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THE IMPACT OF CLIMATE CHANGE ON WHEAT PRODUCTION IN KAZAKHSTAN'S DIVERSE SOIL REGIONS

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1. Introduction

The Republic of Kazakhstan is a country located in the northern part of Central Asia. It has state borders with five countries: in the west and north with Russia, in the south with Turkmenistan, Uzbekistan and Kyrgyzstan, and in the east with China.

Wheat is a key agricultural crop for Kazakhstan and plays an important role in ensuring the country's food security. The northern regions of Kazakhstan are characterized by extensive arable lands and favorable soil conditions. They are considered as the main areas of spring wheat cultivation. However, climate and soil conditions have a significant impact on its yield. Moreover, the yield of wheat can vary significantly depending on the region. These differences are largely related to climatic conditions and soil characteristics that determine plant growth and development opportunities. Although wheat is an essential food resource, especially in conditions of drought and adverse weather, which reduces yields, its quantity directly depends on these natural factors.

Kazakhstan is distinguished by a variety of natural conditions: in one country, there are several different climatic zones and soil types. This diversity can create both favorable and constraining factors for agriculture. The climate varies from sharply continental in most of the territory to milder in the south and coastal areas, which affects the formation of soils such as chernozems in the north and solonchak soils in the desert area. In the context of climate and the need to improve agricultural efficiency, it is becoming particularly relevant to study the influence of climatic factors on wheat yields in different regions. Comparative analysis allows identification of certain tendencies.

1.1 Objectives

The objective of the study is to explore the impact of soil and climate in different regions of Kazakhstan on the productivity of the spring wheat crop in the period from 2015 to 2025, with the help of official data sources. In addition, this research aims to evaluate climatic parameters in different regions, namely Akmola, Kostanay, and North Kazakhstan, to trace alterations in the wheat yield and determine certain tendencies in 2015-2025, and overall, to evaluate the contribution of different regions to the total wheat production of the country. This study is directed to identify tendencies of the influence of soil and climatic conditions on wheat yield in different regions of Kazakhstan, to expand the knowledge of the interrelationships between agroecological factors and crop productivity.

2. Literature Review

2.1 Role of Kazakhstan in the Global Wheat Production

Kazakhstan is the ninth country in the world, and is located in the middle of the Eurasian continent. It has demonstrated steady development in recent years (Karatayev et al., 2022). According to the World Bank, in 2023, the total territory of Kazakhstan accounted for 2.725 million square kilometers (http1).

Based on the Food and Agriculture Organization of the United Nations Corporate Statistical Database, wheat is considered to be one of the main commodities in Kazakhstan, therefore, 12.1 million tonnes of wheat were produced in 2023, as it is demonstrated in Figure 1 below (http2).

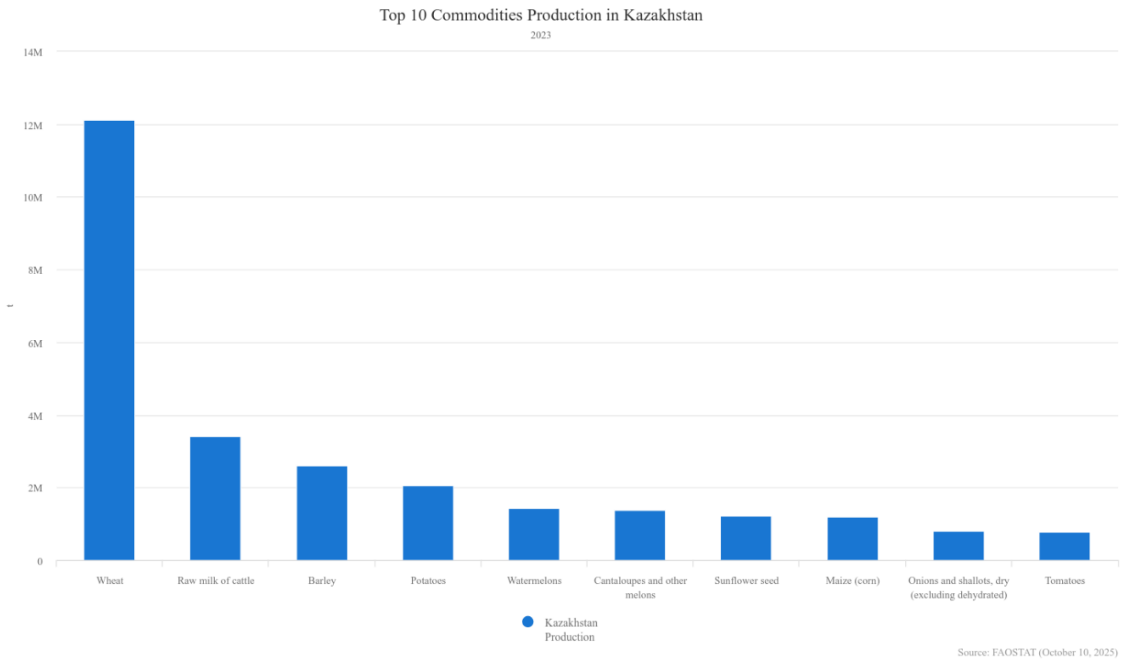

Figure 1. Top 10 commodities production in Kazakhstan in 2023.

Source: FAOSTAT (http2).

Moreover, in accordance with Figure 2 below, Kazakhstan ranks among the top eight global wheat exporters, alongside countries such as the United States, Argentina, Canada, Australia, the European Union, Russia, and Ukraine. Within Europe and Central Asia regions, which together account for roughly 15% of the global agricultural and fishery output. Also, Kazakhstan holds a prominent position, contributing along with the EU, the UK, Russia, Ukraine, and Turkey. Notably, projections indicate that Kazakhstan's wheat production could rise by 26% by 2033, reflecting the growing role in global food security of the country (FAO, 2024).

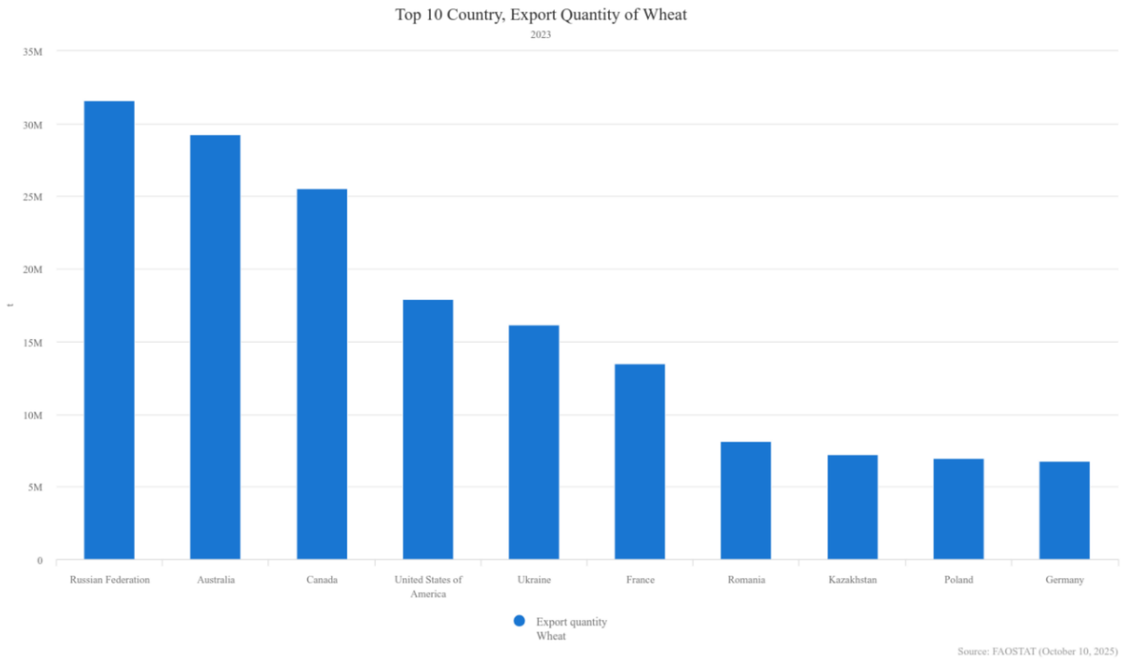

Figure 2. Top 10 countries by wheat export quantities in 2023.

Source: FAOSTAT (http2)

The Republic of Kazakhstan is a leading producer and exporter of wheat (*Triticum spp*.). The country cultivates wheat on an area ranging from 10 to 14 million hectares, with an average annual grain production of 9 to 22 million tonnes (Feher et al., 2017).

The primary wheat-producing area is located in the northern and north-central regions of Kazakhstan, characterized by predominantly flat terrain. In these zones, what is cultivated mainly on fertile chernozem and kashtanozem soils, contributing approximately 70% to the national total wheat output (Feher et. al., 2017). Therefore, wheat production in Kazakhstan is concentrated in three key regions, namely Kostanay, North Kazakhstan, and Akmola (Figure 3). Together, these regions account for around 80% of the country's total wheat output. They are located within the Western Siberian Great Plains (USDA, 2022).

Figure 3. Map of Kazakhstan by regions.

Source: USDA FAS, 2024.

Spring wheat serves as Kazakhstan's primary export crop. A significant portion of the grain supplied to international markets originates from Northern Kazakhstan, where spring wheat cultivation occupies approximately 85% of the sown area, amounting to nearly 10 million hectares (Babkenov et al., 2020).

2.2 Characteristics of the Spring Wheat

Based on studies of Simmons et al. (1985), when a grain of spring wheat is planted, the germination process begins. The root and seed are formed first, followed by the coleoptiles. New roots can form in several places on a young plant, both near the seed and around the crown. The crown is connected to the seed by a short section called the internode, which becomes longer when the seed is planted deeper. As soon as the coleoptile reaches the surface of the soil, it stops growing, and the first real leaf appears at its tip. After the sprout appears above the ground, new leaves appear at a rate of once every four to five days. As a rule, wheat plants develop a total of eight to nine leaves, while later-maturing varieties have slightly more. Shoots develop at the base of the main shoot, where the coleoptile and lower leaves are attached. In normal field conditions, a wheat plant usually forms about three shoots in addition to the main stem, although not all of them necessarily form a grain. Furthermore, during tillering, another important but less noticeable process occurs, which is the formation of plant heads both on the main shoot and on the roots. The elongation of the stem occurs simultaneously with the rapid growth of the heads, during which individual inflorescences mature and become ready for pollination and fertilization.

Considering the spring wheat type, it was found that quality indicators were generally higher in comparison to winter wheat, showing greater volume weight, as well as higher protein and gluten content. However, no significant differences were observed between the two types of wheat in terms of gluten index or falling number. Although spring wheat produced loaves with a slightly larger volume, the difference was not statistically significant. Additionally, the dough made from spring wheat demonstrated better stability (Koppel, R. E. I. N. E., & Ingver, A., 2008).

Moreover, the spring soft wheat variety ‘Shortandinskaya 2012’, which is grown in the northern part of Kazakhstan, demonstrates strong adaptability to environmental conditions, especially under drought stress. It has also shown a positive influence on crop productivity, reflecting the effective overall performance of the plant as an integrated system (Shestakova, 2024).

2.3 Wheat Growing Conditions in Kazakhstan

Consistent with the data from National Agrarian Science and Educational Centre, further NASEC (2019), in the northern regions of Kazakhstan, the successful cultivation of spring wheat largely depends on adherence to specific agronomic practices. The most favorable precursors for wheat sowing include clean fallow, leguminous crops, and perennial grasses, which contribute to improved soil fertility and moisture retention. Soil tillage practices typically involve either minimal or combined approaches, with the use of chisel and sweep cultivators to reduce moisture loss and preserve soil structure. Sowing should be carried out early in the season, once the soil has warmed to 5-6 °C, ensuring optimal germination conditions. Seeds are generally sown at a depth of 4 to 6 cm, with seeding rates ranging from 2.5 to 3.5 million viable seeds per hectare, depending on the variety and prevailing moisture conditions. These measures collectively support stable yields under the region’s semi-arid climate (http3).

Referring to the study conducted by Suleymenov and Baraeva (2020), optimal sowing dates for spring wheat vary across different zones of Northern Kazakhstan due to regional climatic differences. In the dry steppe zone, where late sowing does not pose a risk to crop maturity, spring wheat can be sown between May 18 and May 28-30. In the arid steppe zone, the recommended sowing window is slightly earlier, from May 15 to May 25. For the moderately arid steppe zone, earlier sowing (between May 13 and May 23) is advised to ensure the timely ripening of the grain, and wheat is collected in September.

Furthermore, in accordance with the data from the National Hydrometeorological Service of the Republic of Kazakhstan, Kazhydromet, the climate of North Kazakhstan, Kostanay, and Akmola regions is sharply continental, with sharp contrasts of winter and summer temperature, as well as day and night. Summers are dry and hot, but relatively short, winters are cold, with stable snow cover, strong winds, blizzards, and fogs. The average temperature in July ranges from 18 °C to 24 °C, with highs up to 45 °C. The duration of the warm period with temperatures above 0 °C averages 200-218 days. The annual precipitation varies from less than 220 mm in the south of the Kostanay region to 400 mm in the east of the Akmola region, with most of the precipitation falling during the warm period (April-October) (http4).

Based on the findings of Salnikov et al. (2023), the overall pattern shows an increasing recurrence of the TXx index (the maximum value of the daily maximum temperature over a specified period). However, slight and statistically insignificant negative trends are present in the northeastern and northern regions of Kazakhstan. Notable positive trends are observed exclusively in western Kazakhstan, where the rate of increase ranges from 0.4 to 0.7 °C per decade.

The length of the vegetation period, which is the period when the air temperature stays above 10 °C, varies across the region: it lasts about 130 days in the northern areas, 145 days in the central part, and up to 170 days in the south. In the northern part of the Akmola region, particularly in the Kokshetau Uplands, the season spans 130-135 days, while in the southern part of the Pavlodar district, around the Bayanauyl Uplands, it extends to 140-145 days (Baisholanov, 2025).

