Black Sea Journal of Engineering and Science
doi: 10.34248/bsengineering.1445076

Open Access Journal
e-ISSN: 2619 – 8991

Research Article
Volume 7 - Issue 3: 465-472 / May 2024

MODELING CLIMATE CHANGE SCENARIOS FOR SPRING BARLEY IN SOUTHEAST OF ALMATY IN KAZAKHSTAN USING THE LINTUL APPROACH

Aidana SABITOVA[1], Gulnur SULEIMANOVA[1], Tefide KIZILDENİZ[2]*, Ali Kaan YETİK[2]

[1]Kazakh National Agrarian Research University, Faculty of Agrobiology, Department of Horticulture, Plant Protection and Quarantine, 050000, Almaty, Kazakhstan

[2]Niğde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies, Biosystem Engineering Department, 51240 Niğde, Türkiye

Abstract: Barley stands as a cornerstone in agricultural landscape of Kazakhstan, weaving through diverse climate zones, and annually gracing over 1.5 million hectares. The intricate interplay between climate and food systems necessitates thorough analysis and strategic measures to food safety and nutritional security, as the evolving climate significantly influences both the quantity and quality of our food resources. This study aims to employ the LINTUL-MULTICROP Model to assess how spring barley adapts to both today's climatic conditions and potential climate change scenarios to elevated levels of carbon dioxide and temperature under the specific conditions of southeast of Almaty. Three different global climate change models were studied (GCMs); i) GFDL-ESM2M, ii) HadGEM2-AO, and iii) MPI-ESM-MR for historical period (1986-2005) under RCP 4.5 and RCP 8.5 during the periods of i) 2040-2059 years scenarios, ii) 2060-2079 years scenarios, and iii) 2080-2099 years scenarios. Overall, the HADGEMAO and MPIESMMR models exhibited promising results in simulating yield, projecting an increase in spring barley yield for both RCP4.5 and RCP8.5 scenarios in GFDL-ESM2M model case also demonstrated stable increase in rainfed conditions. In conclusion, it should be noted that in the conditions of Kazakhstan, the cultivation of spring barley tends to change to growth in the southeast of Almaty.

Keywords: Climate change, LINTUL, Spring barley, Yield, Crop modeling

***Corresponding author:** Niğde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies, Biosystem Engineering Department, 51240 Niğde, Türkiye
E mail: tkizildeniz@ohu.edu.tr (T. KIZILDENIZ)
Aidana SABITOVA https://orcid.org/0009-0000-6068-7666
Gulnur SULEIMANOVA https://orcid.org/0000-0002-2322-6155
Tefide KIZILDENİZ https://orcid.org/0000-0002-5627-1307
Ali Kaan YETİK http://orcid.org/0000-0003-1372-8407

Received: March 05, 2024
Accepted: April 16, 2024
Published: May 15, 2024

Cite as: Sabitova A, Suleimanova G, Kızıldeniz T, Yetik AK. 2024. Modeling climate change scenarios for spring barley in Southeast of Almaty in Kazakhstan using the LINTUL approach. BSJ Eng Sci, 7(3): 465-472.

1. Introduction

Climate change, a consequence of human activities, unfolds the profound transformation of our planet's climatic dynamics (Gergis, 2023). The existence of radioactively active substances in the atmosphere of the Earth increases the global average outer layer temperature by 30 °C, creating our world livable for life. From the time of the Industrial Revolution, man-made activities have led to a rise in carbon dioxide and other trace gases, ended up in approximately 2 W m^{-2} of radiative heating in the troposphere and surface. This warmth is anticipated to be compounded by altering in snow, clouds, water vapor, and sea ice (Gergis, 2023). The elevated concentrations of atmospheric carbon dioxide (CO_2) contribute significantly to the greenhouse gas effect, exerting profound consequences on the Earth's climate and ecosystems. As a major greenhouse gas, increased CO_2 concentrations lead to enhanced heat retention within the atmosphere, contributing to global warming including fluctuations in temperature, alterations in precipitation patterns, and the melting of glaciers (Van der Werf and Petit, 2002). With temperatures already on the ascent by approximately 1°C, our world is witnessing the repercussions – heightened heat waves, unpredictable floods, and prolonged droughts that pose significant challenges to our collective well-being (Reddy and Reddy, 2015; McMichael, 2017). In this intricate interplay between humanity and the environment, agriculture assumes a pivotal role, grappling with an array of challenges that strain global food security (Van der Werf and Petit, 2002; Gregory et al., 2005).

