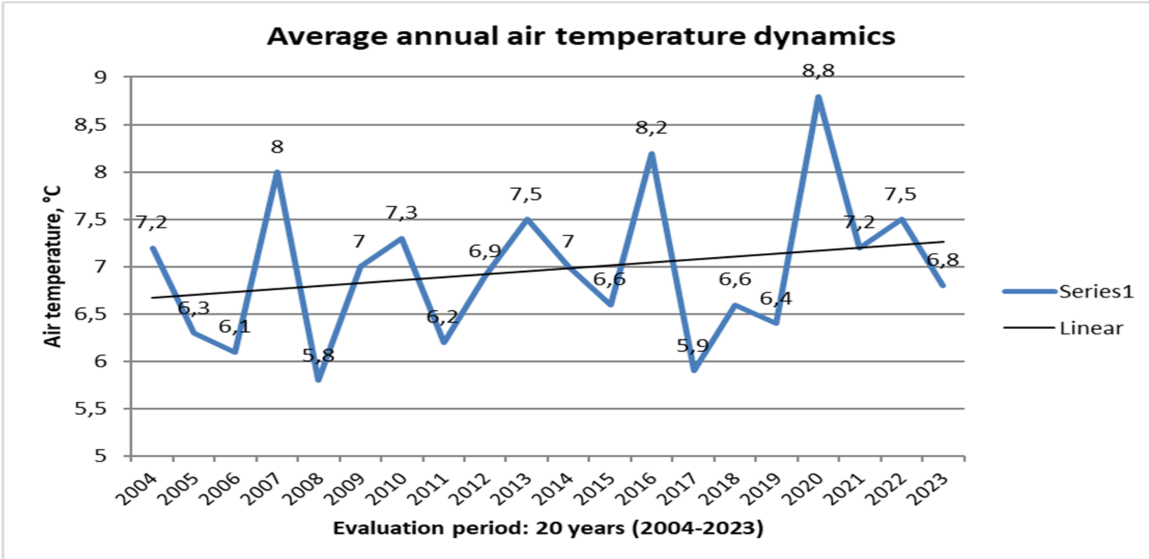


Figure 2. Annual precipitation dynamics throughout 2004–2023.

Observations of the influx of solar radiation showed a definite relationship between the total fall radiation, the duration of sunshine in September, and the degree of aridity in the next growing year. The dynamics of the average annual temperature revealed the highest temperature appeared in 2007 (8 °C) and 2016 (8.2 °C). Later, a further



Figue 3. Average annual air temperature dynamics.

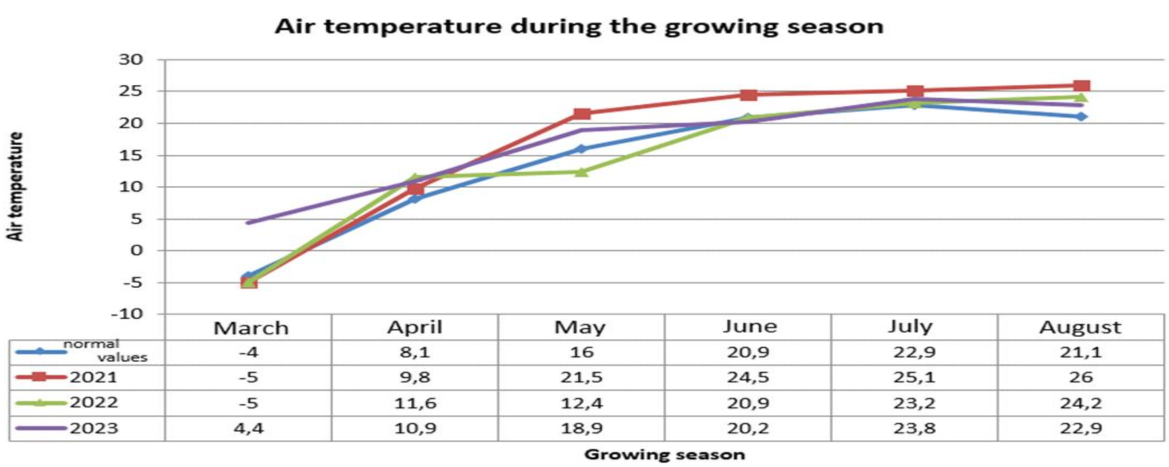


Figure 4. Air temperature during 2021–2023.

increase was evident in 2020 (8.8 °C). Therefore, the data for the last three years are further available. The region emerged as more suitable for the growth and development of long-day plants, and solar radiation under natural conditions is sufficient for optimal vital crop activity. Domínguez-Álvarez *et al.* (2021) emphasized the understanding of solar radiation for efficient agricultural practices, suggesting that sufficient solar radiation in natural conditions can indeed promote optimal crop activity, particularly for crops thriving under long-day conditions.

