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Modeling Scenarios of Climate Change Impacts on Leguminous Crop Production: A Case Study in Kazakhstan

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ABSTRACT

Climate change affects leguminous crop production in Kazakhstan through drought or cold. The Bulk forecasting Arima model was used for the analysis, and we explored the likely impact of climate change on leguminous crop production in Kazakhstan. A base case and three climate change scenarios from 2030 to 2100 were created, and climate data from the Intergovernmental Panel on Climate Change (IPCC) and KazHydromet were used. In particular, special attention should be given to the impact of climate change on crop and land decreases, grain quantity and quality reduction. The results show that decreased rainfall and increased temperatures or frost damage the yield of leguminous crops. Different regions have various climates, and climate change will have a positive effect on crop yields in the North and Southeast Regions and will allow farmers to cultivate economically efficient production. The area of cultivated land is expected to decrease (60%) in the southern and northwestern regions of large-scale farms. Farmers adapt to climate change by using hybrid seeds and new irrigation technologies. Frost days will impact the yield of small-scale farms. Leguminous crops are important export crops, and, in some regions, climate change will impact agricultural productivity and food security in Kazakhstan.

Keywords: Leguminous crop production; Climate change; Modeling scenarios, Adaptation, Food security.

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INTRODUCTION

Climate change affects the countries of Central Asia, whose area is 3.9million km^2, and Kazakhstan has the largest territory. The region's main natural systems include mountains, vast steppes and deserts, numerous lakes, and Transboundary Rivers (Syr Darya, Irtysh, Ili, Caspian and Aral Seas). Due to Transboundary Rivers, drought affects several countries at once, and in future predictions, it will affect agricultural production and security. Climate change makes the region's ecosystems highly vulnerable to anthropogenic stress and drought (Bugubayeva et al., 2024). More than half of the lands in Central Asia are decertified. Large-scale processes of land degradation include water and wind erosion, salinization and pollution of irrigated lands, and degradation of pastures, which ultimately leads to a decrease in land fertility, labor losses, increased poverty and migration. The main agricultural food industry in Central Asia, as well as Kazakhstan, includes grains, legumes and leguminous crops. Climate change also has a negative impact on producers, which leads to significant harvest instability and a decrease in the efficiency of agricultural production in general (Yadav et al., 2010). The economic losses associated with natural disasters in agriculture in Tajikistan, Turkmenistan, Kazakhstan and Kyrgyzstan range from 0.4% to 1.3% of the annual GDP (Issadzhanov, 2020). According to expert forecasts, by 2050, economic damage to the countries of Central Asia may increase to 5% of regional GDP (Semenova, 2012). Moreover, the most vulnerable sector of the economy is associated with floods and droughts in agriculture, where the bulk of the population is employed. Analysis of discrepancies between reported and forecast data for 2021. According to the Social and Economic Development Fund of Kazakhstan data for 2021-2025, economic growth in 2021 was forecasted at 3.1%, and

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actual growth was 4.1% (Bolatova & Engindeniz, 2021). Significant growth rates were achieved in the provision of communication services – 114.6% and trade – 109.2%, which is 8.1 percentage points higher than the forecast level. The growth in agriculture, with a forecast of 105.0%, decreased by 7.4%. The low figure is due to a decrease in crop production of 6.7%. Agriculture accounts for only 6% of Kazakhstan's GDP but remains an important sector of the Kazakh economy (Ahmed et al., 2022; Andrews & Hodge, 2010; Golitsyn, 2019). It employs 18% of the working-age population and is therefore critical for addressing rural income generation, food security and poverty reduction. Exports of food and agricultural products accounted for 5% of Kazakhstan's total exports.

Leguminous crops, such as chickpeas, peas, lentils, beans, and soybeans, are grown in Kazakhstan for grain and green mass (Ansabayeva, 2023; Kenenbayev et al., 2023). Before the general commercialization of agriculture, approximately 400 thousand hectares of leguminous plants (soybeans, peas, chickpeas, beans, beans, lentils) were grown. The role of leguminous crops is significant since the introduction of efficient agricultural practices contributes to a significant reduction in greenhouse gas emissions into the atmosphere and reduces the need for fertilizers. Notably, in agroecosystems, pulses help maintain and/or increase the volume and activity of microbial biomass in the soil. Great interest in growing grain legumes in Kazakhstan is due to the volatility of grain prices and the demand for grain legumes in foreign markets. Legumes are the most reliable and profitable component of mixed crops due to their ability to actively fix nitrogen and high drought resistance. Kazakh farmers widely grow legumes for the main national dish; among leguminous crops, peas are among the most productive and economically profitable crops. At least 450 $/ton of lentils are the most expensive, and approximately 250 $/ton of peas are the most expensive (Golitsyn, 2019; Svetlov et al., 2019).

The world market of leguminous crops (lentils, beans, peas, chickpeas and all their varieties) is becoming one of the fastest-growing markets in the food segment (Boote et al., 2011). Kazakhstan, as a country capable of fully providing itself with meat and supplying it abroad, is simultaneously beginning to increase its crop of grain legumes. According to the State Revenue Committee of the Ministry of Finance of the Republic of Kazakhstan, from July to January 2022/23 MY, 133.7 thousand tons of main legumes were exported from Kazakhstan. This value is 2.5 times greater than the volume of supplies for the same period in 2021/22 MY (52.9 thousand tons). The majority of legume exports were lentils—91.4 thousand tons in volume terms. A total of 35.8 thousand tons of peas and 6.5 thousand tons of chickpeas were exported. The share of lentils in 2022/23 MY increased from 48 to 68% of the total exports of legumes (relative to 2021/22 indicators), and the share of chickpeas increased from 2 to 5%. However, the percentage of peas decreased from 51 to 27%. Exports of Kazakh chickpeas are the most limited both in terms of volume and geography of supply. In July January 2022/23 MY, more than 75% of chickpea supplies were purchased by Turkey—4.9 thousand tons in physical terms—which was 10.6 times greater than that in the same period last year. The second position among importers was taken by Uzbekistan, which increased purchases by 9.7 times—up to 0.7 thousand tons. Additionally, this year, Lithuania, Tajikistan and Russia were among the importers of Kazakh chickpeas. The structure of Kazakhstan's exports of grain legumes includes several varieties of peas and beans, chickpeas and lentils (Nordhaus, 1994; Bosetti et al., 2016).