As per the 2022 IPCC Sixth Assessment Report, there is a strong consensus indicating that climate change, as it stands, has predominantly resulted in adverse effects on both crop yields and crop quality in agriculture. The impact of heightened CO_2 levels extends to terrestrial ecosystems, influencing plant physiology and altering photosynthetic processes (Fleming et al., 2018). While some plants may benefit from increased CO_2 in the short term through enhanced growth (Kizildeniz, 2024; Kizildeniz et al., 2021) and water-use efficiency, the overall ecological balance is at risk due to potential disruptions in nutrient cycling, changes in species composition, and increased susceptibility to pests and diseases (Kizildeniz et al., 2021). Climate change exerts a multifaceted and severe impact on various crops, with barley being no exception. The influence of weather change impact on barley growth manifests in diverse developmental stages, introducing complexities and challenges for agricultural systems, with differences in temperature impacting tiller number, plant height, and dry aboveground plant parts (Gray and Brady, 2016). Barley plants respond to elevated temperatures by promoting elongation growth and accelerating inflorescence development, which can impact canopy architecture and grain production (Zhu et al, 2021). Elevated temperatures resulting from climate change affect the expansion and development process of barley leads to alterations in morphological and developmental traits (Raza et al., 2019).

Kimball et al. (2002) and Long et al. (2005) were revealed that rising carbon dioxide has been shown to directly alter plant photosynthesis and, as a result, the development of plants. Climate change affects seasonal precipitation patterns and raises mean temperatures, causing a detrimental impact on agricultural output (Meehl et al., 2007). Barley is the 4th foremost crop with regard to of worldwide productivity (Giraldo et al., 2019). Photosynthesis of individual barley leaf enhanced with rising CO_2 (Ford and Thorne, 1967; Pettersson et al., 1993), however in various investigations, the processes of photosynthetic was solely intermittently enhanced (Hibberd et al., 1996; Sicher and Bunce, 1997). Barley leaves development responded differently to CO_2 advancement, with an advantageous result (Ford and Thorne, 1967) and a lack of reaction (Bunce, 2004), whereas stem height increased with CO_2 rise (Weigel et al., 1994; Saebo and Mortensen, 1996). Two investigations demonstrated an enhancement in harvest index with CO_2 rise (Pettersson et al., 1993). Nevertheless, in numerous additional studies, an absence or reduction was seen (Weigel et al., 1994). Drought and high temperatures throughout seed formation can diminish productivity and quantity while also affecting seed quality features including dormancy and robustness (Sehgal et al., 2018). Overall, climate change poses challenges to barley crops, but understanding these impacts can inform breeding efforts to develop climate-resilient varieties (Zenda et al., 2021).

Crop models, ranging from empirical to optimizing types, are essential for understanding intricate interactions among atmosphere, crops, and soil. These models, based on physiological knowledge, efficiently simulate various scenarios, aiding agriculture in pest management, breeding, and climate change impact assessment (Boote et al., 2013; Oteng-Darko et al., 2013; Craufurd et al., 2013; Reynolds et al., 2018; Aşık et al., 2021; Akhavizadegan et al., 2021; Wajid et al., 2021). Crop models which have been applied in barley include deep neural network (DNN) and machine learning (ML) regression approaches (Jeong et al., 2022). Models for two- and multi-row spring barley cultivars have been developed, considering factors such as yield structure, plant density, and root characteristics (Newton et al., 2012). However, there are already applied crop models for barley, but they are either tailored for specific environmental conditions or focused on yield components. More to the point, these existing models may not be suitable for application when crop production and quality attributes vary due to unique processes that are not mandated in the model (Tao et al., 2018).

In addition to assessing the adaptability of product to the current climatic conditions, there is a curiosity about its potential yield in the event of climatic changes in the upcoming years. As a result, climate change consequences on altering planting periods and accessibility to water, which may lead to yield decreases, should be examined in order to provide policymakers with credible data in relevant locations. Leveraging the capabilities of the LINTUL model enables the simulation of barley production, allowing for the optimization of land use, streamlining technological operations, and judiciously allocating mineral fertilizers to enhance both yield and profitability. Therefore, beyond evaluating the adaptability of the product to existing climatic conditions, it becomes imperative to ascertain potential yields in the event of climate variations in the upcoming years. Therefore, it is crucial to investigate how climate change may impact shifts in planting seasons and affect water availability, potentially resulting in decreased yields. This research aims to provide policymakers with reliable data in relevant areas. In this research, the LINTUL-MULTICROP Model was employed to scrutinize the habituation of barley to prevailing climatic conditions and anticipated climate change scenarios, elucidating its response to elevated carbon dioxide levels and increased temperatures.

2. Materials and Methods

2.1. Model Explanation

Linus Franke of the University of Bloemfontein adapted the earliest versions of the LINTUL-MULTICROP Model, which had been developed in Fortran, into Microsoft Excel (Franke et al., 2013). Franke et al. (2013) and Haverkort et al. (2013) conducted the initial research study employing this approach. The model demands three major data sets as input: climate, crop and soil data. Spitters (1989) and Spitters and Schapendonk (1990) established a mechanistic model known as LINTUL (Light Interception and Utilization) that calculates dry matter buildup employing solar radiation absorption and radiation addition efficiency ratios. LINTUL is an important tool to evaluate the difference between current and projected crop yield. In addition, by entering precise meteorological factors, the model may compute the amount of grain that could be generated in a particular setting compared to agricultural productivity under existing ecological conditions (Farré et al., 2000). Farré et al. (2000) examined and validated LINTUL for the forecasting of timing of flowering, leaf area index, and production, and agreed that the model correctly estimated outcomes for all maize characteristics.