After the dry year of 2020, the air temperature in all months of the growing season was above normal during 2021 (Figure 4). Later in 2023, the air temperature dropped (Figure 3) and approached the norm, making the year favorable for crop growth and development. As for precipitation in 2021, more rainfall manifested than the norm at the beginning of the growing season. In the following months, when spring crops needed moisture to pour grains, the precipitation was below the norm, which eventually affected crop yields. Among the three years, 2023 was the

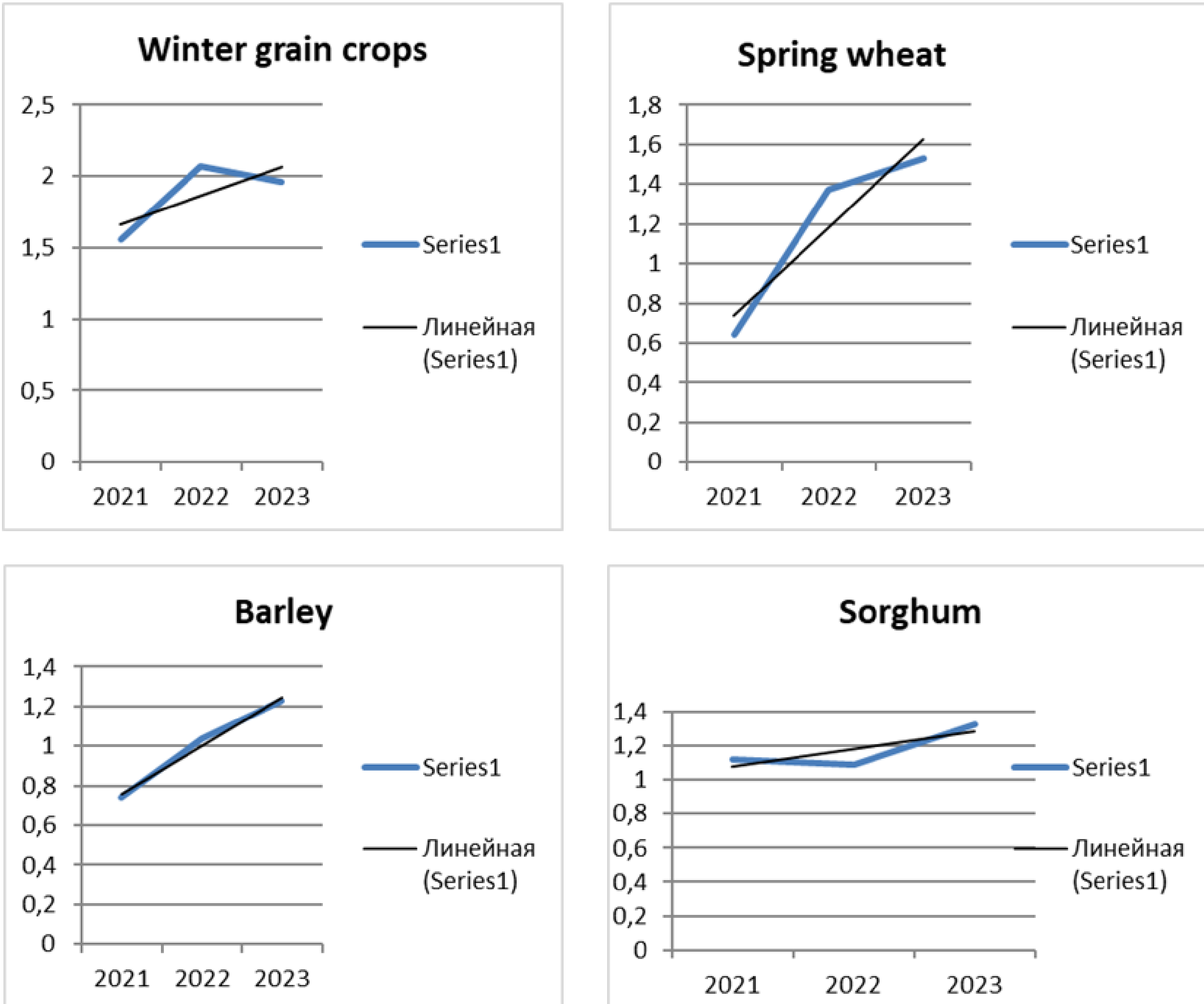


Figure 5. Dependence of the yield of main crops on weather conditions in 2021–2023.

most favorable, since only in June did a deviation in a decreasing direction exist; however, the precipitation exceeded the norm, which positively affected crops' growth and development.