Currently, some research is being conducted on the impact of climate on the production of leguminous crops based on complex agricultural economic-climatic models, which show direct and inverse relationships between variables that correspond to the existing climate on the production of leguminous crops (M'barek et al., 2012; ASPR, 2023). It is worth noting that, for example, in the developed EU iMAP model system, a degree of detail has been achieved that is associated with cost savings and the least negative impact on the climate. Much research has focused on understanding and quantifying future global changes in climate-related hazards and on understanding and modeling the sensitivity of natural and human systems to these changes. Much less effort has been invested in understanding how socioeconomic trends may change both exposure and vulnerability to hazards over time, which may have a decisive impact on the actual risks associated with future climate change and the feasibility and effectiveness of adaptation options at the national scale (Lin et al., 2011; Climate Change Annual Report, 2023). Additionally, the integration of the ESIM partial equilibrium model included in this system with the LPJ vegetation model reflects the likely changes in agriculture of the European Union under different climate scenarios but does not consider the distribution of production factors by country. Models that assess the impact of climate on the agricultural sector of the economy have different structures: climate scenarios are taken from world economic and climate models, and the impact of the production of leguminous crops on the climate is either very small or taken into account in the form of variables that reflect deviations from scenario conditions (Kang et al., 2009; Chugunkova et al., 2018).

According to the Statistics Agency of the Republic of Kazakhstan, in the country, the total area of leguminous crop crops, such as peas, chickpeas and lentils, is 42.8 thousand hectares. Soybean is a relatively drought-resistant crop. Irrigation is necessary when growing soybeans in areas with hot and dry climates. It is also worth noting that pulses can mitigate the effects of changing weather patterns, which contribute to increased food security. Agroforestry systems using pulse crops such as pigeon peas support adaptation to climate change by diversifying income sources, increasing resilience to climate extremes and increasing productivity. Lentils tolerate a temporary lack of moisture more easily than peas, so they thrive in areas with unstable humidity. It is possible to highlight a common feature that exists in scientific research—the assessment of the consequences of predicted climate changes for the production of grain legumes is based on the results of climate modelling and an approximate calculation of the gross harvest of grain leguminous crops under predicted climatic conditions. It is also worth noting that the calculations do not comprehensively and simultaneously reflect the following factors: demand, the spatial distribution of resources-capital and labor-the competitive position of legume production, etc. (Nordhaus, 1994; Bolatova & Engindeniz, 2021).

This article describes the study of leguminous crop production under climate change and provides a model of future impacts in Kazakhstan. Farmers during cultivation require a study to save production and need adaptation programs or strategy plans for leguminous production. During the cultivation of leguminous crops, the key questions are whether the climate will change and whether it will affect the country's economy (Kochorov et al., 2023). The impacts of climate change on land use, yield and the quality and quantity of legume grain have yet to be studied. It is important to address models and scenarios for the impact of climate change on production. Thus, this study aimed to evaluate and create a scenario in which climate change impacts leguminous crop production in Kazakhstan.

MATERIALS & METHODS

Climate change impacts agriculture in different ways but does not affect the agro-industrial complex of Kazakhstan (Sergi et al., 2019; Fedotova & Slozhenkina, 2020; Nurmanbetova et al., 2021). The hypothesis of the study:

H_0: Climate change impacts on the agro-industrial complex of Kazakhstan.

H_1: Climate change impacts on leguminous crop production in the present and future times in Kazakhstan.

H_2: Climate change impacts the economic efficiency of leguminous crops in Kazakhstan.

Kazakhstan has 54000 farmers who cultivate a leguminous crop, and we used a proportional sample size formula to obtain data from the groups and describe the correct data on the impacts on leguminous crop production. The formula shows that 115 farmers should be surveyed. The data were obtained from face-to-face Google Surveys and reports from the IPCC and Kazhydromet, which were coded and transferred for analysis to the PC in 2022-2023. In this article, various statistical programs, such as SPSS, GRETL, and Python, were used. First, the socioeconomic characteristics of the farmers were evaluated, such as the age and education of the farmers, family population, labor force availability and use, land availability and use, capital availability, crop and animal production activities and annual activity results. The following climatic data were analyzed to determine the impacts of climate change on the production area, yield and economic efficiency of leguminous crops. Climate change impacts were evaluated, and models were prepared for future scenarios from 2030 to 2100. Considering that the leguminous crop production area may affect the level of tolerance to climate change, we planned to evaluate the leguminous crop farmers by dividing them into three groups according to the size of the production area in the data analysis. Accordingly, the first group included 19 hectares and farmers with smaller cultivation areas, the second group included farmers with production areas between 20-40 hectares, and farmers with a leguminous crop production area larger than 41 hectares composed the 3rd group. The farmers in the research area represented 45 (39.13%) of the farmers in the 1st group, 39 (33.91%) in the 2nd group and 31 (26.96%) in the 3rd group (Table 1).