LINTUL might be utilized for investigating the effects of various irrigation systems on productivity in diverse regions for crop sustainability. The model is also valuable for researchers in identifying carbon dioxide fixation during photosynthesis (Yetik et al., 2023). LINTUL may evaluate light absorption and utilization rates throughout photosynthetic. It may develop the accumulation of dry mass in the presence of appropriate nutrients and moisture, pest, disease, and without weeds environments, and current weather circumstances (Spitters and Schapendonk, 1990). Dry mass is mostly the result of light interception (Shibu et al., 2010). The versatile LINTUL model not only aids in assessing soil water mechanism like drainage, evapotranspiration, and runoff, but also facilitates the adaptation of cropping patterns and management practices based on the anticipated availability of soil water, generating a diverse set of outputs through its simulation equations (Ahmed et al., 2013). Furthermore, the model's versatility extends to its seamless integration with remote sensing images, facilitating the monitoring of spatiotemporal barley growth patterns and yield dynamics (Gimplinger and Kaul, 2012).

The first of these inputs is climatic data including precipitation (mm), averages of temperature minimum and maximum (°C), solar radiation (MJ m^{-2} day^{-1}) and monthly evapotranspiration values (mm). The additional input agricultural dataset contains the dates of radiation use efficiency (RUE, g MJ^{-1}), sowing and harvest (day), planting, and effective rooting depth (cm), sprout growth rate (Extension of the below ground sprout per day-degree, mm degree day^{-1}), harvest index (%), dry matter concentration (%), effective temperature sum between emergence and 100% ground cover (GC) (0-100% GC, degree day), Lowest and highest temperatures for the photosynthetic as well as optimal photosynthetic (°C). Ultimately, the model provides a default selection for nine distinct kinds of soil with various water capacity, bulk densities, accessible water contents, and wilting points, that the user can simply choose. The LINTUL-MULTICROP Model produces various results. The model might provide climate change adaptation strategies by determining the days between planting and emergence, the duration of growth time (days), the days between 100% GC and harvest and the days between emergence and 100% GC. The model may determine the need for irrigation water using precipitation and ETP data. In addition to that, the model can forecast yield in both irrigated and non-irrigated conditions.

2.2. Study Site

The research was performed in 2023. Field trials were undertaken on the experimental land of for the KazNIIZiR LLP 43°13'10"N 76°41'06"E 803m in southeast of Almaty, located in Kazakhstan (Figure 1).

Figure1. The location of study area

Soil cover of the experimental is represented by irrigated light chestnut soils with deep groundwater (more than 10 meters), characteristic of the foothill plain of the Trans-Ili Alatau. According to the classification principles reported by Dokuchaev (1899), the soil of the stationary site belongs to the light brown subtype. Light-brown and dark chestnut soils of upland agricultural landscapes, developed on loess-like loams of medium loamy mechanical composition, are situated on the foothill-inclined plain of the northern slope of the Trans-Ili Alatau. Generally, the relief of this territory is distinguished by a fairly significant degree of horizontal dissection by a network of branched logs with gentle and sloping slopes used in irrigated agriculture. In general, it is a moderately arid zone with a pronounced continental climate, with large daily fluctuations in air temperatures and annual precipitation.

The soil is marked by relatively low humus content (2.20-2.45%), due to high carbonation, the response of the soil mixture is almost alkaline 7.5-7.8. The uptake capacity does not exceed 15.5 mg /eq., the main part of the absorbed bases is calcium, the amount of absorbed magnesium is not extremely high. Total nitrogen contains 0.20%, total phosphorus – 0.25%. According to the degree of supply of batteries, the experimental site is characterized as poorly provided with phosphorus and high potassium. Weather conditions of the southeast of Almaty and the mean climate data from 2000 to 2023 and the monthly crop evapotranspiration data (ETP) were calculated as Yagiz et al. (2020) are given in Table 1.

2.3. Plant Material

Barley (*Hordeum vulgare* L. spp vulgare) is vital crop in Kazakhstan's agriculture, and it grows various climatic areas covering more than 1.5 million hectares every year. At the moment, it is the nation's 2nd most extensively produced grain crop following wheat, yielding a mean of 2.0 million tons each year (Genievskaya et al., 2018). The ultimate outcome of barley in the nation is feed for livestock in Kazakhstan, with a mean output of 1.5 tons per hectare (Genievskaya et al., 2018). Because of the nation's long, harsh winters and frequently dry summers of Kazakhstan, two-row spring barley is the dominating variety in all major barley growing locations. Summer is a particularly challenging season in two out of three years, with drought and heat resulting in an enormous decline in grain production (Genievskaya et al., 2018).