The primary constraint to increasing spring wheat yield in the northern region of Kazakhstan is moisture deficiency. The average annual precipitation ranges between 320 and 350 mm, which is insufficient to fully meet the crop's water requirements. Over the past five years, droughts of varying severity have occurred two to three times, further exacerbating the challenge of stable wheat production (Babkenov et al., 2020). Additionally, according to studies of Shamanin et al. (2016), although moisture stress remains the primary limiting factor in spring wheat production, rust diseases also pose a significant threat, particularly in years with increased rainfall, when conditions favor the development and spread of these pathogens. In addition to this, yields of spring-sown wheat show significant year-to-year fluctuations and are notably sensitive to drought conditions (Lioubimtseva et al., 2012). Moreover, forecasts indicate that by 2050, moisture availability during the growing season may decline by 11-16%, while climate aridity is projected to rise by 10-15% compared to current levels. These changes could potentially result in a 30-40% reduction in spring wheat yields (Zhumagulov et al., 2023).

Wheat is extensively cultivated in the rainfed conditions of semi-arid regions, where both the amount and frequency of rainfall during the grain-filling stage can fluctuate significantly. These variations often lead to changes in grain quality, affecting key parameters such as protein content and test weight (Ahmed, 2015). In the Akmola region of Northern Kazakhstan, spring soft wheat (*Triticum aestivum L.*) accounts for around 78% of all cereal crops cultivated. This crop demonstrates a promising yield potential, typically ranging from 1.4 to 1.8 tonnes per hectare. This level of productivity enables the region to achieve not only high grain yields but also wheat of superior quality with an elevated protein content (Zholaman et al., 2022).

As reported by NASEC (2022), soft spring wheat (*Triticum aestivum L.*) is the predominant wheat type cultivated in Kazakhstan. It is particularly valued for its adaptability to the local agroclimatic conditions, as this wheat variety is known for its strong drought resistance, resilience against lodging, and moderate to high resistance to common diseases such as rust and smut. The duration of its growing season typically ranges from 75 to 95 days, depending on the specific cultivar. In contrast, another widespread spring wheat (*Triticum durum Desf.*) is primarily grown for pasta production, due to its high-quality grain characteristics. Like soft spring wheat, it also exhibits excellent drought tolerance and lodging resistance. Furthermore, durum wheat demonstrates good adaptability to dryland (rain-fed) farming systems, making it a suitable choice for regions with limited irrigation (http3).

2.4 Geography of Wheat Farming in Kazakhstan

Kazakhstan spans a large territory in the heart of the Eurasian continent, encompassing a wide range of climatic zones, from extremely hot and arid deserts in the south to cold steppes and forested regions in the north. This geographic and climatic diversity leads to a heightened occurrence and severity of hazardous hydrometeorological events (UNEP, 2022).

Referring to the Kazhydromet, Kazakhstan's location within the temperate latitudes (40-55°N) results in high levels of incoming solar radiation, particularly during the summer months of June to August. In the northern part of the country, which is among the most moisture-supplied lowland areas, the evaporation rate significantly exceeds precipitation, therefore by two to three times during summer, leading to moisture deficits. Summers in this region are moderately hot but relatively short, with occasional spikes in temperature reaching up to 41 °C. Moving south into the steppe zone, the climate becomes noticeably drier. This area is marked by an even greater imbalance between evaporation and rainfall, with the evaporation-to-precipitation ratio ranging from 3:1 in the north to as high as 7:1 in the south. Compared to the forest-steppe, summers in the steppe zone are more prolonged and intense, yet considerably less humid. Average July temperatures range between 19 °C and 23 °C, with frequent peaks of 40-42℃, posing significant challenges for crop cultivation, particularly under rain-fed conditions (http4).

Drawing on the research of Geldiyeva et al. (1992), northern Kazakhstan is predominantly composed of steppe and forest-steppe landscapes, featuring a mix of hollows, uplands, and gently undulating plains. The region is characterized by grasslands and steppe meadows, as well as birch and aspen groves and forests, growing on various types of chernozem soils and gray forest saline soils.

The temperate steppe is characterized by a continental climate, a lack of trees in watershed areas, and the dominance of sedge vegetation growing on black and chestnut soils. This biome stretches in a broad. Continuous band from the plains near the Black Sea to western Siberia, but becomes broken up east of the Altay Mountains due to the increasingly mountainous terrain. Also, steppes serve as a traditional biome situated between the humid boreal forests to the north and the dry desert regions to the south. The forest-steppe zone marks the gradual shift from forest to steppe, while semi-deserts represent the transition from steppe to true desert environments (Chibilyov, 2002). Moreover, in Figure 4 (Rachkovskaya, 2006) below, the regionalization of Kazakhstan zones is seen.

Oblast	Sub oblast	Provinces	Sub provinces	Plain	Melko-sopochnik	Mountain
Eurasian steppe	Black Sea – Kazakhstanian steppe	West Siberian forest – steppe	North Kazakhstanian forest– steppe	I		
		Trans Volga – Kasakhstanian steppe	West Kazakhstanian	IIa		
			Trans Ural – Torgai	IIb		
			Central Kazakhstanian		IIc	
			East – Central Kazakhstanian		IId	
			Ertiss – Kulunda	IIe		
		South Altai mountain	West Altai			IIIa
			Kalba – South Altai			IIIb
			Sauyr – Tarbagatai			IIIc

Oblast	Sub oblast	Provinces	Sub provinces	Plain	Piedmont	Mountain
Sahara – Gobian desert	Iran – Turanian	North Turanian	Caspian	IVa		
			West – North Turanian	IVb		
			Central – North Turanian	IVc		
			East – North Turanian	IVd		
		Dzungarian	Dzungarian	V		
		South Dzungarian	West – South Turanian	VIa		
			East – South Turanian	VIb		
		Zhetysus – Alatau – North Tien Shanian	Cis-North Tien Shanian		VIIa	
			Trans Ile			VIIb
			North Zhetysus – Alatau			VIIc
			Kungei – Teriskei – Uzynkarin – South Zhetysus – Alatau			VIId
			Kyrghyzian			VIIe
		Mountain-Middle Asian	Cis-West Tien Shanian		VIIIa	
			Kara Tau			VIIIb
			West Tien Shanian			VIIIc

Figure 4. Phytogeographic regionalization of the Republic of Kazakhstan.

Source: Rachkovskaya, 2006.

2.5 Soils of Northern Kazakhstan

The soil-geographic zones of Kazakhstan, arranged from north to south, are as follows: forest-steppe, steppe, desert-steppe, and desert (Figure 5). Kazakhstan's vertical natural and soil zonation is shaped by mountain elevation, its geographical location within horizontal landscape zones, and the prevailing humid and arid airflows. Ordinary chernozem soils are typically found within the subzone of moderately humid steppe regions. The forest-stepper zone covers limited areas in the northernmost part of Kazakhstan and is characterized by compact patches of grey forest soils. These soils typically form under grassy birch forests, and occasionally beneath birch-aspen or pine stands. Generally, grey forest soils are found in combination with chernozems, meadow-chernozemic soils, and solonetzes (Pachikin et al., 2009).

Figure 5. Map of the soils of Kazakhstan.

Source: Pachikin et al., 2009.

The steppe and forest-steppe regions are typically characterized by two main soil types: chernozems (black soils) and kashtanozems (chestnut soils). Chernozem is considered one of the most fertile soils on Earth. In Northern Eurasia, it spans roughly 1.9 million square kilometers. Unlike many other soils where organic matter builds up as surface litter, in chernozems, it is more evenly distributed throughout the soil profile. This is largely due to the deep and extensive root systems of native vegetation. The most favorable conditions for chernozem formation conditions for chernozem formation are found in the southern forest-steppe, where a combination of rich plant biomass, ideal temperatures, and sufficient moisture supports their development, and by this resuting in thick, nutrient-rich soils. Moving northward, the increasing humidity leads to the leaching of minerals and the beginning of podzolization, which gradually alters the soil's structure and fertility (Chibilyov, 2002).

Chernozem soils are considered highly valuable from both agricultural and environmental perspectives due to their exceptional capacity to retain large amounts of soil organic matter (SOM) (Funakawa et al., 2004).

Chernozem soils cover approximately 25.3 million hectares in Northern Kazakhstan and are considered the most fertile and agriculturally valuable soils in the country (Borovski and Uspanov, 1971). During the Soviet era, around 11 million hectares of chernozem soil were planted annually with spring wheat as part of a political initiative to rapidly boost grain production by extensively plowing lands. Over nearly five decades of continuous wheat monoculture, summer fallow was a common practice in crop rotations to conserve soil moisture, enhance nutrient availability through mineralization, and manage weed growth. These fallow fields were typically tilled multiple times to maintain bare soil throughout the growing season (Karbozova-Saljnikov et al., 2004).

The natural conditions of Northern and Central Kazakhstan, along with the energy capacity of kashtanozem soils, indicate strong potential for agricultural productivity, particularly under irrigation. These soils feature a humus-rich layer 35-50 cm deep, containing 3.0-3.5% humus. Notably, about 75% of this organic matter is concentrated within the top 50 cm, reflecting a shallow humus profile. Soil salinity is minimal, with salt content in the top 100 cm ranging from 0.1-0.2%. The density of the arable layer is between 1.3 and 1.4 g/cm^3. Deep tillage and loosening of the soil enhance water retention and nutrient availability, making these soils well-suited for dryland farming (Rau et al., 2023).

Additionally, according to the results of research conducted by Yapiev et al. (2018), Northern Kazakhstan regions differ by having higher total carbon (TC), total organic carbon (TOC), and total nitrogen (TN) contents.

Furthermore, the levels of microbial carbon and nitrogen in the soils were highest in early summer but declined sharply as the season progressed, following a pattern similar to that of soil moisture content. A strong positive correlation was observed between soil moisture and microbial biomass in most cases (Funakawa et al., 2004).

Moreover, humus is a critical component of soil, playing a key role in determining its natural fertility, mineral nutrient availability for plants, and overall physicochemical properties. Due to its fundamental importance in soil health and agricultural productivity, humans remain a central focus for both researchers and farmers (Kunanbayev et al., 2022). The primary cause of humus depletion during the development of virgin lands is the shift in the composition of organic matter sources. This decline is largely due to a reduced input of plant residues into the soil as natural biocenoses are replaced by agrocenoses, combined with accelerated mineralization resulting from intensive tillage and other agricultural practices (Ershov, 2004).

Additionally, according to the studies of Kunanbayev et al. (2022), since the development of virgin lands, the intensive exploitation of chernozem soils in Northern Kazakhstan has resulted in significant soil erosion and a reduction in humus content. Initially, these virgin soils exhibited low levels of nitrate nitrogen and mobile phosphorus. Microbial communities also differed, with micromycetes prevailing in untouched soils, while cultivated areas showed dominance of ammonifying and immobilizing microorganisms. High carbon dioxide emissions on virgin lands (3.0 CO_2 kg/ha/hour) are attributed to the abundant plant biomass. Among the various management approaches studied, continuous wheat cultivation supplemented with fertilizers and herbicides proved to be the most effective by yielding up to 1580 kilograms per hectare and maintaining soil fertility at 3.26% humus. In contrast, the use of a two-field grain-fallow crop rotation was found to cause considerable and irreversible losses in organic matter, reducing humus levels to 2.48%.

2.5.1 Chernozems and Kashtanozems

According to the research conclusion of Vysložilová et al. (2016), chernozem is a deep, black-colored soil rich in organic matter, developed on calcareous parent material under the distinct conditions of a dry continental climate. While numerous varieties of chernozem exist, its formation is primarily driven by the slow processes of soil maturation and the humification of organic matter.

Agrogenic soil formation significantly differs from natural soil development, particularly in the rate at which organic and mineral components are transformed. Agricultural activities introduced by humans often disrupt the soil's natural biosphere functions and can negatively impact the surrounding ecosystem (Rieznik et al., 2021). Natural chernozems primarily formed on calcareous loess deposits under summer-dry climatic conditions in open, park-like landscapes with scattered forest patches. Their formation began as early as the late glacial period and reached full development during the Atlantic era. The extensive and uniformly thick humus layers suggest variations in the loess substrate, influenced in part by bioturbation processes. It is also characterized by its dark brown to black color, resulting from a high content of well-humified organic matter. Its organic-rich layer is typically at least 40 cm thick. The soil exhibits high base saturation, especially with calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, maintains a near-neutral pH of around 7, possesses a stable aggregate structure, and shows clear signs of active bioturbation (Altermann et al., 2005).

Soil bulk density refers to the ratio of the dry mass of the soil to its total volume, including both solid particles and pore spaces. In agricultural studies, it is commonly measured in grams per cubic centimeter (g/cm^3) (Blake, 1965). Measuring soil bulk density is essential for assessing the soil's physical, chemical, and biological characteristics. As a fundamental property, it provides insights into soil structure, compaction, and porosity. There are two main approaches to measuring bulk density: direct and indirect methods. Among these, direct methods have been more commonly employed in agricultural research due to their longer history of use and greater reliability (Al-Shammary et al., 2018). Research conducted by Belobrov et al. (2020) on the bulk density of ordinary chernozem soil showed that in late fall and early spring, after moldboard plowing, the topsoil layer (0-10 cm) had an average bulk density of about 0.85-0.86 g/cm^3. In the deeper layer (10-20 cm), the density was slightly higher, around 0.91-0.93 g/cm^3. However, on plots with direct seeding (DS), the bulk density was noticeably higher and reached 1.07-1.08 g/cm^3 in the top layer and up to 1.13 g/cm^3 in the 10-20 cm layer.