Table 1: Amounts of the examined groups of leguminous crop farms

Groups	Total number of farmers	%
1st group (≤19 ha)	45	39.13
2nd group (20-40 ha)	39	33.91
3rd group (≥41 ha)	31	26.96
Total	115	100.00

A climate change scenario is a hypothetical representation of potential future conditions. Closely related to this is the concept of paths, which are more specific and action-oriented than scripted. These scenarios help us understand what the future holds (Olatunji & Jiashen, 2023; Siegel & Wagner, 2022). Statistical analysis was performed using IBM SPSS, and the autoregressive integrated moving average (ARIMA) model was used as an effective forecasting model for regression analysis (Vijay & Bala, 2019; Petrunenko et al., 2021; Mohsin et al., 2022). We created a forecasting model for yield and cultivated land that is most affected by climate change. It takes into account the serial correlation of data, which is the most important feature of time series data and provides a systematic alternative to determine the best model, making it the best method for predicting the impact of climate change on leguminous crops. The time series average of the area and yield for the period (January 2020 - December 2023) are used as training data to forecast future data for 2030 - 2100, and during an assessment of the ARIMA (p,d,q) model, the Ljung-Box Q-statistics are also used.

The Arima model formulas:

$$y'(t) = c + \phi 1 * y'(t-1) + \cdots + \phi p * y'(t-p) + \theta 1 * \varepsilon(t-1) + \cdots + \theta q * \varepsilon(t-q) + \varepsilon t \quad (1)$$

Where yt is the data, c is a constant, ϕ1 is the coefficient of the first AR term, ε (t-1(q)) is the error of regression with the residuals of the past observations, p is the order of the AR term, θ1 is the coefficient of the first MA term, and q is the order of the MA term.

The Ljung-Box Q test can also be used to assess autocorrelation in any series with a constant mean. This includes residual series that can be tested for autocorrelation during model diagnostic tests (Hassani & Yeganegi, 2020).

The Ljung-Box Q-statistics formulas:

$$Q_{LB} = n(n+2)\sum_{j=1}^{h} \frac{\rho^2(j)}{n-j} \quad (2)$$

Where sample size is n, ρj is the autocorrelation in lag j, and h is the number of tested lags.

Scenarios can show which decisions will have the most significant impact on mitigation and adaptation. Certain parameters affect how the scripts will look. This article examined 3 types of scenarios. The scenario describes different characteristics of the impact of climate change from drought, precipitation and cold days. The groups also studied how groups use resources, how groups adapt, and the problems, desires and goals of farmers. These scenarios are built based on a farmer questionnaire and IPCC reports and integrate information on the impact of climate change for specific regions of Kazakhstan (IPCC, 1998; IPCC, 2022; IPCC, 2023). Describing the model, the scenario shows adaptive measures for farmers in the future. The impacts of climate change on cultivated leguminous crop areas were also investigated, and the new model was considered to be competitive. The purpose of such a scenario is to predict the future and to present in as much detail as possible different options for the development of cultivated areas of leguminous crops. This will help farmers in each group understand the pattern of whether it would be most efficient to have land under pulses. In the literature, this method is discussed in detail as a method of scenario planning. Using the scenario planning method in agribusiness modeling forces farmers to think about how the model should develop under certain climate conditions. This deepens the understanding of the model and potentially requires changes in leguminous production. Using these scenarios, farmers can be prepared for what tomorrow holds (O'Neill et al., 2014).

The IPCC prepared pathways for climate change impacts on socioeconomic and other development, and in this study, shared socioeconomic pathways (SSPs) were used. SSPs have been developed to complement RCPs to address the various socioeconomic challenges associated with adaptation and mitigation. SSPs are based on five pathways that show future alternative socioeconomic situations in the absence of climate policy intervention, including sustainable development (SSP 1), regional rivalry (SSP3), inequality (SSP4), fossil fuel-based development (SSP5), and intermediate development (SSP2) (Riahi et al., 2017; O'Neill et al., 2017; Meinshausen et al., 2020). This article describes sustainable development, which is referred to as SSP 1. The combination of SSP-based socioeconomic scenarios and climate projections based on representative concentration paths (RCPs) provides an integrative framework for climate impact and climate policy analysis. We describe regional average responses for all future Kazakhstan scenarios and spatial patterns of surface air temperature and precipitation for three marker scenarios: SSP 1.19-SSP 1-2.0. Projections of future climate change are estimates of possible changes that depend on many anthropogenic factors, such as greenhouse gases, reactive gases, aerosols and agriculture. In the SSP experiments, total radiative forcing is largely determined by well-mixed greenhouse gases and is moderated by radiative forcing from tropospheric aerosols. SSP forecasts provide greenhouse gas concentrations. The dominant component of GHG concentration is carbon dioxide for most SSP emission scenarios. Climate change can be divided into three groups (Vuuren et al., 2011; FAOSTAT, 2016; Nazarenko et al., 2022).

RESULTS

At the present stage of development, changing weather conditions have a significant impact on food production and food security worldwide. Climate change may cause an increase in the number of natural disasters such as drought, floods and hurricanes, the consequences of which can affect all levels of food production. It is worth noting that if the necessary measures are not taken, climate change will have an impact on agricultural ecosystems. Based on agricultural genetic research, climate-resistant varieties of these crops can be developed for use in areas prone to floods, droughts and other extreme weather events.

Leguminous Crop Production in Kazakhstan

According to the FAOSTAT, in 2016, 85 million hectares of grain legumes were cultivated worldwide (FAOSTAT, 2016). Including leguminous crops in crop rotation reduces the risk of soil erosion and depletion. Fig. 1 shows the relationship between climate change and leguminous crops (Dutta et al., 2022).

According to the data in Fig. 2, it can be concluded that in 2023, compared to in 2019, the adjusted sown area of grain and legumes in Kazakhstan increased by 13.82%, from 15,396.6 thousand hectares to 17,525.5 thousand hectares. Compared with that in 2019, the yield of grain and legumes in 2023 decreased by 1.1c/ha. The following factors influenced the decrease in yield: during the summer of 2023, there was drought in several regions of Kazakhstan, and in the fall, it rained continuously for 25 days in the main grain-growing regions, creating obstacles to harvesting. Let us directly consider the gross harvest of grains (including rice) and legumes (in weight after processing) in Kazakhstan (Fig. 3). It is worth noting that in 2023, compared to those in 2019, the gross harvest of grains (including rice) and legumes decreased slightly, by 332 thousand tons, but significantly from 2022, by 4,933.9 thousand tons.