Spring barely, which is well suited to the ecological environmental circumstances in the area and barley is a strategically important crop for Kazakhstan, was used as plant material. The input crop data of LINTUL-MULTICROP model achieved from various sources was examined and given in Table 2.

Table 1. The long-term annual climate data of Southeast of Almaty from 2000 to 2023

Months	AT min (°C)	AT max (°C)	AT mean (°C)	AP (mm)	R (MJ m^{-2} day^{-1})	ETP (mm)
January	-8.20	0.78	-4.57	34.67	5.72	28.6
February	-5.60	3.18	-1.96	42.87	8.67	43.4
March	1.29	12.01	6.15	76.91	12.24	61.2
April	7.69	19.24	13.18	102.73	16.41	82.1
May	12.71	24.68	18.59	95.86	19.29	96.5
June	17.59	29.71	23.60	57.07	21.56	107.1
July	19.96	32.33	26.04	36.92	21.27	106.4
August	18.54	31.30	24.71	33.45	20.05	100.3
September	13.12	25.94	19.27	29.00	16.27	81.4
October	5.82	17.52	11.10	56.91	10.94	54.7
November	-0.74	8.04	2.93	59.19	6.98	34.9
December	-5.92	1.76	-2.85	39.05	4.86	24.3
Average	6.36	17.21	11.35	55.38	13.68	68.4

AT min= average temperature minimum, AT max= average temperature maximum, AT mean= average temperature mean, AP= average precipitation R= radiation ETP= evapotranspiration data.

Table 2. Input parameters of LINTUL Model obtained from the field experiment

Parameters		Values
Sowing date (days)		14/04
Planting depth (cm)		5
Harvest date (days)		5/08
Effective rooting depth (cm)		7
Dry matter concentration* (%)		40
Harvest index (%)		25
Sprout growth rate (mm degree day^{-1})		1.4
0-100% GC (degree day)		736
RUE** (g MJ^{-1})		1.48
Temperature for the photosynthesis (°C)	Minimum	5
	Maximum	35
Temperature for the optimum photosynthesis (°C)	Minimum	15
	Maximum	25

*Dry matter concentration (%) of barley data was referred as Stacey et al. (2006). **RUE (g MJ^{-1}) of barley data was referred as Goyne et al. (1993).

2.4. Climate Change Scenarios

In the study, yield calculations for three distinct future periods, namely 2040-2059 (F1), 2060-2079 (F2), and 2080-2099 (F3), were conducted to assess the impacts of climatic variations, excluding the reference period (RF) covering the years 1986-2005. The computed yield values were obtained using climate data from three different models. In the process of model selection, three widely utilized models in academic literature were chosen: HADGEM-AO, GFDL-ESM2M, and MPI-ESM-MR, each recognized for their accurate and reliable representation of complex climatic processes. To encompass a diversity of potential future emission scenarios, two distinct Representative Concentration

Pathways (RCPs) were considered. RCP 4.5, representing stabilization, and RCP 8.5, representing high emissions, were employed to project potential climate conditions. This approach facilitates a comprehensive examination of comparative future trajectories and allows for an in-depth exploration of potential future scenarios. The climate parameters for the reference and future periods presented in this study were derived from scaled projections obtained from the WorldClim database. These projections utilized Coupled Model Intercomparison Project Phase 5 (CMIP5) models with a resolution of 1.0º x 1.0º (100km x 100km), as documented in WorldClim (2023). These models serve as fundamental tools in simulating future climate conditions based on different greenhouse gas emission scenarios, contributing to the robustness of the study.

3. Results

The simulated barley yield in rainfed agricultural systems exhibited a substantial increase across all climate change scenarios, reflecting an evaluation of climate forecasts for precipitation conditions (Table 3) to gauge their impact on spring barley crop yield. Separate assessments were conducted for four distinct periods (1986-2005, 2040-2059, 2060-2079, and 2080-2099) for two scenarios, namely RCP4.5 and RCP8.5, for each model. The historical period (1986-2005) simulations using the LINTUL model revealed barley yields of 6.7 t ha^{-1} for HADGEMAO, 3.8 t ha^{-1} for GFDLESM2M, and 3.5 t ha^{-1} for MPIESMMR. Moving into the future under different RCP scenarios, distinct patterns emerged. Under the RCP4.5 scenario for 2040-2059 (F1), HADGEMAO projected an increase to 7.7 t ha^{-1}, while GFDLESM2M and MPIESMMR showed yields of 4.4 and 4.2 t ha^{-1}, respectively. In the same period under the more severe RCP8.5 scenario, HADGEMAO exhibited higher yields at 8.3 t ha^{-1}, while GFDLESM2M and MPIESMMR showed 4.2 and 4.8 t ha^{-1}, respectively. Transitioning to 2060-2079 (F2), HADGEMAO, GFDLESM2M, and MPIESMMR under RCP4.5 yielded 8.1, 4.3, and 5.3 t ha^{-1}, respectively. Meanwhile, under RCP8.5, HADGEMAO yielded 7.8 t ha^{-1}, GFDLESM2M yielded 3.9 t ha^{-1}, and MPIESMMR yielded 4.4 t ha^{-1}. In the final projection period (2080-2099, F3), RCP4.5 showed HADGEMAO, GFDLESM2M, and MPIESMMR yields of 8.9, 4.1, and 4.4 t ha^{-1}, respectively. Contrastingly, under RCP8.5, the yields were 8.2 t ha^{-1} for HADGEMAO, 4.2 t ha^{-1} for GFDLESM2M, and 3.8 t ha^{-1} for MPIESMMR. The results underscore the variability in simulated barley yields across different climate models, scenarios, and time periods, with RCP8.5 consistently projecting higher yields compared to RCP4.5, and model-specific responses to changing climate conditions.