For early-spring crops, the growing season duration was 193–211 days. However, for late-spring crops, the growing season duration increased from North to South (from 160 to 179 days) and in thermophilic crops (from 110 to 120 days). During the growing season (with an air temperature above 5 °C), heat accumulated from 3,100 °C to 3,800 °C. During the period with an air temperature of above 10 °C, heat accumulated from 2,900 °C to 3,600 °C. In the northern part of the region, 2,270 °C of heat comprised 90%, while in the south, about 3,520 °C of heat was notable for a period with a temperature above 10 °C. Concerning thermophilic crops (at temperatures above 15 °C), the heat resources necessary for growth ranged from 2,400 °C to 3,100 °C. In 2021, the barley had a yield of 0.516 t/ha, and in 2022, it was at 1.01 t/ha, while in 2023, which had favorable weather conditions, it resulted in 1.06 t/ha (Figure 5). These findings complement the observations made by Zhunisova and Baisholanov (2024), who reported that, in Almaty Region, Kazakhstan, the longest growing season was prominent in the central part (190 to 200 days).

In West Kazakhstan, the weather conditions for spring wheat cultivation detailed characteristics of insignificant moisture reserves at the beginning of sowing, with arid spring and summer, high deficiency of humidity, and large daily air temperature amplitudes. In the sowing and germination phases, the plants' development usually had low air and soil temperatures. During the period of tillering and waxy ripeness, immature plants, as affected by intense drought and dry winds, negatively affected the yield. The year 2021 was the driest year, in which the spring wheat yield was the lowest (0.6 t/ha). Meanwhile, in the favorable 2023, the yield was 2.2 times higher (1.5 t/ha), with an average annual temperature of 7.5 °C. Therefore, to ensure higher spring wheat yields, it is vital to promptly determine the optimal sowing time. For adaptation of agriculture at the regional and local levels, other strategies include the breeding of new crop varieties (Islam *et al.*, 2024), land use change, innovative breeding methods, and efficient use of water and soil resources through agronomic methods (Konopianov *et al.*, 2024) and farmer training (Ydyrys *et al.,* 2023).

The grain yield data of spring and winter crops for 2021–2023 sustained analysis, and the year 2021 appeared as the most unfavorable for precipitation and temperature. In that year, early-spring crops reacted to unfavorable conditions with reduced yields, whereas the winter crops had good yields. For forage crops, the data based on barley and sorghum bore scrutiny. The barley crop is very demanding of climate; therefore, high yields were evident in 2023, found favorable based on agroclimatic data. Sorghum belongs to late crops and is resistant to drought, reaching authentication as not a demanding crop by the soil. The sum of temperature (2,800 °C–3,500 °C) occurred as favorable for this culture. Sorghum consumes 300 parts of water to form a unit of dry matter. Based on the yield data, sorghum also showed good yields in the unfavorable year of 2021. Moreover, in subsequent years, its yield was consistently high. Bulekova *et al.* (2023) reported that sorghum is well-suited for cultivation in West Kazakhstan due to its adaptability to various soil and climatic conditions, particularly in arid environments. The research conducted during the period of 2019–2021 at the Ural Agricultural Experimental Station, Kazakhstan, demonstrated sorghum can be effectively grown after perennial grass mixtures, enhancing soil fertility and providing a viable option for crop rotation.

CONCLUSIONS

For the said study, the air temperature and the productive moisture reserves over 20 years, as analyzed, established the dependence of yield indicators on air temperature and productive moisture reserves over this period. The most effective way to resist drought is to grow the best productive and drought-resistant winter and sorghum crops. The analysis showed that, in spring wheat, the maximum yield recorded in the administrative districts of the region was about 50% of the bioclimatic potential (BCP). This means that in the region, the upper level of BCP utilization was about 50%, which revealed an insufficiently high level of agriculture but highlighted its potential. At the regional and national levels, we propose more elaborate financial schemes, insurance, competent migration policy, the development of agricultural and meteorological services, and research and development departments for forecasting systems. Future research could focus on developing advanced climate prediction models and drought-resistant crop varieties to enhance agricultural resilience.

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