The assessed groups of leguminous crops were divided into 3 groups by cultivated area. The total cultivated area of leguminous crops was 2912 ha, but the lowest cultivation area was in the 1st group (589 ha), and the largest area was in the 3rd group (1476 ha); in the 2nd group, the cultivated area was 847 ha. The average cultivated area in Kazakhstan was approximately 25.32 ha. This means that approximately 25.32 ha of cultivated leguminous crops were cultivated, and the lowest was 13.08 ha (1st group); however, the largest area was 47,61 ha (3rd group), and in the 2nd group, approximately 22 ha of cultivated leguminous crops were cultivated. Half of the cultivated area in the 3rd group was 50.69%. The average total number of leguminous crops and the yield of the assessed farms were 18166kg/ha. The largest yield average was in the 3rd group (10545kg/ha). Interestingly, between the 1st (3524kg/ha) and 2nd (4097kg/ha) years, the group difference was 573kg/ha. The average gross production value obtained from leguminous crops per hectare on the examined farms was calculated as $684,21. On the 3rd and 2nd group farms, the leguminous crop is sold and exported at a relatively high price, and the gross production value per hectare is relatively high (Table 2).

Table 2: Leguminous crop production amount and yield of the evaluated farms

Groups	Total cultivated area (ha)	Average cultivated area (ha)	%	Average yield (kg/ha)
1st group (≤19 ha)	589	13.08	20.23	3524
2nd group (20-40 ha)	847	21.71	29.09	4097
3rd group (≥41 ha)	1476	47.61	50.69	10545
Total	2912	25.32	100.00	18166

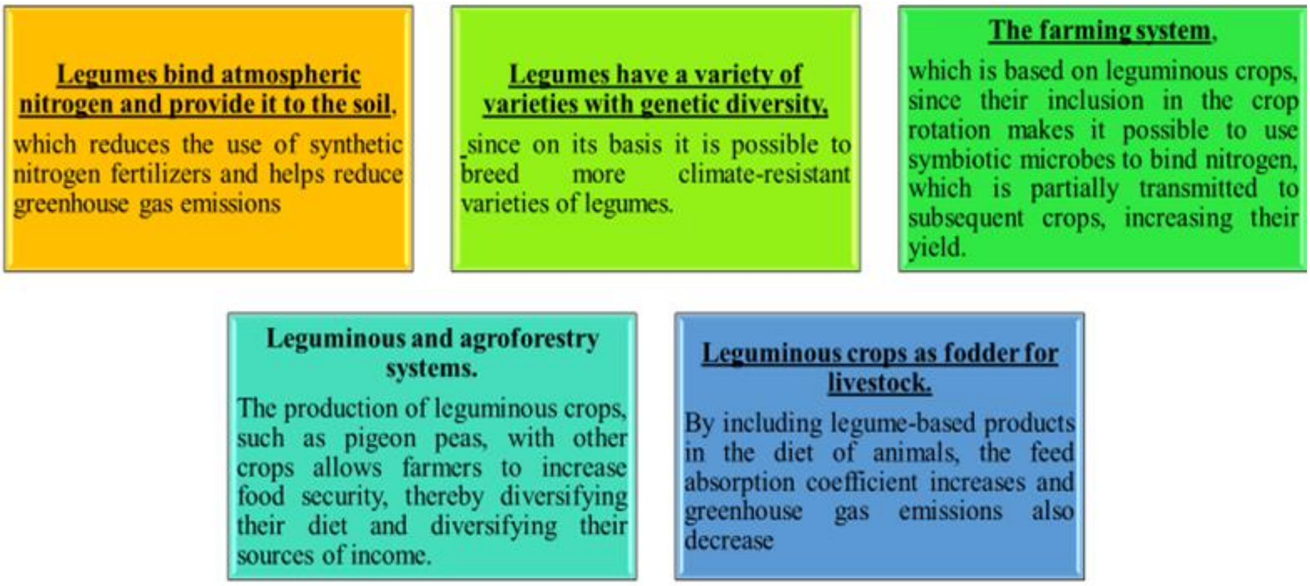

Fig. 1: Climate change and leguminous crops

Fig. 2: Main indicators of grains and legumes in Kazakhstan, here are: a) Specified sown area of grains (including rice) and legumes in Kazakhstan, (1000 ha); b) Productivity of grains (including rice) and legumes (in weight after processing), (centner/ha)

Impacts of Climate Change on Leguminous Crop Production and Climate Change Scenarios in Kazakhstan

Leguminous crops are grown everywhere, but the continental climate in Southeast Kazakhstan is affected by climate change. The area most affected by drought is southern Kazakhstan, which is in the southeastern region affected by floods and drought, and drought has an impact on leguminous crop production and food quality (Fig. 4).

From a statistical point of view, rainfall has not changed in the long term. Additionally, during this period, the unevenness of precipitation over time increased, with heavy rains followed by periods of drought. The IBM SPSS program forecast model analyses were used to determine the yield and cultivation area of a leguminous crop. The ARIMA forecast model showed 0 predictors in the two models; the R2 of yield was 0.973 and that of land was 0.250. Ljung-Box Q-statistics showed a significant p value of 0.018 for yield and 0.000 for cultivated area. This means that the null hypothesis is rejected, and H1 and H2 are accepted. The statistical results given in the table show that the Ljung-Box Q-statistic for autocorrelation test statistics (=32.630 for crop and =66.705 for cultivated land) is significant at the 5% significance level, which means $P<0.05$). In addition, these statistical results show that the significant autocorrelation Q statistic rejects the random walk hypothesis (RWH), which also indicates the rejection of the climate change influence hypothesis on the AIC.