Table 3. Yields (t ha^{-1}) and yield changes (%) of different scenarios for spring barley

Model	1986-2005 (Historical)	RCP scenarios	2040-2059 (F1)	2060-2079 (F2)	2080-2099 (F3)
HADGEMAO	6.7^{a}	4.5	7.7 (14.9^{b})	8.1 (20.9)	8.9 (32.8)
		8.5	8.3 (23.9)	7.8 (16.4)	8.2 (22.4)
GFDLESM2M	3.8	4.5	4.4 (15.8)	4.3 (13.2)	4.1 (7.9)
		8.5	4.2 (10.5)	3.9 (2.6)	4.2 (10.5)
MPIESMMR	3.5	4.5	4.2 (20.0)	5.3 (51.4)	4.4 (25.7)
		8.5	4.8 (37.1)	4.4 (25.7)	3.8 (8.6)

^{a}Simulated yields (t ha^{-1}), ^{b}Yield changes (D, %) D= [(Yield−Historical yield) ÷ Historical yield] × 100.

The HADGEMAO model, under the RCP4.5 scenario, demonstrated a consistent upward trend across three future periods. The percentage increase was 14.9% in the 2040-2059 periods, escalating to 20.9% in the 2060-2079 period, and reaching 32.8% in the 2080-2099 periods. In the case of the HADGEMAO RCP8.5 scenario, a projected profitability increase of 23.9%, 16.4%, and 22.4% was forecasted for the respective periods of 2040-2059, 2060-2079, and 2080-2099. The second model, GFDL-ESM2M, with RCP4.5, indicated a 15.8% increase in yield during the 2040-2059 periods. In the middle future period (2060-2079) was observed with an increase of -13.2%. The model projected an increase of -7.9% in the 2080-2099 periods. For the GFDL-ESM2M model with RCP8.5, a mixed trend emerged, showcasing increases of 10.5%, 2.6%, and 10.5% in the periods 2040-2059, 2060-2079, and 2080-2099, respectively. The MPIESMMR model, under the RCP 4.5 scenario, displayed substantial increases in barley yield during the periods 2040-2059 (20.0%) and 2060-2079 (51.4%), with a subsequent increase of 25.7% in 2080-2099. Under the RCP 8.5 scenario, stable percentage was (37.1%), (25.6%), (8.6%) increase in barley yield were observed across the periods 2040-2059, 2060-2079 and 2080-2099.

Overall, the HADGEMAO and MPIESMMR models exhibited promising results in simulating yield, projecting an increase in spring barley yield for both RCP4.5 and RCP8.5 scenarios in GFDL-ESM2M model case also demonstrated stable increase in rainfed conditions.

4. Discussion

Climate change, particularly the rise in ambient temperatures, is anticipated to exert a considerable impact on agricultural yields (Wang et al., 2018). The future yield estimations of barley were conducted through the application of the LINTUL Model to create a strategy to the critical threshold imposed by this phenomenon. On the other hand, Gardi et al. (2022) utilization of the DSSAT-CERES-Barley model for Ethiopian barley production reveals potential yield increases despite climate change. Projections suggest a consistent temperature rise of up to 5 °C and variable rainfall patterns. Despite a simulated significant decline in production, up to 98 and 63% for Traveller and EH-1493, respectively, adaptation strategies involving early sowing, an increase in both density (25%), and fertilizer rate (50%) counteract these negative effects. The study highlights the efficiency of the model in assessing the influence of climate change on rainfed barley yield in Ethiopia and suggesting measures for adaptation, providing a parallel perspective to our investigation utilizing the LINTUL model. Mirgol et al. (2020) found that, under certain climate scenarios, the irrigation water requirements (IR) for winter wheat and barley in Iran's semi-arid Qazvin Plateau are projected to increase significantly by 38%–79% highlighting the critical importance of water resource management under the climate change conditions. In our study, we focus different point, highlighting that our observed increase in potential yield is attributed to our precise management of irrigation, maintaining soil water level at the optimal threshold for crop needs. Bento et al. (2021) examined the influence of climate change on production of barley in the Iberian Peninsula, revealing a projected increase in the northern regions due to early winter warming stimulating earlier growth, while the southern regions face potential severe yield losses primarily attributed to rising spring maximum temperatures. Ko et al. (2019) assessed geospatial variations in South Korean barley production under climate change scenarios (RCP 4.5 and 8.5) using the CERES-barley model. Projected yields for four barley cultivars demonstrated moderate rises under RCP 4.5 and rapid enhancement under RCP 8.5, revealing notable regional variation. Trnka et al. (2004) demonstrated that the combined effects of direct and indirect impacts of doubled CO_2 on potential yields resulted in a substantial 19-30% increase in barley yields across various localities. The observed increase in barley yields with rising temperatures can be attributed, in part, to the potential enhancement of photosynthetic processes. Warmer temperatures may stimulate enzymatic reactions associated with photosynthesis, leading to increased carbon assimilation and a subsequent positive impact on crop yield. This experience is particularly relevant to C3 crops like barley. However, it is crucial to note that while elevated temperatures may have beneficial effects, the relationship between temperature and yield is nuanced. There exists a threshold beyond which the positive effects may turn detrimental due to heat stress. In regions where water resources are limited, the potential impact of increased temperatures on barley yields should be carefully considered (Al-Bakri et al., 2011).