Moreover, analysis of microaggregate-size distribution in typical chernozem soils shows that smaller microaggregates are more common in plowed soils, while larger ones dominate under direct sowing practices. This difference is likely due to the increased presence of less-decomposed plant residues in direct sowing, where crop stubble remains on the surface, compared to traditional plowing, where residues are mixed into the soil. Typical chernozems provide the most favorable conditions for forming stable organic matter, followed by ordinary and southern chernozems. This is reflected in their varying carbon content. Southern chernozems also contain more calcium, which reacts with dissolved organic matter, therefore, reducing its mobility but also helping to build stable soil structure, especially in particle sizes smaller than 7 mm (Belobrov et al., 2020).

Speaking of kashtanozems, they are distinguished by the presence of gypsum and highly soluble salts in the lower layers of the soil profile. Because of their rich, chestnut-like color, farmers started calling them Kashtanozem soils, which simply means 'chestnut soils' in translation from the Russian language (Kutílek et al., 2015). These soils develop across a variety of landscape features, including river terraces, intermountain basin bottoms, deluvial slopes, flat coastal plains, and elevated plateaus. The diversity of the terrain contributes to differences in soil age and leads to a wide range of parent materials. These variations are evident in the genesis, texture, lithology, and chemical composition of the deposits that form chestnut soils (Pankova et al., 2018). Figure 6 below demonstrates chernozem and kashtanozem soils.

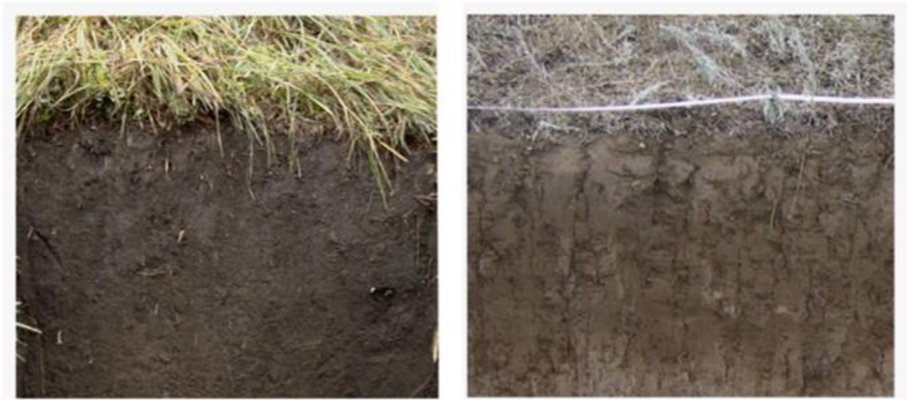

Figure 6. A – chernozem soil, B – kashtanozem soil
Source: Borisov et al., 2019.

2.5.2 Soils in The Akmola Region

In the Akmola region, chernozems develop in arid steppe conditions, confined to elevated surfaces, and extend within the region from west to east is up to 80-100 km wide, mostly occupying southern parts of the region. Saline chernozems are found in various complexes with salt deposits. The type of salinity is mainly sulfate. Dark kashtanozem soils occupy the central and eastern parts of the Akmola region (Ramazanova & Zhapparova, 2012).

Moreover, light-kashtanozem, dark-kashtanozem, and ordinary chernozem soils are present. Dark kashtanozem is a medium-sized soil of medium loamy mechanical composition with a humus content in the soil in the range of 3.8-4.1%. This soil is characterized by a low content of easily hydrolysable nitrogen, a moderate content of mobile phosphorus, and a high content of potassium. Before sowing spring wheat, there were no significant differences in soil density between the experimental variants: with minimal processing technology in the soil layer of 0-20 cm, the volume weight was in the range of 1.14-1.16 g/cm^3, with zero processing technology, it was 1.20-1.21 g/cm^3 (Bakirov & Karipov, 2017).

Ordinary carbonate chernozems are characteristic of elevated plains in the Akmola region, spread over open watersheds composed of carbonate loams and clays. They are characterized by a high amount of carbonated in the upper horizon. The humus content is 6-8%. The soils contain calcium carbonates in all their horizons, the upper horizon boils violently from hydrochloric acid, and the lower part of the profile contains easily soluble salts. Additionally, southern chernozems develop in conditions of arid steppe, confined to elevated surfaces, and extend within the Akmola region from the west to the east up to 80-100 km wide. The thickness of the humus horizon of the soil is 45-47 cm. The content of humus on virgin soil is 5-6 to 7%, nitrogen 0.30-0.35%, whereas on old arable land 4-5% and 0.25-0.30% respectively. Also, it is characterized by low content of phosphorus. The carbonate content of southern carbonate chernozems is detected from the surface or from a depth of 28-30 cm, and gypsum within 100-120 cm. A characteristic feature of soils is the large reserves of nitrate nitrogen in the profile. According to chemical and agrophysical indicators, these soils are close to ordinary chernozems (Baisholanov, 2017).

In addition, according to the research of Zvyagin et al. (2024), arable land and abandoned arable land of chernozem soil in the Akkol district of the Akmola region were demolished. The study showed that the average humus content in a layer of 0-20 cm in arable land averages 2.72%, like the same soil a fallow land of 25-30 years ago shows 3.20% humus. At the same time, an increase in humus content is noticed only starting from the 15th anniversary of the abandoned agricultural area. The arable soil density in layers 0-10 cm and 10-20 cm was 1.04-1.22 g/cm^3.

2.5.3 Soils in The Kostanay Region

In the Kostanay region, chernozem prevails as a type of soil. The region has dark chestnut soils, southern carbonate medium-humus chernozems, light and heavy chernozems in terms of granulometric composition, and ordinary chernozems (Amerguzhin, 2003). The most common and fertile soil type in the Kostanay region is chernozem, followed by kashtanozem soils. The least fertile soils are moist and salty solonetz soils (Kraemer et al., 2015). Based on studies of Jalankuzov et al. (2017), within the Kostanay region, the southern chernozem subzone is located south of ordinary chernozems and covers an area of 3.7 million hectares, of which the share of arable land is 2.0 million hectares. The main soils of the subzone are southern normal chernozems (1,160 thousand ha), carbonate (750 thousand ha), and solonetz soils (760 thousand ha). Additionally, the structure of the soil profile corresponds to the typical genesis of the southern chernozems. According to the thickness of the humus horizon (A+B), medium-sized soils are 60-70 cm. Carbonates are released in the lower part of the humus horizon (from 45-50 cm). Also, soil is mainly saturated with calcium (70-85%) and partly with magnesium (15-30%). The content of exchangeable sodium is 0.5-1.0%. The soil is practically not saline with easily soluble salts (Jalankuzov et al., 2017).

The amount of salt in the profile does not exceed 0.1-0.2%. Salinization is often observed in the soil-forming rock from a depth of 110-150 cm. Moreover, the lowest field moisture capacity of ordinary, medium-loamy chernozems in the Kostanay regions, in the Karabalyk district, is 45 mm in 0-20 cm, and 186 mm in 0-100 cm depths. The thickness of the humus horizon of the soil averages 60-80 cm, including humus accumulative of 15-25 cm. The content of humus (nitrogen) from above reaches on virgin soils 7.5-8.0% (0.4-0.5%), whereas in the old field, it decreases to 6.2% (0.3-0.4%), respectively. They are poor in phosphorus, their gross content in the soil is about 0.1%. The depth of manifestation of carbonate is 35-40 cm, gypsum is detected from a depth of 140-160 cm. The amount of exchangeable sodium in the profile does not exceed 1%, which indicates the absence of salinity (Baisholanov, 2017).

In the chernozems of the Kostanay region, the humus level is 6.3%. The pH level is 6.8-7.4. The soil is characterized by a small potential reserve of phosphate and a good potential reserve of potassium. Moreover, it was found that soil fatigue is observed on chernozem and dark kashtanozem soils with prolonged, permanent cultivation of wheat or with a high proportion of it in crop rotation. With permanent wheat crops, soil fatigue manifests itself in a decrease in the diversity and composition of microorganisms, an increase in the hydrophobicity and phytotoxicity of the soil, as well as in a decrease in yield and deterioration of its quality (Amerguzhin, 2003).

2.5.4 Soils in The North Kazakhstan Region

In North Kazakhstan region, approximately 70% of the territory is occupied by lands classified as mainly arable, used for arable land, mainly without irrigation. These are the massifs of zonal soils of the forest-steppe and steppe, unsalted, weakly medium-calcareous, heavy, medium and light loamy soils and their complexes with salinity of no more than 30%. They are mainly represented by common and southern chernozems. In the extreme southeast, small areas are occupied by dark kashtanozem soils. About 30% of the region’s territory is mainly pasture and partly hayfields, which are solonetz and solonchak soils. Furthermore, the most common soils are southern common chernozems, carbonated chernozems, and meadow-chernozems. The soils are provided with nitrogen and potassium to a high degree. The quality of these soils is decreasing due to the worst water-physical properties, easy exposure to wind erosion (Zakirina et al., 2017)

Gray forest soils develop under grassy birch, birch-aspen forests, and spikes. They have a humus horizon thickness of 30-40 cm. The humus (nitrogen) content at the surface reaches 8-

13% (0.4-0.7%) but decreases sharply in depth. The upper horizons of soils have a slightly acidic reaction, and the lower horizons have a neutral or slightly alkaline reaction. Whereas, meadow-chernozem soils occupy low relief elements of the plains of the North Kazakhstan regions, in some places of low floodplain terraces of rivers and lakes. The morphological features of these soils are the darker color of the humus horizons, the presence of rust spots, and bluish spots in the lower horizons. The soil is mostly medium-humus (7-9%, 6-8% in arable land), but there is low-humus (4-7%, 4-6% in arable land) and high-humus (over 9%, more than 8% in arable land). The total nitrogen in them is 0.4-0.5%, gross phosphorus is 0.1-0.2% (Baisholanov, 2017).

Medium-quality lands include dark kashtanozems, heavy loamy, and sometimes solonetz soils. The potential fertility of these soils is quite high. The humus in the arable layer contains about 4%. The very harsh agroclimatic conditions of kashtanozem soils make the yield directly dependent on the successful fight for the accumulation and preservation of moisture in soils. The total land is more than 20% of the area of arable land in the region. Eventually, the best lands of the region are ordinary chernozems and leached chernozems. They occupy well-drained parts of the Ishim-Irtysh watershed. They are characterized by a homogeneous flat relief, which allows the use of powerful agricultural machinery, and the presence of a relatively powerful humus layer that reaches plowing to a great depth. Additionally, they have a neutral reaction of the soil environment, favorable for the development of zoned crops, and the absence of salinity in the soil profile. Moreover, the soil has a high natural fertility, favorable agrochemical properties and water-air regime. Furthermore, since spring wheat is the leading crop (monoculture) in the North Kazakhstan regions, and grain-and-steam crop rotations prevail in agriculture, the humus balance in soils is negative. The humus content decreases by an average of 0.5-0.6% per year. To date, large areas of cultivated land in the North Kazakhstan region contain 4.0% less humus. In addition to this, with a 1.0% reduction of humus (from 5.6% to 4.5%), the crop shortage is about 5 kg/ha (Zakirina et al., 2017).

3. Materials and Methods

3.1 Study Areas

Agriculture plays a significant role in the economic, social and environmental development of Kazakhstan. Kazakhstan is the largest grain producer in Central Asia and the only major exporter, considered to have great agricultural potential. It has significant export potential for grain and flour. The main specialization in crop production in Kazakhstan is the cultivation of grain crops such as wheat, barley, oats, and millet. At the same time, the main share is occupied by wheat, and Kazakhstan is one of the largest exporters of this grain. The fact is that the northern regions of Kazakhstan are vast plains with a continental climate, very snowy winters, and abundant spring moisture. The climate of the Northern part of Kazakhstan is well suited for growing spring wheat, which is the focus of this study. Kazakhstan demonstrates steady growth in exports of wheat crops, which is the result of both the high-quality work of the agricultural sector and an active foreign economic policy. The expansion of sales markets and the increase in supplies to traditional and new countries emphasize the high competitiveness of Kazakhstan's products in the international arena.

Based on Figure 7 below, Kostanay, Akmola, and North Kazakhstan are the three primary grain-producing areas in northern Kazakhstan, and these are the subject of this study. The three northern regions account for 27%, 28% and 24% respectively, of the total amount of wheat produced in Kazakhstan. Furthermore, they are frequently referred as the 'grain belt', as most of Kazakhstan's wheat and barley is cultivated there. Because of their location on the flat steppe, which has extremely fertile soil, these areas are crucial to producing wheat.

Due to large sizes of the regions' territories, one leading wheat-producing district from each of the above-mentioned regions was selected in order to study the meteorological parameters. Therefore, the Karabalyk district was chosen for the Kostanay region, the Akkol district for the Akmola region, and the Blagoveshchenka district for the North Kazakhstan region.

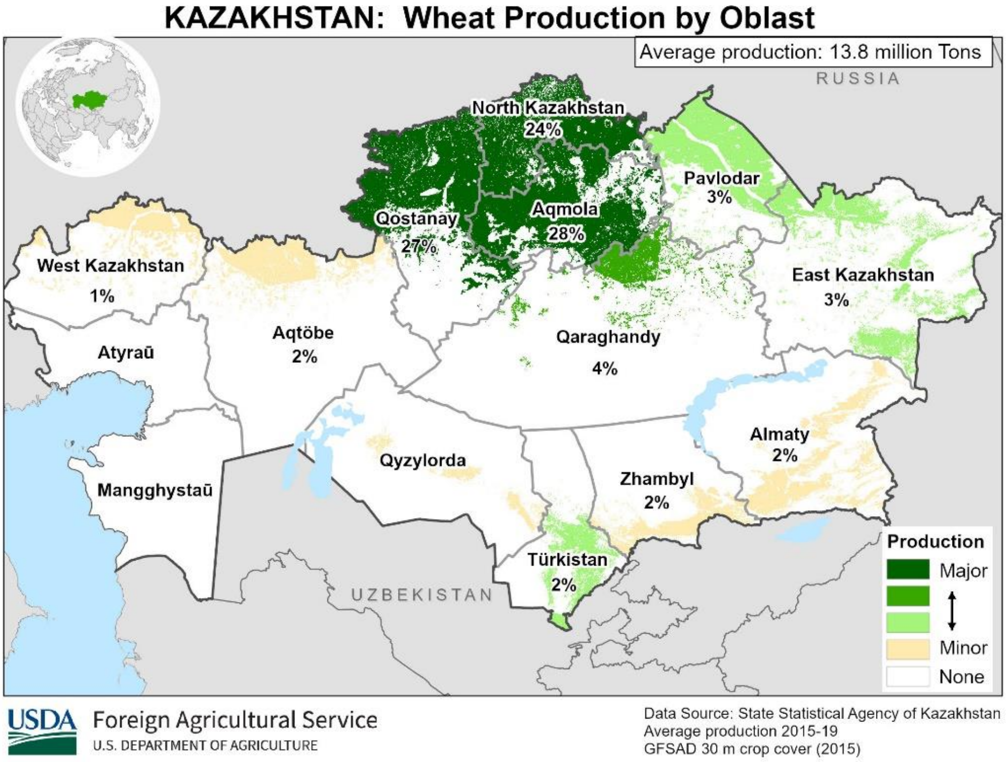

Figure 7. Average wheat production ratio in Kazakhstan divided by regions and expressed in percentages.