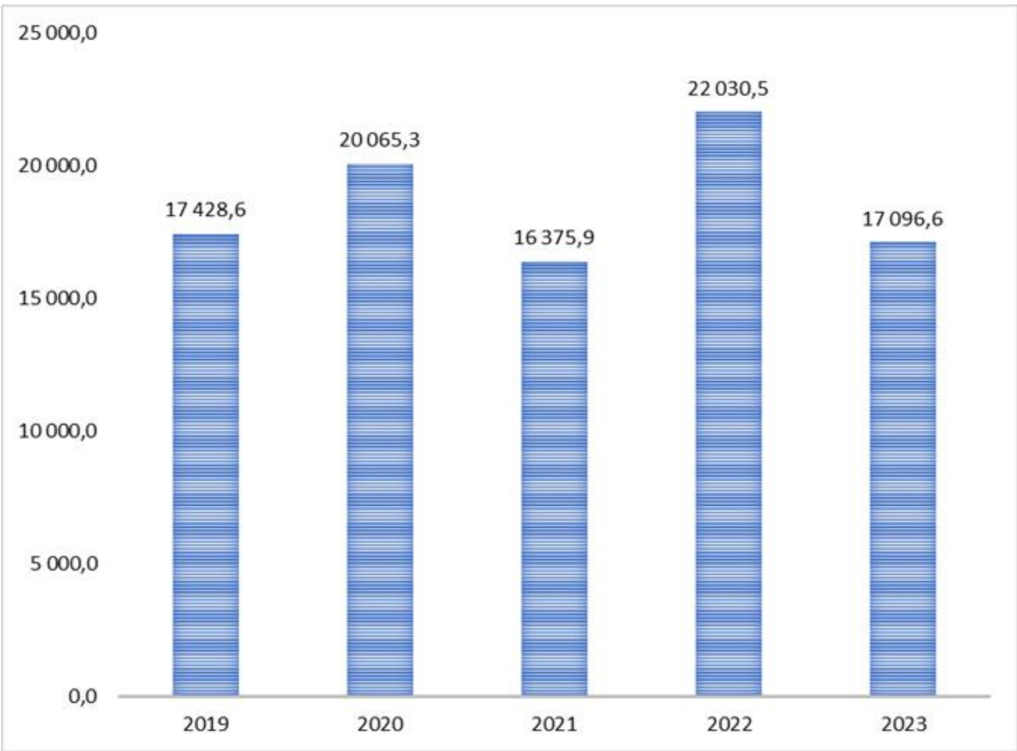

Fig. 3: The gross harvest of thousand tons of grains (including rice) and legumes (in weight after processing) in Kazakhstan

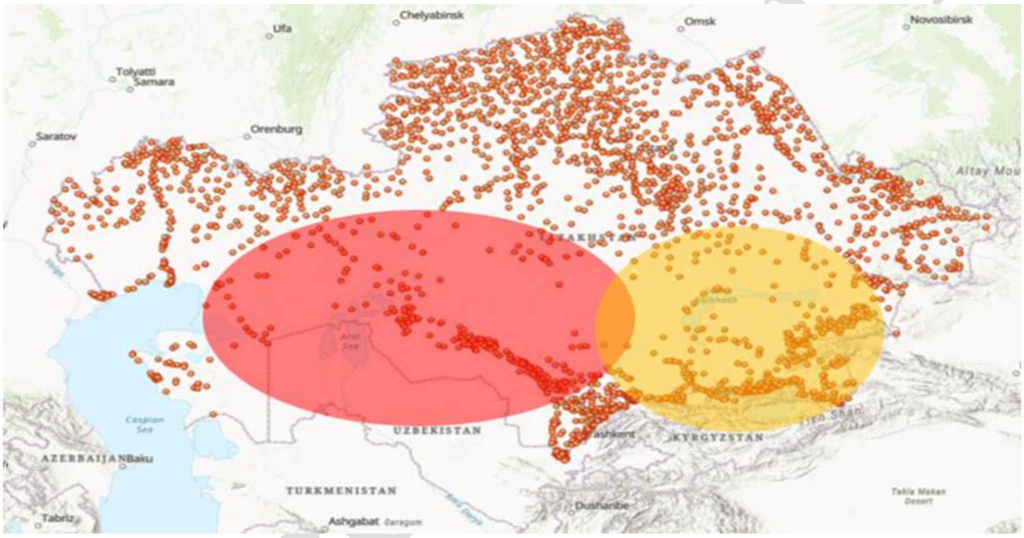

Fig. 4: Climate change-impacted regions of leguminous crops in Kazakhstan

This indicates that successive values are correlated with each other, that the series are not independent, that climate change affects production, and that climate change is effective in Kazakhstan (Table 3).

Thus, after ensuring that the ARIMA model satisfies all the requirements, it can be used for prediction. The forecasts for 2030-2100 are shown in Fig. 5. These forecast values can be used to make management decisions for leguminous crop farmers, the forecast accuracy is good, and the model meets all the requirements. The forecast statistical model results show that the upper (UCL) and lower (LCL) confidence limits are quality characteristics that have good value and variation (Fig. 5).

Projected climate change scenarios according to SSP1-1.9: In 2040–2059, the amount of precipitation will decrease to 3–2 mm. Under SSP 1–1.9, the average temperature in the winter months will decrease to -1°C, and in the summer months, it will increase to 2–3°C in 2040–2059. Historically, there were more frosty days in 1995–2014 than in 2040–2059. In future scenarios, the duration of frosty days will decrease to a maximum of 3–4 days. These scenarios show that temperature and precipitation will change between 2040 and 2059, affecting pulse production (Table 4).