4. Conclusion

The optimization of yields is the critical determinant the improvement of the quality and economic value of crops. In recent years, the landscape has undergone significant changes to achieve optimal cultivation efficiency, due to alterations in precipitation patterns as an outcome of climate change, as well as an increase in air temperature and atmospheric CO_2 levels. In this current research, the reaction of spring barley harvested in southeast of Almaty to explored various climatic scenarios and assessed optimal growth conditions for adaptation. The analysis of three models of global climate change and various scenarios shows a significant a rise in spring barley yield under different climate change scenarios. Particular emphasis should be given to the positive trends observed in the HADGEMAO and MPIESMMR models predicting an increase in spring barley yield for both RCP 4.5 and RCP 8.5 scenarios. These data open up valuable prospects for making informed decisions that climate change in the southeast of Almaty practically does not threaten the barley harvest, highlighting the critical importance of water resource management in response to the challenges posed by climate shifts. However, it is crucial to note that while elevated temperatures may have beneficial effects, the relationship between temperature and yield is nuanced. There exists a threshold beyond which the positive effects may turn detrimental due to heat stress. In regions where water resources are limited, the potential impact of increased temperatures on barley yields should be carefully considered.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	A.S.	G.S.	T.K.	A.K.Y.
C	10	20	40	30
D	10	10	40	40
S			80	20
DCP	90	10		
DAI	60		10	30
L	60	10	10	20
W	60	10	10	20
CR		20	40	40
SR			90	10
PM			80	20
FA	40	60	0	0

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

References

Ahmed M, Asif M, Hirani AH, Akram MN, Goyal A. 2013. Modeling for agricultural sustainability: a review. Bhullar G, Bhullar NK, editors. Agriculture Sustainability. Elsevier, London, UK, pp: 145.

Akhavizadegan F, Ansarifar J, Wang L, Huber I, Archontoulis SV. 2021. A time-dependent parameter estimation framework for crop modeling. Sci Rep, 11(1): 11437.

Al-Bakri J, Suleiman A, Abdulla F, Ayad J. 2011. Potential impact of climate change on rainfed agriculture of a semi-arid basin in Jordan. Phys Chem Earth A/B/C/, 36(5-6): 125-134.

Aşık M, Yetik AK, Candoğan BN, Kuşçu H. 2021. Determining the yield responses of maize plant under different irrigation scenarios with AquaCrop model. Int J Agric Environ Food Sci, 5(3): 260-270.

Bento VA, Ribeiro AF, Russo A, Gouveia CM, Cardoso RM, Soares PM. 2021. The impact of climate change in wheat and barley yields in the Iberian Peninsula. Sci Rep, 11(1): 15484.

Boote KJ, Jones JW, White JW, Asseng S, Lizaso JI. 2013. Putting mechanisms into crop production models. Plant Cell Environ, 36(9): 1658-1672.

Bunce JA. 2004. Carbon dioxide effects on stomatal responses to the environment and water use by crops under field conditions. Oecologia, 140: 1-10.

Craufurd PQ, Vadez V, Jagadish SK, Prasad PV, Zaman-Allah, M. 2013. Crop science experiments designed to inform crop modeling. Agric For Meteorol, 170: 8-18.

Dokuchaev VV. 1899. A contribution to the theory of natural zones: Horizontal and vertical soil zones. Mayor’s Office Press, St. Petersburg, Russia, pp: 123.

Farré I, Van Oijen M, Leffelaar PA, Faci JM. 2000. Analysis of maize growth for different irrigation strategies in northeastern Spain. Eur J Agron, 12(3-4): 225-238.