Source: USDA (http5)

3.2 Data Collection

Data on meteorological conditions were sourced from Kazhydromet, which is the official national hydrometeorological service. The Hydrometeorological Service appeared in Kazakhstan in January 1922. Nowadays, this large scientific enterprise is part of the Ministry of Ecology and Natural Resources. It unites the Republican state enterprise of Hydrometeorology and environmental monitoring, as well as the state accounting of the water fund and the water register. Therefore, through the application of the Kazhydromet official database, information about air and soil temperatures, and air precipitation in three regions over the past 10 years has been obtained (http4). The data has been measured every day for 10 years; therefore, the average monthly, yearly values of all parameters will be considered in the study.

In addition to this, in the course of the research, the official data published by the National Bureau of Statistics of Kazakhstan was used to determine the indicators of the gross harvest, the specified areas of the main agricultural crops, and the total yield of major agricultural crops, including wheat, by region. The use of statistics from a reliable government source ensured the objectivity of the analysis and made it possible to compare the scale of grain production with the characteristics of the soil cover and climate change in various areas. The Bureau of National Statistics of the Republic of Kazakhstan is engaged in the formation of statistical methodology and the implementation of statistical activities in compliance with the principles of state statistics (http6).

Moreover, various reputable sources have been used to ensure the reliability and relevance of the data used for the study. The main data and literature were obtained from open-access academic databases that provide access to peer-reviewed scientific articles and materials, such as Google Scholar, ResearchGate, and ScienceDirect. Statistical information on agricultural productivity in Kazakhstan was collected from the FAOSTAT database, which provides official international statistics. Moreover, data from the United States Department of Agriculture (USDA), and United Nations Environment Programme (UNEP) were used for this study. In addition, relevant regional reports, scientific publications, and government databases were analyzed. The study used up-to-date data covering the period from 2010 to 2025, and focused mainly on the Northern regions of Kazakhstan. Thus, data from regional and international sources were used to provide a global context and understanding.

3.3 Evaluated Meteorological Parameters

With the help of Kazhydromet, the official national hydrometeorological service of Kazakhstan, raw data were collected from three regions under study. Data on atmospheric and soil temperature, maximum, minimum, and average values for the day were collected. Moreover, information was also found on the average and minimum humidity values, and the amount of precipitation per day.

The average air temperature is the arithmetic mean of all temperature values measured over a certain period of time. There are average daily, monthly, and annual average temperatures. Maximum temperature is the highest value of temperature (air, soil) observed in a given location for a certain period of time. Minimum temperature is the lowest value of temperature (air, soil) observed in a given location for a certain continuous period of time. Precipitation is the total amount of water that has fallen from the atmosphere to the earth's surface over a certain period, measured in millimeters (mm). Eventually, the data was measured at the central weather stations of each study area of the three regions, namely, the Akkol, Karabalyk and Blagoveshchenka weather stations.

3.4 Statistical Methods

In order to convert hourly measured meteorological data into daily, and monthly averages, the Statistical Package for the Social Sciences (IBM SPSS Statistics Version 29.0.1.0 program was used to process statistical data. It is suitable for its descriptive statistics and automatic report generation. For all the indicators, the main descriptive characteristics: the mean, the standard deviation, as well as the minimum and maximum values, were calculated.

For a more visual and demonstrative analysis and output of meteorological data, a percentage comparison was used. The monthly average value of each parameter in the period from 2015 to 2019 inclusive was found, and after each subsequent year from 2020 to 2025 was compared with the average of the initial 5 years. The difference is represented as a percentage of growth or decline.

In addition to the software, electronic Excel spreadsheets (Microsoft® Excel® for Microsoft 365 MSO (Version 2508 Build 16.0.19127.20192)) have been used for data visualization and analysis.

4. Results and Evaluation

4.1 Wheat Growing Area and Wheat Yields Evaluation

The Akmola region is in the center of the Republic of Kazakhstan. The area of the Akmola region is 146 200 square kilometers (further km^2). The typical specified area of cereals, including rice and legumes, is 4.5 million hectares in the period from 2015 to 2024 inclusively. Eventually, wheat occupies 3.8 million hectares of land, which can be expressed in a percentage ratio of approximately 85.4%. Whereas the total area of the Kostanay region is 196 001 km^2. The usual total area under cultivation of cereals, including rice and legumes, in this region is 5.2 million hectares, of which 3.6 million hectares are occupied by wheat, which is 68.2%. Ultimately, the North Kazakhstan total territory is 98 000 km^2. The typical specified sown area of cereals, including rice and legumes, is 4.3 million hectares in the period from 2015 to 2024. Of this, wheat occupies 2.3 million hectares of land, which can be expressed in a percentage ratio of about 56.6%. Regardless of the territory size of the regions, the Akmola region stands out for its special emphasis on wheat production.

Figure 8 below shows the average area allocated for wheat production, and Figure 9 below demonstrates the average wheat harvest, in the period from 2015 to 2024, in three northern regions of Kazakhstan: Akmola, Kostanay, and North Kazakhstan regions. It can be noted that the largest wheat-producing areas are in Akmola (about 3.8 million hectares), followed by the Kostanay region (about 3.5 million hectares). The smallest areas were recorded in the North Kazakhstan region, which is approximately 2.3 million hectares.

Moreover, regarding the average wheat yield, it is clearly seen that the highest average wheat yield is observed in the North Kazakhstan region, which is 1.48 t/ha. In Akmola and Kostanay regions, the indicator is approximately the same and amounts to about 1.04 t/ha.

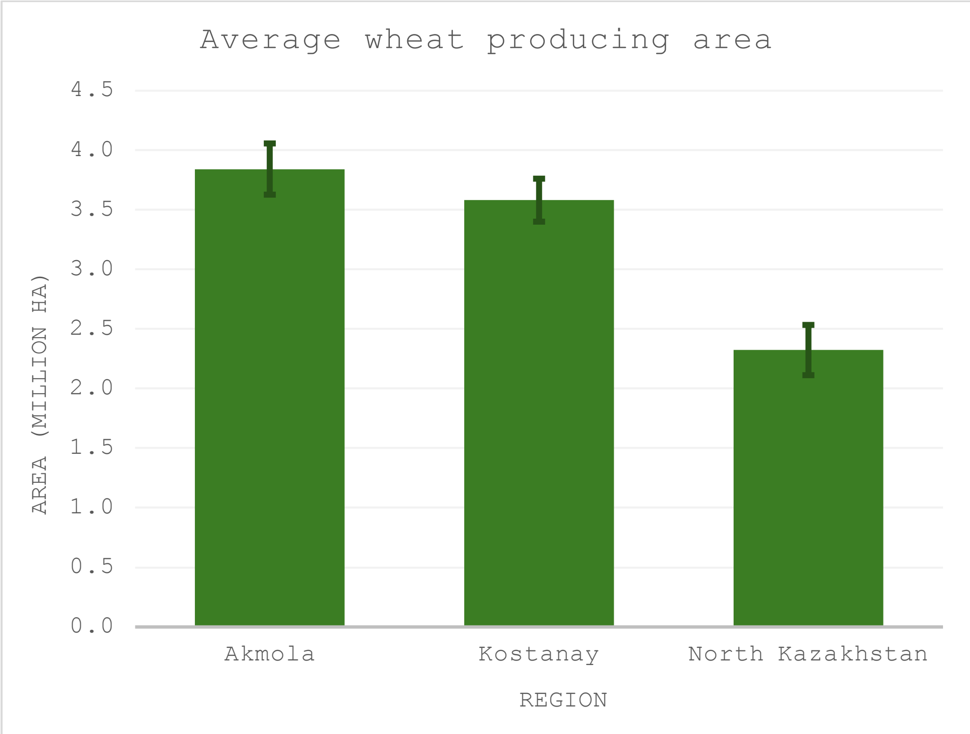

Figure 8. Average wheat producing area and standard deviation in different regions of Kazakhstan in 2015-2024, expressed in millions of hectares.

Source: own work, based on data from the National Bureau of Statistics of Kazakhstan (2024, http6).

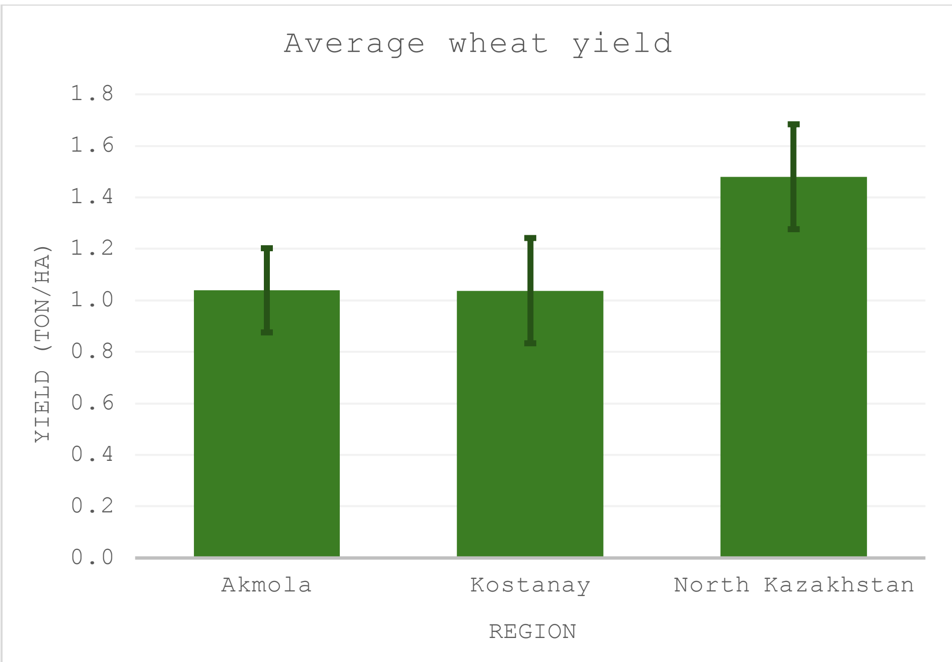

Figure 9. Average wheat yield and standard deviation in different regions of Kazakhstan in 2015-2024, expressed in tonnes per hectare.

Source: own work, based on data from the National Bureau of Statistics of Kazakhstan (2024, http6).

An evaluation of the data in Figures 8 and 9 shows the difference in strategies of the regions. Akmola and Kostanay regions provide a high gross wheat harvest due to large areas with lower average yields. The North Kazakhstan region, on the contrary, has relatively smaller areas, but demonstrates higher yields. Thus, two types of production models can be distinguished: extensive (increased area at moderate yields) and intensive (smaller area at high yields).

Based on Table 1 below, which shows the average annual area of wheat cultivation in three regions of Kazakhstan, a stable trend with minor deviations both upward and downward can be noted. Moreover, the steady leadership of the Akmola region is clearly noticed. Since 2019, the area under cultivation in this region has been showing gradual and steady growth and will reach a maximum of about 4.2 million hectares in 2023, after which a slight decrease may be observed in 2024 (4.0 million hectares). Kostanay region ranks second in terms of area, with a decrease in area recorded in 2017-2019, but after 2020, this parameter increased again and approached 3.9 million hectares by the end of the period. The North Kazakhstan region consistently has a smaller area under wheat production (about 2.0-2.5 million hectares), however, starting in 2019, there is a gradual increase until 2024, when the indicator stabilizes at about 2.5 million hectares. These data indicate a stable focus of Kazakhstani farmers on wheat production.

Table 1. Average wheat producing area changes in different regions of Kazakhstan, in period of 2015-2024, expressed in millions of hectares.

Source: own editing based on National Bureau of Statistics of Kazakhstan (2024, http6).

Year	**Area producing wheat (million hectares)**		
	Akmola	**Kostanay**	**North Kazakhstan**
2015	3.7	3.6	2.3
2016	3.8	3.8	2.5
2017	3.7	3.7	2.2
2018	3.6	3.5	1.9
2019	3.6	3.3	2.0
2020	3.7	3.4	2.3
2021	4.0	3.6	2.4
2022	4.0	3.5	2.4
2023	4.2	3.8	2.6
2024	4.0	-	2.5

Figure 10 below represents the dynamics of changes in the amount of wheat harvest in the northern regions from 2015 to 2024, with the exception of the Kostanay region, since the data provided included the period only up to 2023.

Despite the stable approach to the area of land allocated for growing wheat, its yield has not had the same stability over the past 10 years. All three northern regions of Kazakhstan show a similar trend, in which it can be noted that from 2015 to 2018, crop yields were stable, with a slight increase in the North Kazakhstan region in 2017. However, starting in 2019, wheat yields became very uncertain, producing certain significant changes almost from year to year. Thus, in 2019, the amount of wheat in three regions is decreasing, which is especially noticeable in the Kostanay region, where the harvest is decreasing by about 36.4% compared to the previous 4 years. Further, in 2020, the harvest is growing, however in 2021, it is decreasing significantly again. In 2022 the harvest will stabilize again, but in the next 2023 it shows a low result again. After all, in 2024, the wheat harvest in Akmola and North Kazakhstan regions increases significantly, by about 13.6% and 11.8% respectively.