The rainfall forecast for 2040-2059 showed that changes in rainfall will affect crop yields. Profitability mainly affects the price of products (Fig. 6). The multiple correlation coefficient in SSP 1-1.9: Precipitation in 2040-2059 is the dependent variable, which shows that the crop depends on the decrease in rainfall, and in the model, rainfall will also affect agricultural economies. Precipitation is statistically significant, which means that the changes are acceptable (precipitation R2=0.019 and R2=0.015). The forecast model shows that impacts on production will change from August (61%) to October (63%), and precipitation will change to 2 mm. The precipitation

Table 3: ARIMA (0,0,0), (1,0,0) statistical models of yield and cultivated area

Model	Number of predictors	Fit Measures						Ljung-Box Q-statistics			Deviations number
		Stationary R2	R2	RMSE	MAPE	MAE	Normalized BIC	X-squared	DF	P value	
Yield	0	0,923	0,973	15,152	40,175	9,129	5,766	32,630	18	0,018	7
Cultivated area	0	0,224	0,250	12,995	61,225	9,283	5,212	66,705	18	0,000	1

Table 4: Climate change scenario model for Kazakhstan

Items	Months											
	01	02	03	04	05	06	07	08	09	10	11	12
Precipitation 1986 – 2015 (mm)	19	15	18	22	27	25	28	19	13	18	22	22
SSP 1 – 1.9. Precipitation in 2040-2059 (mm)	3	3	2	1	1.5	0.5	0	-0.1	1	1.1	2	5
Average temp. in 1995 – 2014 (C)	-10	-9	-2	8	17	21	25	22	18	8	-1	-9
SSP 1 – 1.9. Average temp. in 2040-2059 (C)	-9	-8	-1	9	18	23	28	25	19	9	0	2
Number of frosty days in 1995 – 2014 (days)	30	27	26	12	3	0	0	0	1	12	24	29
SSP 1 – 2.0. Number of frosty days in 2040-2059 (days)	29	24	24	10	1	0	0	0	1	8	22	28

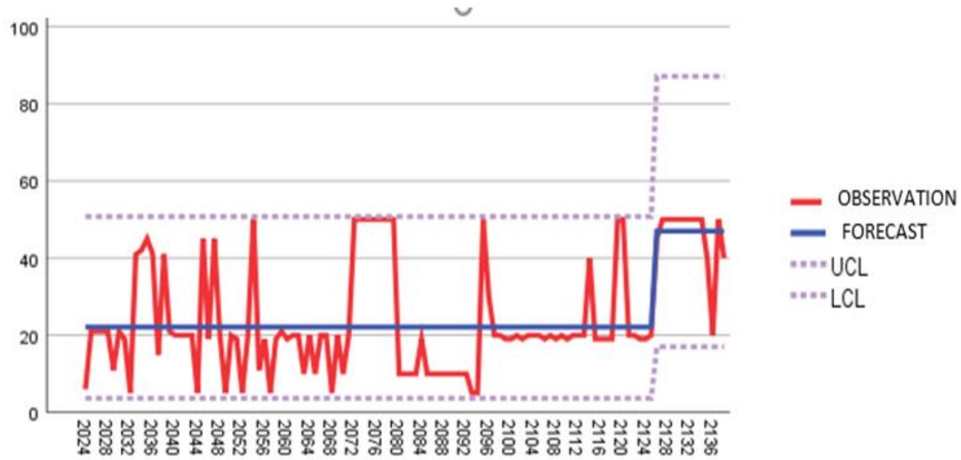

Fig. 5: Forecast model of leguminous crop production

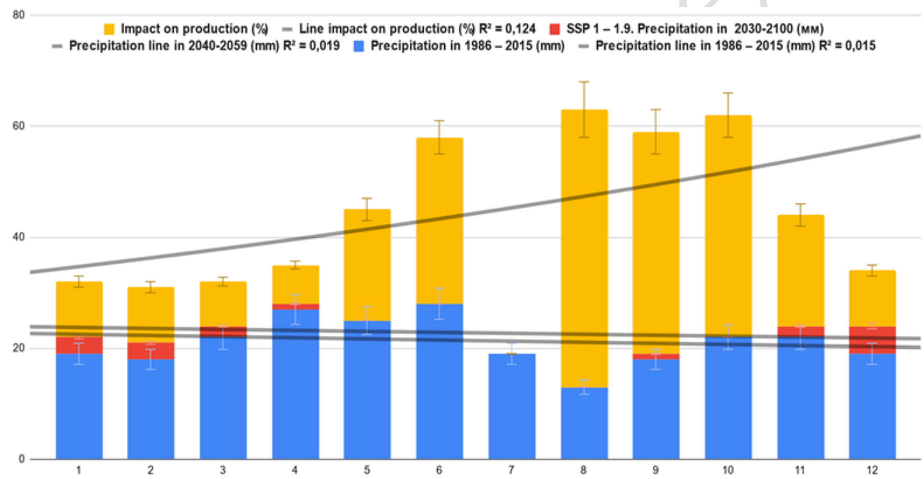

Fig. 6: Projection of precipitation and impact on production in 2040-2059

models for December, January and February predict that the precipitation will change to 5 - 15 mm. Kazakhstan experiences problems from climate change, such as drought in the southern regions, but the model shows that all groups will have impacts on production.

The average temperature increased significantly from 1995 to the present. The scenarios showed that under SSP 1–1.9, the average temperature in the winter months will decrease to -1°C, and in the summer months, it will increase to 2–3°C in 2040–2059, which will also affect crop yields. The main temperature aspect of agriculture and leguminous crop production will increase by 60% from October to December. The average temperature did not affect large- or middle-scale farms, but small-scale farms had impacts on yield and seed quality (Fig. 7).

The results of Fig. 8 show that more frosty days in 1995–2014 than in 2040–2059. In future scenarios, the duration of frosty days will decrease to a maximum of 3–4 days. According to the percentage of the influence of frosty days on yield, it falls in February/October, and this has a descriptive effect on the spring-summer periods of growing leguminous crops. Frost days impact mainly small-scale farms (1st group), but large-scale farms are not affected.