Fleming ZL, Doherty RM, Von Schneidemesser E, Malley CS, Cooper OR, Pinto JP, Feng Z. 2018. Tropospheric Ozone Assessment Report: Present-day ozone distribution and trends relevant to human health. Elem Sci Anth, 6: 12.

Ford MA, Thorne GN. 1967. Effect of CO_2 concentration on growth of sugar-beet, barley, kale, and maize. Ann Bot, 31(4): 629-644.

Franke AC, Haverkort AJ, Steyn JM. 2013. Climate change and potato production in contrasting South African agro-ecosystems 2. Assessing risks and opportunities of adaptation strategies. Potato Res, 56: 51-66.

Gardi MW, Memic E, Zewdu E, Graeff-Hönninger S. 2022. Simulating the effect of climate change on barley yield in Ethiopia with the DSSAT-CERES-Barley model. Agron J, 114(2): 1128-1145.

Genievskaya Y, Almerekova S, Sariev B, Chudinov V, Tokhetova L, Sereda G, Turuspekov Y. 2018. Marker-trait associations in two-rowed spring barley accessions from Kazakhstan and the USA. PLoS one, 13(10): e0205421.

Gergis J. 2023. Humanity's moment: A climate scientist's case for hope. Island Press, London, UK, pp: 45.

Gimplinger DM, Kaul HP. 2012. Calibration and validation of the crop growth model LINTUL for grain amaranth (Amaranthus sp.). J App Bot Food Qual, 82(2): 183-192.

Giraldo P, Benavente E, Manzano-Agugliaro F, Gimenez E. 2019. Worldwide research trends on wheat and barley: A bibliometric comparative analysis. Agron, 9(7): 352.

Goyne PJ, Milroy SP, Lilley JM, Hare JM. 1993. Radiation interception, radiation use efficiency and growth of barley cultivars. Aust J Agric Res, 44(6): 1351-1366.

Gray SB, Brady SM. 2016. Plant developmental responses to climate change. Dev Biol, 419(1): 64-77.

Gregory PJ, Ingram JS, Brklacich M. 2005. Climate change and food security. Phil Trans R Soc A, 360(1463): 2139-2148.

Haverkort AJ, Franke AC, Engelbrecht FA, Steyn JM. 2013. Climate change and potato production in contrasting South African agro-ecosystems 1. Effects on land and water use efficiencies. Potato Res, 56: 31-50.

Hibberd JM, Richardson P, Whitbread R, Farrar JF. 1996. Effects of leaf age, basal meristem and infection with powdery mildew on photosynthesis in barley grown in 700 μmol mol−1 CO_2. New Phytol, 134(2): 317-325.

Jeong S, Ko J, Shin T, Yeom JM. 2022. Incorporation of machine learning and deep neural network approaches into a remote sensing-integrated crop model for the simulation of rice growth. Sci Rep, 12(1): 9030.

Kimball BA, Kobayashi K, Bindi M. 2002. Responses of agricultural crops to free-air CO2 enrichment. Adv Agron, 77: 293-368.

Kizildeniz T. 2024. Assessing the growth dynamics of alfalfa varieties (Medicago sativa cv. Bilensoy 80 and Nimet) response to varied carbon dioxide (CO_2) concentrations. Heliyon, DOI:https://doi.org/10.1016/j.heliyon.2024.e28975.

Kizildeniz T, Pascual I, Irigoyen JJ, Morales F. 2021. Future CO2, warming and water deficit impact white and red Tempranillo grapevine: Photosynthetic acclimation to elevated CO2 and biomass allocation. Physiol Plant, 172(3): 1779-1794.

Ko J, Ng CT, Jeong S, Kim JH, Lee B, Kim HY. 2019. Impacts of regonal climate change on barley yield and its geographical variation in South Korea. Int Agrophys, 33(1): :81-96.

Long SP, Ainsworth EA, Leakey AD, Morgan PB. 2005. Global food insecurity. Treatment of major food crops with elevated carbon dioxide or ozone under large-scale fully open-air conditions suggests recent models may have overestimated future yields. Phil Trans R Soc B, 360(1463): 2011-2020.

Meehl GA, Stocker TF, Collins WD, Friedlingstein P, Gaye AT, Gregory JM, Zhao ZC. 2007. Global climate projections. Cambridge University Press, Cambridge, UK, pp: 41.

McMichael A. 2017. Climate change and the health of nations: famines, fevers, and the fate of populations. Oxford University Press, Oxford, UK, pp: 28.

Mirgol B, Nazari M, Eteghadipour M. 2020. Modelling climate change impact on irrigation water requirement and yield of winter wheat (Triticum aestivum L.), barley (Hordeum vulgare L.), and fodder maize (Zea mays L.) in the semi-arid Qazvin Plateau, Iran. Agric, 10(3): 60.

Newton AC, Guy DC, Bengough AG, Gordon DC, McKenzie BM, Sun B, Hallett PD. 2012. Soil tillage effects on the efficacy of cultivars and their mixtures in winter barley. Field Crops Res, 128: 91-100.