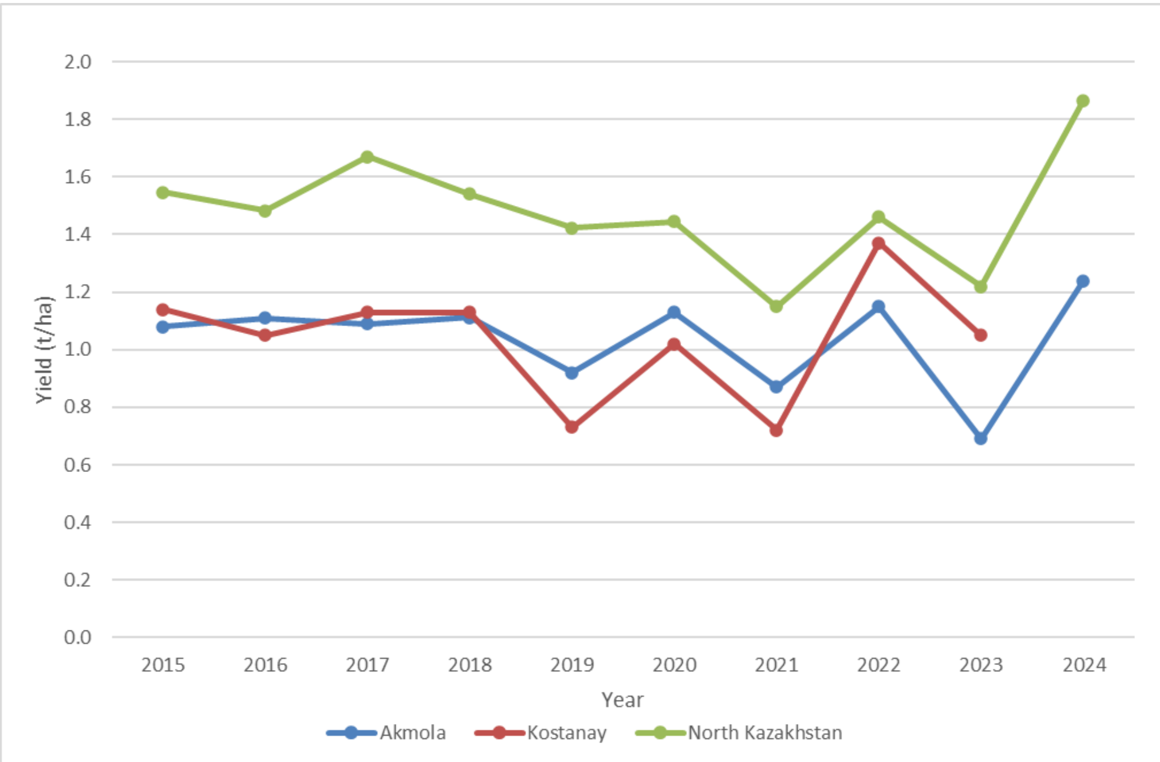

Figure 10. Average wheat yield change in different regions of Kazakhstan, period of 2015-2024, expressed tonnes per hectare.

Source: own work, based on data from Kazhydromet (http4).

The peculiarity of the central region of Kazakhstan, Akmola, is that in 2023, the area of wheat cultivation was the highest among all other regions and other years, which amounted to about 4.2 million hectares. In spite of this, the yield for this year was the lowest compared to previous years and in neighboring regions, which equals to 0.69 t/ha. This is 33.6% less than the usual yield, when the average yield for spring wheat of the Akmola region approximately equals to 1.04 t/ha.

Whereas Kostanay region, the dynamics of spring wheat yields for the period 2015-2023 are characterized by moderate fluctuations and generally remain at the level of 1.0-1.2 t/ha. Figure 10 shows that the most noticeable decrease in yields was observed in 2019, 2021, and 2023. It is also possible to note a sharp increase in wheat yield in 2022.

Eventually, the wheat-growing area in the North Kazakhstan region remains stable in comparison with other regions of the country. The yield indicator shows stability in the period from 2015 to 2020, but after, in 2021 and 2023, a sharp decline in the harvest is detectable.

It can be emphasized that in 2019, there was a decrease in yields in Akmola and Kostanay regions, which coincides with a reduction in the total growing area of wheat in those regions that year. Thus, the area decreased by 10.8% in the Kostanay region, and by 5.4% in the Akmola region in the period 2018-2019. However, the tendency for yield fluctuations may be related to the weather conditions of specific years as well. Therefore, the temperature of the soil, air, and precipitation could have an affecting role in determining the amount of wheat harvested.

4.2 Evaluation of Soils

Based on the scientific and applied handbook of Agro-Climatic Resources of different regions of Kazakhstan, issued by the Ministry of Education and Science of the Republic of Kazakhstan (Baisholanov et al., 2017), a comparative table of soils of the Akmola, Kostanay, and North Kazakhstan regions was created (Table 2 below).

Table 2. Comparative table of soils in Akmola, Kostanay and North Kazakhstan regions, containing different soil parameters. Source: own editing based on Ministry of Education and Science Republic of Kazakhstan (Baisholanov, 2017)

Parameter	Akmola Region	Kostanay Region	North Kazakhstan Region
Prevailing soil type, mechanical composition	Southern carbonate, heavy loamy chernozems	Common, medium loamy chernozems	Meadow, gray forest and heavy loamy chernozems
Humus content, %	4-6	6.2	6-8
pH level	-	6.8-7.4	7.1
The lowest field moisture capacity, mm	0-20 cm: 60 0-100 cm: 203	0-20 cm: 45 0-100 cm: 186	0-20 cm: 65 0-100 cm: 259
Thickness of humus horizon, cm	45-47	60-80	30-40
Content of humus nitrogen, %	0.25-0.3	0.3-0.4	0.4-0.5
Gross content of phosphorus, %	low	0.1	0.1-0.2
The depth of carbonate occurrence, cm	28-30	35-40	-
Gypsum occurrence depth, cm	100-120	140-160	-

An analysis of the different soil characteristics in the three regions under study shows certain differences in fertility and suitability for wheat cultivation. The North Kazakhstan region demonstrates the most favorable conditions due to the higher humus content in the soil (6-8%) and the relatively high moisture capacity of the fields (up to 259 mm). High soil moisture capacity is very important, especially during periods of low precipitation.

Kostanay region also has fertile soil with a deep humus horizon (60-80 cm) and an average humus content (6.2%), although the soil moisture capacity is relatively lower than that in North Kazakhstan. The Akmola region has lighter soils with lower humus and nitrogen content, shallower humus horizons, and lower phosphorus content, which indicates a decrease in soil fertility and moisture retention.

4.3 Evaluation of Climatic Conditions

4.3.1 Evaluation of Average Air Temperature During Vegetation Period

Figure 11 below shows the changes in average air temperature each month during the wheat growing season from 2015 to 2025 of three regions (Akmola, Kostanay, North Kazakhstan). The calculation considers the growing period of wheat, specifically 6 months starting from April and ending in September. The average atmospheric temperature in June, July, and September shows stability, while the same parameter in April, May, and August shows certain alterations from year to year, which may have a particular effect on wheat yields.

Figure 11. Mean air temperature change in 2015-2025 from April to September, in different regions, where Akm – Akmola, Kst – Kostanay, NK – North Kazakhstan.
Source: own work, based on data from Kazhydromet (http4).

Wheat stress occurs when it deviates from optimal temperatures: both too low (freezing) and too high (drought), which disrupts the metabolism, flowering, and fruiting of the crop, as well as damages individual parts of the plant. For the remaining months, the average atmospheric temperature remains stable with small deviations.

4.3.1.1 Evaluation of April

In April 2018-2019, the average air temperature in all three regions is falling, and will not exceed 5 °C in 2019, which may signal frosts and the late start of wheat cultivation this year. In 2020, the April average air temperature returned to normal, reaching about 7.5 °C in all three regions of northern Kazakhstan. In the following 2021, the temperature indicator will decrease again to about 4.5 °C in Northern Kazakhstan and Akmola, and to 6 °C in the Kostanay region. In 2022, the temperature will rise again to an average of 8 °C per month, and in 2023 it will decrease. This cooling particularly affects the Akmola region, where the average temperature was about 4 °C. Starting from 2024, there is also a tendency for average temperatures to rise, which corresponds to the regional warming trend. Eventually, April is an important month, the beginning of wheat cultivation, therefore, as Figures 10 and 11 show, the average air temperature in April has a strong influence on the subsequent final wheat harvest.

4.3.1.2 Evaluation of May

The next month with noticeable changes over the course of 10 years is May, in which in 2018, in all three years, the average air temperature drops to about 10 °C. Further, this indicator is gradually increasing, reaching maximum values in 2021 in all regions: 17.2 °C in Akmola, 19.4 °C in Kostanay, and 18.5 °C in the North Kazakhstan region. Further, the temperature fluctuates from year to year, so in 2022, the temperature dropped to about 13 °C in all three regions. In 2023, it is growing again, and in 2024, it is declining again. This tendency is similar to the trend shown in Figure 10, or rather to the yield of spring wheat in different years. Thus, in 2019, due to unusual fluctuations, wheat productivity is falling. Moreover, in 2021 and 2023, when it gets warmer than usual, the harvest also decreases. But in 2020, 2022 and 2024, when the average atmospheric temperature shows its average, returning to normal, which is about 13-15 °C, the amount of harvest also increases accordingly.

4.3.1.3 Evaluation of August

Finally, the month that also has differences during the time period under study is August, the last month of summer. In 2016, the average air temperature in the regions of Kostanay and

Northern Kazakhstan increased to 22.6 °C and 20.4 °C, respectively. This change is comparable to a slight decrease in the yield of spring wheat in the same year in these two regions. In 2021, this parameter in the Kostanay region will rise again to 22 °C, which again coincides with a crop loss. And in 2022, in the Akmola region, this temperature parameter decreases to a minimum of 15.8 °C, and at the same time, wheat productivity increases from 0.9 to 1.2 tonnes per hectare. By 2024, the temperature in all three northern regions of Kazakhstan is decreasing to about 16 °C, moreover, the amount of wheat harvest per ton per hectare increases in the same year.

4.3.2 Evaluation of Air and Soil Temperature Extremes

4.3.2.1 Evaluation of Air and Soil Temperature Extremes in Akmola Region

In Table 3 below, the average, minimum, and maximum temperatures of air and soil from 2015 to 2025 inclusive have been demonstrated.

Table 3. Mean, minimum, maximum temperatures of air and soil in Akmola region, in April, May and August, in period of 2015-2025, expressed in Celsius degrees. Source: own work, based on Kazhydromet (2025)

Month	Year	Air temperature (°C)			Soil temperature (°C)		
		Mean	Minimum	Maximum	Mean	Minimum	Maximum
April	2015	4.3	-17.1	22.7	4.7	-18.0	38.0
	2016	8.1	-2.0	24.0	9.1	-4.0	39.0
	2017	5.4	-16.1	28.3	5.5	-17.0	31.0
	2018	3.2	-12.3	23.3	3.1	-14.0	28.0
	2019	4.7	-8.5	21.3	5.7	-12.0	32.0
	2020	8.2	-6.1	28.0	9.0	-10.0	44.0
	2021	4.7	-18.1	24.2	5.9	-20.0	44.0
	2022	7.8	-7.4	28.6	8.6	-8.0	48.0
	2023	4.0	-18.2	27.3	4.8	-20.0	46.0
	2024	7.4	-5.4	26.1	7.8	-8.0	45.0
	2025	9.7	-8.8	27.0	9.8	-9.0	40.0
May	2015	14.0	1.7	28.0	16.3	-1.0	50.0
	2016	12.2	-3.7	28.0	15.7	-7.0	54.0
	2017	13.9	-2.8	30.1	17.1	-7.0	50.0
	2018	9.1	-2.9	30.6	11.1	-7.0	45.0
	2019	12.0	-7.4	29.0	15.7	-8.0.	52.0
	2020	16.6	-2.7	35.5	21.4	-4.0	58.0
	2021	17.2	-2.0	36.1	21.9	-1.0	62.0
	2022	14.5	-4.9	33.8	18.1	-7.0	56.0
	2023	13.8	-3.1	32.6	18.7	-5.0	57.0
	2024	10.6	-1.4	25.8	13.2	-6.0	46.0
August	2015	16.4	4.1	33.0	19.8	2.0	54.0

	2016	18.6	2.1	31.0	22.9	0.0	56.0
	2017	18.5	3.8	34.6	23.3	2.0	56.0
	2018	16.3	5.1	32.1	18.8	2.0	54.0
	2019	18.1	2.3	36.2	22.6	1.0	59.0
	2020	17.8	5.3	32.5	21.1	4.0	55.0
	2021	19.1	1.5	33.2	23.9	0.0	58.0
	2022	15.9	2.0	30.6	19.3	2.0	54.0
	2023	18.4	6.9	35.7	21.9	4.0	57.0
	2024	16.3	5.1	35.2	18.1	4.0	54.0

The reason for the low wheat harvest in 2021 and 2023 in the Akmola region can be attributed to the low average air temperature in April, which was below +5 ℃. Ultimately, April, the minimum air temperature dropped to -18.1 ℃ in 2021, and to -18.2 ℃ in 2023, which was approximately 62% less than the average lowest air temperature in 2015-2019 (-11.2 ℃). At the same time, the soil temperature showed the lowest -20℃ in both years, and it was less than the average in past years (-13.0 ℃) by 59.9%. Low air and soil temperatures in April can have a negative impact on the yield of spring wheat, as this month falls during the period of seed germination and initial plant growth. At low temperatures, biochemical processes slow down, which leads to a delay in the appearance of seedlings and a weak development of the root system. In addition, cold soil limits the availability of nutrients and reduces the rate of their absorption. If there are frequent frosts in April, they can damage young shoots, reducing the density of crops and overall, the harvest potential. Thus, unfavorable temperature conditions in the early stages of vegetation create stress for plants and reduce their productivity in the future.