DISCUSSION

The Kostanay region most closely meets the requirements for diversification of crops and production, the Akmola and North Kazakhstan regions have taken a turn towards specializing in lentils, the East

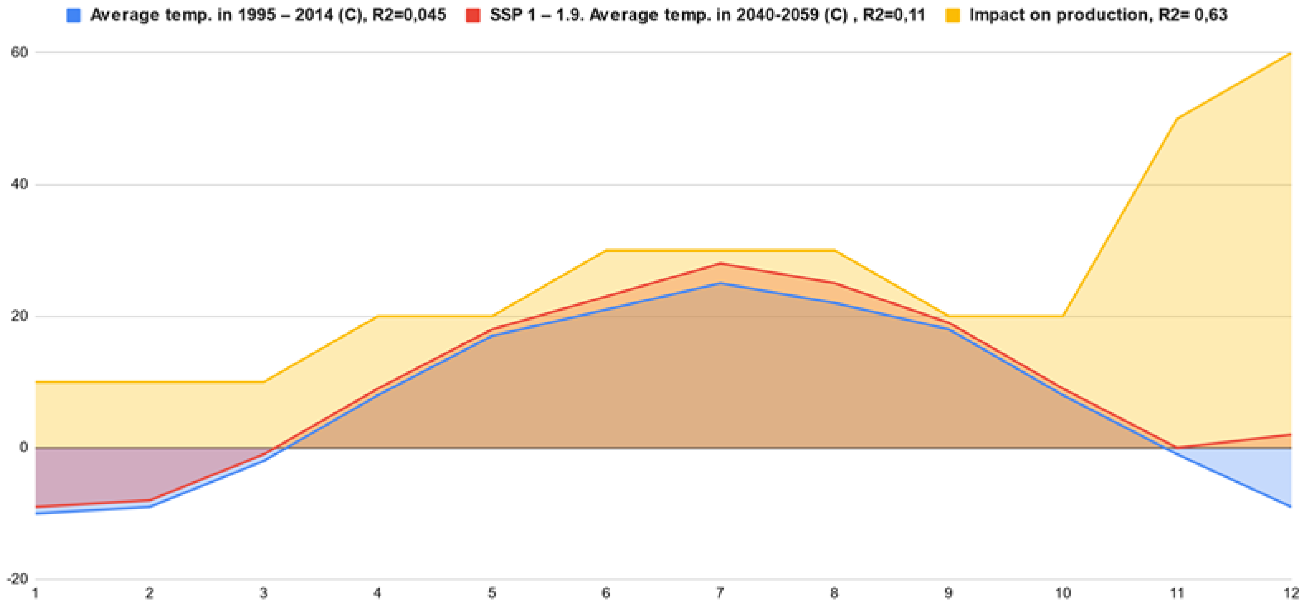

Fig. 7: Projection of average temperature and impact on crops in 2040-2059

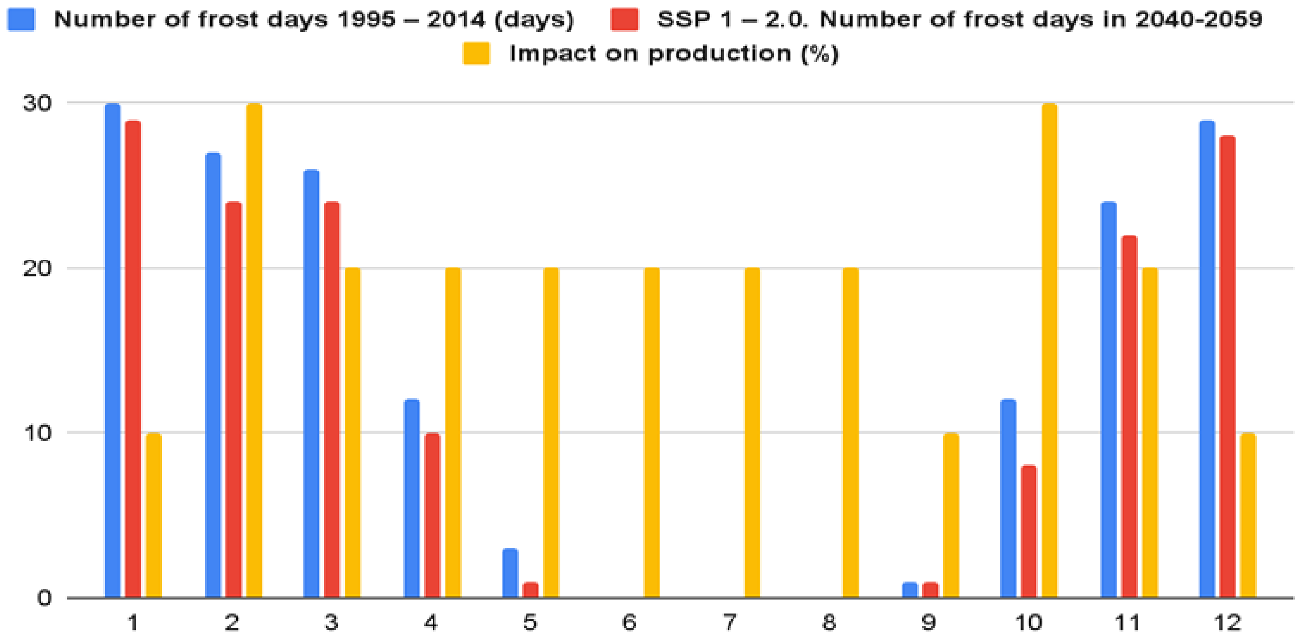

Fig. 8: Projection of frost and impact on crops in 2040-2059

Kazakhstan region has a focus on growing peas, and the Pavlodar region for the first time has loudly declared itself as one of the possible leaders of the agro-industrial complex in the future.

The main factors for both the rise and fall of lentil production were the dynamics of world prices and changes in the composition of the main players importing grain legumes (Serekpayev et al., 2023; Saikenova et al., 2021). Lentils have lost their market attractiveness for agricultural producers, which has caused a decrease in interest in growing them in favor of other crops.