Oteng-Darko P, Yeboah S, Addy SNT, Amponsah S, Danquah EO. 2013. Crop modeling: A tool for agricultural research–A review. J Agri Res Develop, 2(1): 1-6.

Pettersson R, Lee HSJ, Jarvis PG. 1993. The effect of CO 2 concentration on barley. URL: https://link.springer.com/article/10.1007/BF00048180 (accessed date: April 14, 2022).

Raza A, Razzaq A, Mehmood SS, Zou X, Zhang X, Lv Y, Xu J. 2019. Impact of climate change on crops adaptation and strategies to tackle its outcome: A review. Plants, 8(2): 34.

Reddy PP, Reddy PP. 2015. Impacts of climate change on agriculture. Reddy PP, editor. Climate resilient agriculture for ensuring food security. Springer, London, UK, pp: 43-90.

Reynolds M, Kropff M, Crossa J, Koo J, Kruseman G, Molero Milan A, Vadez V. 2018. Role of modelling in international crop research: overview and some case studies. Agron, 8(12): 291.

Saebo A, Mortensen LM. 1996. Growth, morphology and yield of wheat, barley and oats grown at elevated atmospheric CO2 concentration in a cool, maritime climate. Agric Ecosyst Environ, 57(1): 9-15.

Sehgal A, Sita K, Siddique KH, Kumar R, Bhogireddy S, Varshney RK, Nayyar H. 2018. Drought or/and heat-stress effects on seed filling in food crops: impacts on functional biochemistry, seed yields, and nutritional quality. Front Plant Sci, 9: 1705.

Shibu ME, Leffelaar PA, Van Keulen H, Aggarwal PK. 2010. LINTUL3, a simulation model for nitrogen-limited situations: Application to rice. European J Agron, 32(4): 255-271.

Sicher RC, Bunce JA. 1997. Relationship of photosynthetic acclimation to changes of Rubisco activity in field-grown winter wheat and barley during growth in elevated carbon dioxide. Photosynth Res, 52: 27-38.

Spitters CJT. 1989. Crop Growth Models: Their usefulness and limitations. Acta Hortic, 267: 349-368.

Spitters CJ, Schapendonk AH. 1990. Evaluation of breeding strategies for drought tolerance in potato by means of crop growth simulation. Gen Aspects Plant Min Nut, 2: 151-161.

Stacey P, O'Kiely P, Hackett R, Rice B, O'Mara FP. 2006. Changes in yield and composition of barley, wheat and triticale grains harvested during advancing stages of ripening. Ir J Agric Food Res, 2006: 197-209.

Tao F, Rötter RP, Palosuo T, Gregorio Hernández Díaz-Ambrona C, Mínguez MI, Semenov MA, Schulman AH. 2018. Contribution of crop model structure, parameters and climate projections to uncertainty in climate change impact assessments. Global Change Biol, 24(3): 1291-1307.

Trnka M, Dubrovský M, Žalud Z. 2004. Climate change impacts and adaptation strategies in spring barley production in the Czech Republic. Clima Change, 64(1-2): 227-255.

Van der Werf HM, Petit J. 2002. Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods. Agric Ecosyst Environ, 93(1-3): 131-145.

Wajid A, Hussain K, Ilyas A, Habib-ur-Rahman M, Shakil Q, Hoogenboom G. 2021. Crop models: Important tools in decision support system to manage wheat production under vulnerable environments. Agric, 11(11): 1166.

Wang J, Vanga SK, Saxena R, Orsat V, Raghavan V. 2018. Effect of climate change on the yield of cereal crops: A review. Clim, 6(2): 41.

Weigel HJ, Manderscheid R, Jäger HJ, Mejer GJ. 1994. Effects of season-long CO2 enrichment on cereals. I. Growth performance and yield. Agric Ecosyst Environ, 48(3): 231-240.

WorldClim. 2023. Climate Data at the National Center for Atmospheric Research. Disponible URL: http://www.wdi.worldbank.org/ (accessed date: 15 January, 2024).

Yagiz AK, Cakici M, Aydogan N, Omezli S, Yerlikaya BA, Ayten S, Haverkort AJ. 2020. Exploration of climate change effects on shifting potato seasons, yields, and water use employing NASA and national long-term weather data. Potato Res, 63: 565-577.

Yetik AK, Kızıldeniz T, Ünal Z. 2023. Simulating The Yield Responses of Sugar Beet to Different Climate Change Scenarios by LINTUL-MULTICROP Model. BSJ Eng Sci, 6(2): 53-59.

Zenda T, Liu S, Dong A, Duan H. 2021. Advances in cereal crop genomics for resilience under climate change. Life, 11(6): 502.

Zhu T, Fonseca De Lima CF, De Smet I. 2021. The heat is on: how crop growth, development, and yield respond to high temperature. J Exp Bot, 72(21): 7359-7373.