Moreover, it can be noted in Table 3, the data for the Akmola region confirm this: the maximum temperatures in May temperatures in May 2020-2023 exceeded 32.0-36.0℃. Particularly high values were observed in 2021 (36.1℃), which coincided with dry conditions and was accompanied by a sharp decrease in yields. High temperatures in May can significantly reduce the yield of spring wheat when the need for moisture is particularly high. Accelerated warming of the air leads to more intense evaporation of moisture from the soil and increased transpiration, which causes water stress with a lack of precipitation. In addition, excessive heat shortens the duration of the growing season, as a result of which, plants form fewer productive shoots, and the grain becomes weaker. Therefore, abnormally high temperatures in May can create unfavorable conditions for the normal growth and development of wheat and can lead to a noticeable decrease in yields.

August in the Akmola region is relatively stable in terms of air temperature, but only in 2022, at the same time when the amount of harvest showed an increase, the average air temperature was lower than usual, about 15.8 °C.

Furthermore, until 2019, the average air temperature in April exceeded 7 °C only once, which was in 2016 (8.1 °C). After that, the temperature rose above this indicator was higher several times, specifically in 2020, 2022, 2024, and 2025. This pattern may indicate a general warming trend.

4.3.2.2 Evaluation of Air and Soil Temperature Extremes in Kostanay Region

Since 2017, the average air temperature decreased in April, thus, according to Table 4 below, it became about 3.8 °C. And this April cold snap continued until 2019 inclusively, which could cause a decrease in yields with a stable sowing area. The cold April of 2018 could have a noticeable impact on the decline in wheat yields in 2019. Low temperatures in spring led to late snowmelt and a delay in the start of sowing, which shortened the growing season and affected plant development. In such conditions, the soil structure deteriorates, the mineralization of organic matter slows down, and the availability of nutrients, especially nitrogen, decreases. This leads to a weakening of plants and a decrease in soil fertility, the consequences of which may persist during the next season. In addition, adverse weather conditions in 2018 could lead to depletion of soil moisture reserves, which worsened the situation in 2019, especially with insufficient precipitation in spring and summer. In the following months of the growing season, the average air temperature was much higher, so precipitation should be given great importance.

Table 4. Mean, minimum, maximum temperatures of air and soil in Kostanay region, in April,May and August, in period of 2015-2025, expressed in Celsius degrees. Source: own work, based on Kazhydromet (2025)

Month	**Year**	**Air temperature (°C)**			**Soil temperature (°C)**		
		Mean	Minimum	Maximum	Mean	Minimum	Maximum
April	2015	5.2	-6.6	23.6	6.4	-11.0	40.0
	2016	8.2	-1.8	23.6	8.3	-3.0	36.0
	2017	5.7	-12.3	22.2	5.5	-15.0	34.0
	2018	3.8	-11.1	19.5	4.4	-14.0	29.0
	2019	4.9	-10.3	22.0	6.2	-10.0	36.0
	2020	7.1	-7.2	19.2	7.5	-9.0	28.0
	2021	6.1	-7.3	22.2	6.4	-9.0.	32.0
	2022	9.0	-2.5	24.6	8.8	-6.0	34.0
	2023	7.3	-10.7	25.2	7.6	-11.0	40.0

	2024	9.7	-2.8	29.3	9.2	-6.0	42.0
	2025	10.3	-1.8	26.0	11.7	-5.0	42.0
May	2015	13.9	0.8	31.8	17.0	-1.0	51.0
	2016	14.0	0.1	29.3	18.1	-3.0	54.0
	2017	12.3	-3.1	25.8	15.4	-4.0	44.0
	2018	11.5	-4.3	30.7	14.2	-5.0	47.0
	2019	15.2	-4.6	31.2	18.9	-5.0	50.0
	2020	16.7	-1.2	36.3	20.2	-2.0	51.0
	2021	19.4	-1.8	36.0	24.0	-3.0	58.0
	2022	12.3	-2.9	27.3	15.5	-4.0.	45.0
	2023	15.7	1.0	34.3	20.5	-1.0	59.0
	2024	10.2	-3.4	23.6	13.1	-4.0	40.0
August	2015	16.4	0.6	37.0	21.0	-1.0	56.0
	2016	22.6	5.0	34.8	28.4	4.0	56.0
	2017	19.8	7.2	32.7	23.7	7.0	50.0
	2018	17.8	7.2	30.3	21.9	6.0	54.0
	2019	18.2	6.5	34.1	21.3	6.0	50.0
	2020	19.5	8.2	35.1	22.4	7.0	50.0
	2021	22.1	5.0	36.3	26.8	4.0	61.0
	2022	20.4	5.0	34.0	25.8	5.0	51.0
	2023	18.3	4.9	30.7	21.7	6.0	51.0
	2024	16.7	8.0	25.3	19.5	7.0	45.0

Moreover, based on Table 4, in April 2022 and 2024, the air and soil temperatures were favorable for wheat, as yields showed high results during these times. Thus, in April 2022, the minimum air and soil temperatures were -4.9 °C and -6 °C, respectively, which are 38.1% and 31.8% higher, respectively, compared to the average in 2015-2019. In addition, in 2024, the minimum air temperature rose to 0.1 °C and the minimum soil temperature to -2 °C, which also shows an increase of 101.3% and 77.3% respectively compared to the first 4 studied years. This trend and the relationship with wheat yields show how important April and warm, favorable weather conditions are for soil seeds to germinate.

In addition, August had certain differences in the Kostanay region in the period from 2015 to 2024, which could also have an impact on the number of spring wheat harvests. Therefore, the productivity rate is decreasing in 2016 and 2021, judging by Figure 11, which can be attributed to high air and soil temperatures in August: the average soil temperature was 28.5 °C in 2016, and 26.8 °C in 2021. This indicator is much higher than the average, for instance, in 2021, the growth of average temperatures was almost 15.0% compared to the mean value of the same parameter in the period 2015-2019 (18.9 °C air and 23.3 °C soil average temperature). In fact, this high temperature could play a key role in determining the productivity of spring wheat with insufficient rainfall, indicating a drought. Moreover, in 2023, the average temperature extremes of air and soil are getting lower, which indicates a mild August, thus, the maximum air temperature is 30.7 °C, which is 9.1% less than the average value of the same indicator during the period of stable wheat yields (2015-2019).

In addition, estimating the overall change in the average atmospheric temperature, there is a regular warming. Therefore, until 2019, the April average atmospheric temperature exceeded the threshold of 7.0 °C once, which was in 2016 (8.2 °C). However, after 2019, this limit was exceeded several times, more precisely in 2020 (7.1 °C), in 2022 (9.0 °C), in 2023 (7.3 °C), in 2024 (9.7 °C) and in 2025 (10.3 °C). Furthermore, in April, there is a detectable trend of an increase in the average soil temperature. Before 2019, this climate parameter was above 7.0 °C only in 2016 (8.3 °C), although then it surpassed the threshold in 2020 (7.5 °C), 2022 (8.8 °C), 2023 (7.6 °C), 2024 (9.2 °C), and 2025, reaching a maximum of 11.7 °C in 2025.

Assessing May in this way, it can be seen that since 2019, the average air temperature has been above 15.0°C several times. It was 15.2 °C in 2019, 16.6 °C in 2020, 19.4 °C in 2021, and 15.7 °C in 2023.

In addition to this, in August, the average temperature tends to rise as well. Thus, until 2019, this climate parameter exceeded 19 °C only in 2016 and 2017 (22.6 °C and 19.8 °C, respectively). And then, this trend became more frequent, repeating in 2020 (19.5 °C), 2021 (22.1 °C), and 2022 (20.4 °C). These changes may reflect broader climate shifts, which may be related to global warming.

4.3.2.3 Evaluation of Air and Soil Temperature Extremes in the North Kazakhstan Region

Based on Figure 11, the North Kazakhstan region records the lowest temperatures (4.0-10.0 °C) in April, due to its more northern location, thus, for example, according to Table 5 below, in 2021 and 2023, the minimum soil temperature reached -14.0 °C and -12.0 °C respectively, which could have been too cold for spring wheat seeds to germinate.

Table 5. Mean, minimum, maximum temperatures of air and soil in the North Kazakhstan region, in April, May and August, in period of 2015-2025, expressed in Celsius degrees. (Source: own work, based on Kazhydromet (2025))

Month	**Year**	**Air temperature (°C)**			**Soil temperature (°C)**		
		Mean	Minimum	Maximum	Mean	Minimum	Maximum
April	2015	3.6	-16.4	22.1	3.2	-18.0	31.0
	2016	8.0	-2.0	22.2	8.4	-3.0	31.0

	2017	4.4	-16.0	23.2	4.8	-16.0	31.0
	2018	2.8	-13.3	23.9	2.53	-14.0	28.0
	2019	3.8	-9.7	20.5	3.1	-12.0	22.0
	2020	8.0	-4.6	27.6	8.1	-6.0	33.0
	2021	4.2	-11.1	17.3	3.1	-14.0	26.0
	2022	7.9	-5.6	26.5	9.0	-6.0	39.0
	2023	5.8	-10.7	26.8	7.0	-12.0	37.0
	2024	7.3	-3.3	28.4	7.0	-4.0	33.0
	2025	9.4	-6.9	25.0	11.1	-8.0	36.0
May	2015	14.3	4.2	29.0	17.4	2.0	52.0
	2016	12.9	-5.0	29.3	18.0	-6.0	50.0
	2017	12.8	-1.8	28.9	16.8	-5.0	47.0
	2018	9.6	-4.5	28.1	10.7	-7.0	38.0
	2019	13.6	-5.1	30.1	15.5	-6.0	53.0
	2020	16.5	-0.4	34.8	18.9	-1.0	51.0
	2021	18.5	-1.1	35.7	22.7	-2.0	58.0
	2022	13.4	-3.3	32.2	15.2	-6.0	40.0
	2023	14.7	-4.6	30.5	18.5	-9.0	53.0
	2024	10.0	-4.2	24.6	13.2	-5.0	42.0
August	2015	15.1	1.6	33.6	18.6	1.0	47.0
	2016	20.4	5.8	32.7	26.6	6.0	55.0
	2017	18.8	5.4	32.6	23.6	3.0	55.0
	2018	16.3	6.7	30.0	19.8	6.0	52.0
	2019	17.2	4.2	34.3	20.1	2.0	50.0
	2020	19.3	7.9	35.3	22.9	9.0	59.0
	2021	20.0	3.7	33.7	24.1	2.0	56.0
	2022	18.4	4.9	32.0	23.3	4.0	52.0
	2023	18.1	4.4	31.8	22.9	4.0	54.0
	2024	16.7	7.2	31.1	20.1	5.0	51.0

Nevertheless, a general warming trend has been observed since 2023, possibly linked to climate change. In May, temperatures range from 13.0-16.0 ℃, showing a similar temporary decline in 2018-2019 before returning to average levels.

Based on Figure 11, In June, average temperature reach 17.0-20.0 ℃, with noticeable interannual variability, especially in 2015-2017, when sharp fluctuations were recorded.

Accordingly, in July, the warmest month, the average temperature is 20.0-22.0 ℃. The period shows stable summer conditions, though gradual warming is visible in recent years. In August, temperatures slightly decrease to 18.0-21.0 ℃, followed by a stronger decline in September, when average temperatures drop to 8.0-10.0 ℃. In 2022-2023, however, temperatures rose to 13.0-14.0 ℃, indicating a relatively warm autumn period.

In 2024 and 2025, there is a distinguishable natural connection between the wheat harvest and the temperature level in April, at the beginning of the growing season, thus according to Table 5, warming is noticed in these years, which creates favorable conditions for wheat production. Furthermore, in 2025, the average soil temperature is 11.1 °C, which is 51.6% higher than the average value from 2015 to 2019 (4.4 °C).

But in May 2021, on the contrary, abnormal warming occurs, which, along with insufficient precipitation, could lead to drought and lower yields in the process, thus the average soil temperature is 22.7 °C, which is 44.6% higher than the same indicator during the stable harvest period. Moreover, the air temperature reached a maximum value of 35.7 °C at that time.

In August, the average air temperature was relatively stable. However, the harvest decreased slightly in 2016, which can also be attributed to an increase in the average atmospheric and soil temperatures (20.4 °C and 26.6 °C, respectively). Together with insufficient rainfall, this could indeed lead to a drought of a certain scale and thus to a reduction in the yield of spring wheat. This situation repeats itself in 2021, when the average air temperature is 20.0 °C and the soil temperature is 24.1 °C. However, by 2024, both indicators are on the decline, which is also noticeable by the wheat harvest this year, showing growth.

In the North Kazakhstan region, it is also possible to identify a trend towards general warming. Thus, in April until 2019, the average air temperature exceeded the limit of 7 °C, only once in 2016 (8.0 °C). After that, it exceeded this limit in 2020 (8.0 °C), 2022 (7.9 °C), 2024 (7.3 °C), and 2025 (9.4 °C). This trend may be a clear example of global warming, which also has an impact on the harvest of spring wheat. This may also indicate the early onset of spring and the accumulation of heat during the growing season of wheat.

4.3.3 Evaluation of Precipitation Sum

The temperature parameter alone may be insufficient to explain the decrease in the yield of spring wheat in Kazakhstan, because an equally important factor is the amount of precipitation, as the irrigation of these areas is not a real option in these regions of Kazakhstan. In Table 6 below, the accumulated amount of precipitation is demonstrated in each month of the vegetation period, from 2015 to 2024. A comparison of temperature and precipitation data makes it possible to trace the complex influence of climatic factors on the yield of spring wheat in the studied regions.