The costs of leguminous crop production include labor and pulling costs, material (seed, fertilizer, etc.) expenses, interest in total expenses, management provisions, land rents and land taxes (Yessenbayeva et al., 2024). In this study, family labor provision was added to the wages paid for temporary workers by farmers in the calculation of labor costs.

The cost of land varies depending on the locality. The average cost of land is $21.16/m2. The average cost of production of leguminous crops per hectare for the surveyed farmers was determined to be 221.99 US dollars. The production costs belong to the 3rd group, the highest. The lowest production cost was in group 1. The farmers' average labor and traction costs averaged $80.81/ha, and the material costs averaged $58.10/ha. Other costs in the total cost of production represent interest in general expenses, management reserves, land rents and land taxes.

The costs will only continue to fluctuate due to climate change. Various studies have shown scenarios in which Kazakhstan is subject to high levels of exposure due to limited imports of agricultural raw materials

(Moldakhmetova et al., 2023). According to the scenarios for 2030, premature measures will increase the percentage of quality seeds from 93 to 98% and the percentage of mineral fertilizers from 20 to 29%. Scientific studies and reports from the National Hydrometeorological Service of the Republic of Kazakhstan show that climate change scenarios affect legumes differently. Extreme temperatures may particularly impact the resources and agribusiness sectors. Climate projections for the interim future period of 2040–2059 indicate that temperatures will increase to 2.2–2.7°C. A minimum temperature (Tasmin) below 50% will increase by 2.3-2.8°C.

Research has shown that climate air temperatures increased from 1941 to 2010 in almost all seasons of the year throughout Kazakhstan, except for some local areas. The average annual air temperature increases every 10 years by an average of 0.31°C, and in future predictions, it will increase by 3°C every year. The amount of precipitation in winter will increase, especially in the southern regions; in the northern regions, in the foothills and mountains of southern Kazakhstan in summer, there will be an increase in dry weather. In eastern Kazakhstan, according to forecasts, there will be a decrease in precipitation in winter (Karynbayev et al., 2023). In summer, the amount of precipitation will decrease in all regions of Kazakhstan, including the northern regions (FAOSTAT, 2016; Nazarenko et al., 2022).

The highest annual increases in summer days are projected to be significant, especially for the southern and western regions, which have semiarid and arid climates (Nasiyev et al., 2024). The number of hot days will increase, indicating the number of days per year with a maximum temperature above 35°C. An increase in the number of hot days is the main cause of drought, especially in the southern and western regions of Kazakhstan. Climate change and changes in precipitation increase the risk of floods, landslides, and mudflows in mountainous regions, but hot and dry days cause fires in the forests of Kazakhstan.

The future projected models of impacts of climate change on land show that the area will decrease to 50% in 2056, between 2072-2080, 2096 and above, but the forecast shows that the change will be 22% from 2024 to 2120. The forecast model shows that from 2024 to 2120, the value will increase to 48% (Fig. 5). The forecast of leguminous crop production groups shows that the 3rd group (large, cultivated area group) will have problems with cultivation area (Madenova et al. 2019; Chebyshev et al. 2024). The 1st and 2nd groups will not experience significant damage or impact from climate change on leguminous crop production and cultivation areas.

In this study, three models were created: the precipitation model, temperature, and frost days. All models show statistical significance, which means that climate change affects the production of leguminous crops. Precipitation is likely to become more frequent due to climate change, which could contribute to higher levels of landslide activity in Kazakhstan. Heavy rainfall occurred from June to September, and most landslides were reported during the same period. We can predict future rainfall and quickly identify potentially dangerous months for pulse crop production. The observed average monthly precipitation in Kazakhstan (1986-2005) ranged from 12-28mm/month but has now changed. Each data point represents the average of the simulated values from five integrated assessment models from the IPCC. Some precipitation was observed in February and September, and decreased precipitation in the summer months combined with rising surface air temperatures could have important consequences, such as rapid depletion of soil moisture leading to drought.

Frost days also impact the quality and quantity of leguminous crop seeds and influence food security in Kazakhstan (Paptsov & Shelamova, 2018; Islyami et al., 2020). Climate change impacts the economic efficiency of leguminous crop farms and affects the agricultural economy of the country.

It is necessary to make a new method to assess current responses to water stress to better understand how they will respond to climate change, which is an added layer of complexity. Climate change scenario models will be mandatory to help farmers cope with challenges such as water shortages, reduced yields and the quality of seeds to send to market. Climate change and rising temperatures will affect the spread of pests and diseases, and control methods will affect economic efficiency and production profits. It is necessary to adapt seeds and make appropriate effective strategies to combat drought, cold and pests in the face of climate change.

In the future forecast models of leguminous crops that predicted future changes in precipitation, temperature and frost day. It will lead to significant reductions in the yields of many leguminous crops, in Kazakhstan and particularly in (sub) tropical areas. The study shows that climate change impacts on quality and quantity of seeds in leguminous crops and some research has also explored the nutrient content of crops (Paptsov & Shelamova, 2018; Scheelbeek et al., 2018; Islyami et al., 2020).

Conclusion

Climate change may affect leguminous crop production. The process of developing these scenarios was as important as their content in terms of overall validity and significance. The assessed models show significant future changes, such as in production. The scenario models prepared (Precipitation, Temperature and frosty days for 2030–2100) were accurate because in the future, they will affect the yield and cultivated area of leguminous crops. Precipitation will greatly affect production, and drought will affect approximately 60% of leguminous crops. Analysis of the model showed that in the future, temperatures will change to 2-3°C. Frosty days will have a greater impact on small-scale farms' cultivated areas, and large-scale farms will decrease in cultivation areas. It reflects specific aspects that influence mitigation measures and adaptation options at the national level and are therefore more likely to be used by farmers making decisions about the cultivation and production of leguminous crops. Due to climate change, we encourage you to think about new technologies and irrigation and improve your overall growth and production process.

Conflicts of Interest

The authors declare no conflicts of interest. The funders had no role in the design of the study and the analyses, in the writing of the manuscript and in the decision to publish the results.

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