Table 6. Air precipitation sums in months, sum for the vegetation period, and average air precipitation in a month and a wheat growing year, in Akmola, Kostanay and North Kazakhstan regions, expressed in millimeters, in period of 2015-2024.

Source: own work based on Kazhydromet (2025, http4).

Air Precipitation Sum (mm)								
Region	**Year**	**April**	**May**	**June**	**July**	**August**	**Septembe r**	**Sum during the growing period**
Akmola	2015	38.9	66.7	71.3	40.7	40.2	20.6	278.4
	2016	34.8	32.6	48.5	101.3	45.1	40.0	302.3
	2017	26.9	19.0	18.0	58.6	7.6	11.4	141.5
	2018	32.3	29.8	81.9	44.0	96.7	24.4	309.1
	2019	35.2	19.6	42.7	21.5	30.8	55.7	205.5
	2020	55.8	2.6	56.6	59.5	28.6	38.1	241.2
	2021	6.0	24.0	15.8	24.5	20.4	29.5	120.2
	2022	4.0	14.6	37.4	123.9	36.3	26.5	242.7
	2023	46.6	5.4	11.7	26.3	49.6	79.3	218.9
	2024	28.4	78.9	65.1	67.8	78.1	18.6	336.9
	Average	**30.9**	**29.3**	**44.9**	**56.8**	**43.3**	**34.4**	**239.7**
Kostana y	2015	34.5	84.2	33.1	26.7	21.4	19.4	219.3
	2016	74.0	12.7	75.5	72.7	6.0	22.6	263.5
	2017	15.4	59.6	30.2	87.9	32.5	9.9	235.5
	2018	28.5	31.1	43.3	49.2	26.5	8.3	186.9
	2019	23.7	29.1	91.5	54.3	48.7	34.3	281.6
	2020	27.4	38.0	30.2	47.6	34.2	69.4	246.8
	2021	2.9	10.0	9.0	32.8	23.7	31.3	109.7
	2022	11.6	33.9	17.7	26.6	9.6	17.4	116.8
	2023	0.4	7.4	45.3	22.0	116.5	39.5	231.1
	2024	16.2	43.4	52.0	122.1	59.4	14.2	307.3
	Average	**23.5**	**35.0**	**42.8**	**54.2**	**37.8**	**26.6**	**219.8**
North Kazakhs tan	2015	21.2	42.5	22.1	94	41.6	39.8	261.2
	2016	17.4	18.9	152.8	75.7	5.4	22.5	292.7
	2017	27.8	18.5	47.9	33.0	25.2	9.4	161.8
	2018	26.4	70.5	53.7	125.7	31.9	36.0	344.2
	2019	20.1	26.1	47.7	36.7	55.1	47.8	233.5
	2020	29.0	49.6	21.1	28.1	50.5	35.2	213.5
	2021	11.3	15.0	19.8	0.0	45.2	16.9	108.2
	2022	9.4	48.1	52.5	82.4	13.6	22.6	228.6
	2023	1.8	48.9	48.2	21.1	50.9	35.2	206.1
	2024	24.4	42.1	70.1	121.4	64.5	26.7	349.2
	Average	**18.9**	**38.0**	**53.6**	**68.7**	**38.4**	**29.2**	**239.9**

In the Akmola region, during 2021 and 2023, abnormally high temperatures were observed in May (up to 36.1°C and 32.6°C, respectively), which coincided with extremely low precipitation amounts during the critical period of tillering and release of plants into the tube (24 mm in May 2021, and only 5.4 mm in May 2023). The data presented in Table 6 confirms that in these years the total precipitation amount during the wheat vegetation period was significantly lower than the long-term level (120.3 mm in 2021, and 218.9 mm in 2023, at a rate of over 250 mm). The sum of precipitation is very important, especially at the beginning of the growing season. In the region of Kostanay, in accordance with Table 6, it is noticeable that in April 2021 and 2023, the amount of precipitation is very low (2.9 mm and 0.4 mm, respectively), which could cause the seeds and soil to lack moisture. However, it should be borne in mind that the snowfall that fell earlier in winter could provide the missing moisture for the wheat seeds. But despite this, overall, in 2021, the amount of precipitation during the wheat growth period was very low, which was exactly 109.7 mm, and that is less than the average (219.8 mm) by approximately 50.1%.

Eventually, the data for the North Kazakhstan region shows a relatively stable moisture supply during the analyzed period compared to the other regions, which directly affects the stability of spring wheat yields. In most years, the amount of precipitation during the growing season exceeded 250 mm. Moreover, in some years, such as in 2018 and 2024, it reached 340 mm, creating optimal conditions for plant growth and development. Accordingly, Figure 10 shows that the yield in these years was one of the highest, which was 1.5 and 1.9 t/ha, respectively. However, the precipitation indicators demonstrate a possible drought in 2021, since the amount of precipitation during the growing season is almost half less (108.2 mm) than in other years. Despite this, the region of North Kazakhstan remains relatively stable due to favorable climate conditions and a more even distribution of precipitation over the months. This proves that the North Kazakhstan region remains one of the most favorable areas of the country for growing spring wheat, where high productivity potential remains even in certain dry seasons.

As a result, the combination of cold April, a sharp warming in May, and a pronounced lack of moisture in May-August led to severe water stress on plants and became the main reason for the decrease in yields. In contrast, in more favorable years, for instance, in 2016 or 2024, when moisture availability exceeded 300 mm, and temperatures did not exceed extreme values, wheat yields remained significantly higher. Therefore, the integration of temperature and hydrometeorological instruments demonstrates that yields are formed not only by a single factor, but by a combination of climatic conditions during the crucial phases of the growing period.

5. Conclusions and Proposals

In conclusion, this research work has shown that the level of spring wheat harvest in Northern Kazakhstan is closely related to regional climatic and soil conditions. Moreover, this is consistent with the conclusions of scientific paper of Babkenov et al. (2020), emphasizing that the yield of spring wheat in Northern Kazakhstan is highly dependent on climate variability, especially temperature fluctuations in April, May, and August, and additionally, on uneven precipitation during the growing season. My results confirm this trend, specifically in 2019, 2021 and 2023, when low spring temperatures and insufficient rainfall led to lower yields. The analysis of Akmola, Kostanay, and North Kazakhstan regions showed that despite the similar continental climate, differences between precipitation distribution, soil and air temperatures, as well as soil characteristics, determine differences in wheat yields.

The abnormally cold April in 2021 and 2023 had a negative impact on the wheat harvest, which led to late sowing. However, the presence of a thick snow cover in winter could provide additional moisture to the soils, which could have a good effect during a drought in summer, especially in the Akmola region in 2021, when the accumulated precipitation amount did not exceed 25 mm in each month during the growing season of wheat. My results concerning air precipitation are consistent with the findings of Babkenov (2020) and Lioubimtseva et al. (2012): the amount of precipitation is indeed a key obstacle to increasing the yield of spring wheat in the northern region of Kazakhstan. Moreover, consistent with the research of Funakawa et al. (2004), the soil microbial biomass is strongly connected with the soil moisture content, which might mean that a lack of precipitation could lead to a corresponding lack of microbiological processes in the soil, which in turn leads to a decrease in the yield of spring wheat. A more uniform distribution of precipitation and mild temperatures in summer compared to other regions was in the North Kazakhstan region. This region has more stable conditions for the production of wheat, which also proves the high yield of the region despite the lowest growing area. Furthermore, the temperature rise trend identified in this study confirms the conclusions of Salnikov et al. (2023), which reported gradual warming and an increase in temperatures in Kazakhstan over the past decade. However, my results show that even short-term temperature anomalies and unequal precipitation distribution still have a strong impact on annual yield fluctuations.

Regarding the soil cover, dark kashtanozems and chernozems predominate in the Akmola region, with moderate humus content (4-6%). However, soils are disposed to compaction and salinization. They also have a low nitrogen content, which is essential for the soil for plant growth, as it is a key component of proteins, nucleic acids, and chlorophyll. Shortage of nitrogen leads to slower growth, yellowing of leaves, and reduced yields. In the Kostanay region, chernozems with a high humus content (up to 6.2%) are more common. Whereas, in the North Kazakhstan region, ordinary and leached chernozems are well spread, which have a comparatively higher humus content (6-8%). North Kazakhstan soils have the highest rate of the minimal field moisture capacity (65-259 mm), whereas the Kostanay region had the lowest rate of this soil parameter (45-186 mm). Moreover, the soils of the northern regions of Kazakhstan are susceptible to monoculture production, which, as a result, has a negative effect on the biological and chemical state of the soil, for example, by reducing the density or lowering the composition of humus. Regarding this, the study confirms the conclusions of Kunanbayev et al. (2022), who found that continuous cultivation and monocropping practices lead to humus depletion and soil compaction. This may also be a key reason for the unstable spring wheat harvest that began in 2019.

Overall, the North Kazakhstan region showed the most stable and high wheat yields, regardless of the relatively smaller area allocated for wheat cultivation, due to a more favorable combination of moderate temperatures, evenly distributed precipitation, and fertile chernozem soils with a higher humus content and moisture retention capacity. On the contrary, Akmola and Kostanay regions, occupying larger wheat-producing areas, demonstrated lower yields due to less favorable soil and climate conditions. Furthermore, since 2023, there has been a slight upward trend in average temperature, which may indicate future arid conditions in the regions, especially with insufficient precipitation. This trend converges with the study of Zhumagulov et al. (2023), which forecasted the decline of moisture availability and increase of aridity by 2050, which may lead to a potentially significant reduction in volumes of spring wheat yields.

Eventually, according to FAOSTAT, due to the warm weather conditions, Kazakhstan farmers began to grow more sunflower seeds and maize (corn). Thus, in 2021, the area of maize sown increased by 16.6%. Also, the area allocated for sunflower seed rose by 26% in 2021, and by another 15.3% in 2022. This focus on other crops indicates the adaptation of Kazakhstani farmers to changing weather conditions.

In future work, I consider it worth deliberating the precipitation throughout the whole year in the regions, so that it is possible to assume what could compensate for low precipitation rates during the vegetation period. Moreover, the soils of the northern regions of Kazakhstan are susceptible to monoculture production, which has an unfavorable influence on the soil biochemical conditions. Therefore, in future studies, it would be possible to consider the effect of wheat monoculture on the soil, and accordingly, the spring wheat yields.

6. Summary

Wheat plays a key role in human diet. Flour is obtained from its grains, which is used for the production of bread, pastries and pasta. Moreover, it is valued as a source of vitamins, antioxidants, and fiber that strengthen the immune system and normalize metabolism of humans. Kazakhstan, the ninth largest country, is located in the center of the Eurasian continent. One of the main products produced in Kazakhstan is spring wheat (*Triticum spp*.). Kazakhstan occupies a large territory, therefore it includes different climatic zones. For this reason, climatic conditions and soil characteristics vary throughout the country, which may have different effects on spring wheat production.

This study is aimed to evaluate the influence of soil and climate in three major wheat-producing regions of Kazakhstan (Akmola, Kostanay, North Kazakhstan) on the yield of spring wheat, and identifying trends and relationships between these factors and the amount of spring wheat harvest, namely in the period from 2015 to 2025. Various reliable sources, both international and local, were used to collect data within the framework of the study, such as Kazhydromet, the official national hydrometeorological service, National Bureau of Statistics of Kazakhstan, Food and Agriculture Organization of The United Nations (FAOSTAT) database, United States Department of Agriculture (USDA), and United Nations Environment Program (UNEP), Google Scholar, ResearchGate, and ScienceDirect. Data on the area used for growing wheat, and the yield, was processed using Excel to calculate averages, standard deviation, and create graphs and tables. Meteorological data includes the average, minimum, and maximum values of air and soil temperatures, as well as the amount of precipitation. They were processed using the SPSS program.

The results showed that the largest area dedicated to wheat cultivation belongs to the Akmola region, while the smallest belongs to the North Kazakhstan region. Despite this, the North Kazakhstan area stands out for the highest yield throughout the 10 studied years, while Akmola occupies the last position in this comparison. In general, in all three regions, the area allocated for wheat production remains stable, which proves the importance of wheat for Kazakhstan's agriculture. April, May, and August are the most variable during the growing season and are the months that determine the wheat harvest. Low temperatures in April, high temperatures in May and August, and insufficient rainfall were the main reasons for lower yields. Regarding the soil condition, chernozem prevails in all three regions, however, in the North Kazakhstan region, chernozems are distinguished by higher humus content and moisture

storage capacity. These characteristics of chernozem soils can help during the dry periods of the growing season.

In conclusion, Akmola, Kostanay, and North Kazakhstan regions have similar climatic features regarding air and soil temperature, but Akmola is characterized by relatively greater variability. Kostanay gets the least amount of precipitation. Dry periods are one of the main factors limiting wheat production. The North Kazakhstan region, on the other hand, is characterized by a relatively higher amount of precipitation and a more moisture-storing soil, so this region shows significantly better results.

Moreover, in future studies, it is definitely worth considering the impact of monocultural wheat production on soil conditions, more detailed meteorological data, especially snow cover, and a more detailed chronology of spring wheat production in Kazakhstan.

7. References

OECD/FAO (2024), OECD-FAO Agricultural Outlook 2024-2033, Paris and Rome, https://doi.org/10.1787/4c5d2cfb-en.

Fehér I., Lehota J., Lakner Z., Kende Z., Bálint C., Vinogradov S., Fieldsend A., (2017). Kazakhstan's Wheat Production Potential. *The Eurasian Wheat Belt and Food Security, Global and Regional Aspects.* Editors: Sergio Gomez y Paloma, Sébastien Mary, Stephen Langrell, Pavel Ciaian.

FAS Staff, Lucas Blaustein, USDA (2022). The Foreign Agricultural Service. Report "Kazakhstan: Grain and Feed Update". Report Number: KZ2024-0006.

Babkenov, A. T., Babkenova, S. A., Abdullayev, K. K., & Kairzhanov, Y. K. (2020). Breeding spring soft wheat for productivity, grain quality, and resistance to adverse external factors in Nothern Kazakhstan. *Journal of ecological engineering*, *21*(6).

Ahmed, M. (2015). Response of spring wheat (Triticum aestivum L.) quality traits and yield to sowing date. *PloS one*, *10*(4), e0126097.

Zholaman, R., Fedorenko, E., Savin, T., Aituganov, K., & Shvidchenko, V. (2022). Influence of the North Kazakhstan plains weather on the productivity of the spring soft wheat. *Scientific Horizons*, *10*(25), 53-61.

Suleymenov M.K., Baraeva A. I. (2020), Сроки сева яровой пшеницы (The timing of spring wheat sowing). *The Agricultural Sector Magazine (№ 1(43)).*

Chibilyov, A. (2002). Steppe and forest-steppe. *The physical geography of northern Eurasia*, 248-266.

Rachkovskaya, (2006). National Atlas of the Republic of Kazakhstan, volume 1, Natural conditions and Resources. Almaty, 2010. p. 109.

UNEP, 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability, the Working Group II Contribution to the Sixth Assessment Report. 2022.

Geldiyeva, G.V.; Veselova, L.K. *Landscapes of Kazakhstan*; Gylym: Alma-Ata, Kazakhstan, 1992; pp. 71–79.

Salnikov, V., Talanov, Y., Polyakova, S., Assylbekova, A., Kauazov, A., Bultekov, N., ... & Beldeubayev, Y. (2023). An assessment of the present trends in temperature and precipitation extremes in Kazakhstan. *Climate*, *11*(2), 33.

Baisholanov, S., Akshalov, K., Mukanov, Y., Zhumabek, B., & Karakulov, E. (2024). Agro-Climatic Zoning of the Territory of Northern Kazakhstan for Zoning of Agricultural Crops Under Conditions of Climate Change. *Climate*, *13*(1), 3.

Shamanin, V., Salina, E., Wanyera, R., Zelenskiy, Y., Olivera, P., & Morgounov, A. (2016). Genetic diversity of spring wheat from Kazakhstan and Russia for resistance to stem rust Ug99. *Euphytica*, *212*(2), 287-296.

Lioubimtseva, E., & Henebry, G. M. (2012). Grain production trends in Russia, Ukraine and Kazakhstan: New opportunities in an increasingly unstable world?. *Frontiers of Earth Science*, *6*, 157-166.

Zhumagulov I.I., Satbaldieva Z.Z. (2023). Analysis of the impact of meteorological conditions on the productivity of spring wheat in 2023 using the example of the tayynsha meteorological station in the north kazakhstan region. *Kazhydromet.*

Pachikin, K., Erokhina, O., & Funakawa, S. (2009). Properties and distribution pattern of soils in Kazakhstan. *Pedologist*, *53*(1), 30-37.

Borovski, V.M., Uspanov, U.U., 1971. Soils of Kazakhstan and the ways of their use. Institute of Soil Science, Alma-Ata, 10 (in Russian)

Funakawa, S., Nakamura, I., Akshalov, K., & Kosaki, T. (2004). Soil organic matter dynamics under grain farming in Northern Kazakhstan. *Soil science and plant nutrition*, *50*(8), 1211-1218.

Karbozova–Saljnikov, E., Funakawa, S., Akhmetov, K., & Kosaki, T. (2004). Soil organic matter status of Chernozem soil in North Kazakhstan: effects of summer fallow. *Soil Biology and Biochemistry*, *36*(9), 1373-1381.

Rau, A., Koibakova, Y., Nurlan, B., Nabiollina, M., Kurmanbek, Z., Issakov, Y., ... & Dávid, L. D. (2023). Increase in productivity of chestnut soils on irrigated lands of northern and Central Kazakhstan. *Land*, *12*(3), 672.

Yapiyev, V., Gilman, C. P., Kabdullayeva, T., Suleimenova, A., Shagadatova, A., Duisembay, A., ... & Inglezakis, V. (2018). Top soil physical and chemical properties in Kazakhstan across a north-south gradient. *Scientific data*, *5*(1), 1-8.

Kunanbayev, K., Churkina, G., Filonov, V., Utebayev, M., & Rukavitsina, I. (2022). Influence of cultivation technology on the productivity of spring wheat and the humus state of southern carbonate soils of Northern Kazakhstan. *Journal of Ecological Engineering*, *23*(3).

Ershov Y.I. 2004. Organic matter of the biosphere and soil. Nauka, Novosibirsk, 104.

Altermann, M., Rinklebe, J., Merbach, I., Körschens, M., Langer, U., & Hofmann, B. (2005). Chernozem—soil of the year 2005. *Journal of Plant Nutrition and Soil Science*, *168*(6), 725-740.

Rieznik, S., Havva, D., Butenko, A., & Novosad, K. (2021). Biological activity of chernozems typical of different farming practices.

Vysloužilová, B., Ertlen, D., Schwartz, D., & Šefrna, L. (2016). Chernozem. From concept to classification: a review. *AUC GEOGRAPHICA*, *51*(1), 85-95.

Blake, G. R. (1965). Bulk density. *Methods of soil analysis: Part 1 physical and mineralogical properties, including statistics of measurement and sampling*, *9*, 374-390.

Al-Shammary, A. A. G., Kouzani, A. Z., Kaynak, A., Khoo, S. Y., Norton, M., & Gates, W. (2018). Soil bulk density estimation methods: A review. *Pedosphere*, *28*(4), 581-596.

Belobrov, V. P., Yudin, S. S., Yaroslavtseva, N. V., Yudina, A. V., Dridiger, V. K., Stukalov, R. S., ... & Kholodov, V. A. (2020). Changes in physical properties of chernozems under the impact of no-till technology. *Eurasian Soil Science*, *53*, 968-977.

Pankova, E. I., & Chernousenko, G. I. (2018). Comparison of chestnut soils of Central Asia with their analogs in other soil-geographical provinces of the dry-steppe zone of the Eurasian subboreal belt. *Arid Ecosystems*, *8*(2), 89-96.

Kutílek, M., & Nielsen, D. R. (2015). Dear Soil, What Is Your Name?. In *Soil: The Skin of the Planet Earth* (pp. 187-220). Dordrecht: Springer Netherlands.

Simmons, S. R., Oelke, E. A., & Anderson, P. M. (1985). Growth and development guide for spring wheat.

Koppel, R. E. I. N. E., & Ingver, A. (2008). A comparison of the yield and quality traits of winter and spring wheat.

Shestakova N., Shelia V., Absattarova A., Shvidchenko V., Nurpeissov D., Gordeyeva Y., Amantayev B., Kipshakbayeva G., Almanova Z., Kurishbayev A. & Hoogenboom G. (2024) Adaptation of spring soft wheat (Triticum aestivum L.) to steppe and dry steppe growing conditions, Cogent Food & Agriculture, 10:1, 2412732, DOI: 10.1080/23311932.2024.2412732

Amerguzhin, H. A. (2003). *Агроэкологическая характеристика почв Северного Казахстана (Agroecological charactertics of the soils of Northern Kazakhstan).* (Doctoral dissertation, Soil Institute named after V. V. Dokuchaeva RASN).

Bakirov, D. R., & Karipov, R. H. (2017). *Эффективность возделывания яровой пшеницы на основе сокращённой и нулевой технологии в условиях АО «Акмола-феникс» Акмолинской области*. (The efficiency of spring wheat cultivation based on reduced and zero technology in the conditions of Akmola-Phoenix JSC in the Akmola region.)

Kraemer, R., Prishchepov, A. V., Müller, D., Kuemmerle, T., Radeloff, V. C., Dara, A., ... & Frühauf, M. (2015). Long-term agricultural land-cover change and potential for cropland expansion in the former Virgin Lands area of Kazakhstan. *Environmental Research Letters*, *10*(5), 054012.

Zvyagin, G. A., Kekilbayeva, G. R., Kasipkhan, A., Hamzina, B. N., Shoyinbayeva, A. D., & Orynbayeva, B. T. (2024). Современное гумусное состояние залежных земель Акмолинской области в подзоне черноземов южных. *Почвоведение и агрохимия*, (4), 5-15. (The current humus state of the fallow lands of the Akmola region in the southern chernozem subzone. Soil science and agrochemistry).

Zakirina, A. O., Taizhanova, M. M., Doskenova, B. B., & Bodunovskaya, N. S. (2017). Особенности почв Северо-Казахстанской области. In *Проблемы экологического образования в XXI веке* (pp. 82-86). (Soil features of the North Kazakhstan region. In Problems of environmental education in the 21st century)

Jalankuzov, T. D., Mukhametkarimov, K. M., & Aisalkin, T. (2017). Влияние способов обработки почвы на химические и водно-физические свойства черноземов южных Костанайской области Казахстана. *Лебедева Надежда Анатольевна–доктор философии в области*, 13. (The influence of tillage methods on the chemical and water-physical properties of chernozems of the southern Kostanay region of Kazakhstan. Lebedeva Nadezhda Anatolyevna–Doctor of Philosophy in the field).

Ramazanova R.H., Zhapparova A.A., (2012), Краткий курс почвоведения с основами геологии. Учебно-методическое пособие. Алматы: Казахский национальный аграрный университет, 99 p. (A short course in soil science with the basics of geology. Educational and methodical manual. Almaty: Kazakh National Agrarian University).

Baisholanov, S. S. (Ed.). (2017). *Agroclimatic resources of Akmola region: Scientific and applied reference book.* Astana: Institute of Geography LLP. ISBN 978-601-7150-83-9

Baisholanov, S. S. (Ed.). (2017). *Agroclimatic resources of Kostanay region: Scientific and applied reference book.* Astana: Institute of Geography LLP. ISBN 978-601-7150-86-0

Baisholanov S. S., (2017). *Agroclimatic resources of the North Kazakhstan region: Scientific and applied reference book*. Astana: Institute of Geography LLP. ISBN 978-601-7150-88-4

Borisov, A. V., Krivosheev, M. V., Mimokhod, R. A., & El'tsov, M. V. (2019). "Sod blocks" in kurgan mounds: Historical and soil features of the technique of tumuli erection. *Journal of Archaeological Science: Reports*, *24*, 122-131.

Internet Sources:

http1: https://www.worldbank.org/ext/en/home
http2: https://www.fao.org/faostat/en/#home
http3: https://nasec.kz/en
http4: https://www.kazhydromet.kz/en/
http5: https://fdc.nal.usda.gov/
http6: https://stat.gov.kz/en/

8. List of Tables and Figures

9. Declarations

MATE Organizational and Operational Regulations
III. Requirements for Students
III.1. Study and Examination Regulations
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Annex 4.2: Declaration of public access and authenticity of the thesis/thesis/dissertation/portfolio

DECLARATION

the public access and authenticity of the thesis

Student's name:	Altynay Chaiparova
Student's Neptun code:	HEFU6S
Title of thesis:	The Impact of Climate Change on Wheat Production in Kazakhstan's Diverse Soil Regions
Year of publication:	2025
Name of the consultant's institute:	Institute of Environmental Sciences
Name of consultant's deparment:	Department of Soil Sciences

I declare that the thesis submitted by me is an individual, original work of my own intellectual creation. I have clearly indicated the parts of my thesis or dissertation which I have taken from other authors' work and have included them in the bibliography. Furthermore, I declare that the artificial intelligence tools (e.g. text generation, linguistic correction, translation, data analysis) used during the preparation of the thesis did not substitute my own research and creative work; their use was indicated either in the list of sources or in the methodology section, and I acted in accordance with professional and ethical expectations.

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Date: ___2025___ year ___11___ month ___3___ day

Student's signature

DECLARATION

Altynay Chaiparova (name) (student Neptun code: HEFU6S)
as a consultant, I declare that I have reviewed the thesis and that I have informed the student of the requirements, legal and ethical rules for the correct handling of literary sources.

<u>**I recommend**</u> **/ do not recommend** the final thesis / dissertation / portfolio to be defended in the final examination.

The thesis contains a state or official secret: yes <u>no</u>

Date: 2025. 11. 03.

insider consultant

Declaration of Students and Doctoral Candidates on the Use of Artificial Intelligence (AI)”

1. general information:

Name of the student:	**Altynay Chaiparova**
Neptun ID:	**HEFU6S**
Level of program (mark with X):	BSc/BA
Name and code of the subject*:	**Environmental Engineering, B-GOD-N-EN-KORNY**
Title of the work:	**The Impact of Climate Change on Wheat Production in Kazakhstan’s Diverse Soil Regions**

* Not required to be completed in the case of a doctoral dissertation.

2. Declaration on the Use of AI

I, the undersigned, fully aware of my ethical responsibility, make the following declaration:

I have used an artificial intelligence system or service.

(Please fill in the relevant tables!)

3. Details of Artificial Intelligence Usage

TABLE I: Assistant or Minor Usage (e.g., translation, language proofreading, brainstorming, etc.)

(For these uses, attaching the specific prompts and responses is not required.)

Purpose of Use	**Name and Version of the AI Tool Used**	**Affected Section (if not applicable to the entire text)**
Translation, language proofreading	ChatGPT 5, Grammarly	Several paragraphs in the entire text

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(In these cases, documenting the key prompts used and the raw responses provided by the AI, and attaching them as an appendix to the work, is required.)

Purpose of Use	**Name, Version, and Access Information of the AI Tool Used**	**Exact Number of the Affected Chapter / Figure / Table**	**Entry Number of the Appendix Containing the Prompt Log**

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Rules Prescribed by the Lecturer or Supervisor

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I declare that I have critically reviewed, edited, and incorporated any content potentially generated by AI in all cases. I take full responsibility for every element of the submitted work, including its originality and scientific validity. I acknowledge that the Hungarian University of Agriculture and Life Sciences may check the submitted work with an artificial intelligence detector and may initiate proceedings if my declaration is found to be false or incomplete.

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....

Signature of the Student **Signature of the Advisor/Supervisor**