Eurasian Journal of Agricultural Research 2024; Vol: 8, Issue: 1, pp: 85-95

Assessing Wheat Yield Responses and Growing Stages Alterations to Diverse Climate Change Scenarios

Ahmet Fatih AKANSU[1], Tefide KIZILDENİZ[2*]

[1]*Department of Plant Production and Technologies, Ayhan Şahenk Faculty of Agricultural Sciences and Technologies, Niğde Ömer Halisdemir University, Niğde, Türkiye.*

[2]*Department of Biosystem Engineering, Ayhan Şahenk Faculty of Agricultural Sciences and Technologies, Niğde Ömer Halisdemir University, Niğde, Türkiye.*

[*]*Corresponding Author: tefidekizildeniz@gmail.com*

ORCID: 0000-0002-5254-1082[1], 0000-0002-5627-1307[2]

Abstract

Climate change is now acknowledged as being one of the globe's most significant environmental challenges of today's World. One of the most frequently utilized agricultural crops in the world and is cultivated a wide range of staple foods and energy sources for its crucial economic significance in the Anatolia. Wheat is adapted to the local ecological circumstances in the Central Anatolian province of Konya. Therefore, it is essential to predict its response to changing climate. This work aimed to assess the potential influence of climate change on wheat yield and phenology alteration in Konya by applying the LINTUL-MULTICROP Model. Four distinct scenarios were contrasted to limit the impact of climate change on wheat production in the Konya province. The scenarios are as a) current condition, b) current condition +2°C, c) current condition +4°C, and d) current condition +200 ppm. Results indicate that a 2°C temperature increase leads to the yield from 5.5 to 6.9 t ha^{-1}, while a 4°C increase further boosts the yield from 5.5 to 8.0 t ha^{-1}. Additionally, an increase of 200 ppm in CO_2 levels results in a yield of 7.1 t ha^{-1} with a corresponding change in Radiation Use Efficiency (RUE) to 1.56 g MJ^{-1}. Changing the planting date can lessen the detrimental impacts of climate change on cereal production. It highlights the significance of irrigation to increase agricultural output and efficiently manage water resources.

Keywords: Crop modelling, Climate change, Wheat, LINTUL, Yield Estimation

Research article
Received Date: 18 April 2024
Accepted Date: 24 June 2024

INTRODUCTION

Climate change is now acknowledged as being one of the globe's most significant environmental challenges of today's world (Raihan, 2023) with extensive consequences such as rising temperatures being the principal source of concern (Lee et al., 2023), along with drought and other climate-change related factors across the world (IPCC, 2018). Consequently, increased food demand, especially regarding to wheat that is considered as the world's second largest consumed cereals commodity (Asseng et al., 2015), and its yield is estimated to reduce by 0.2-0.8 t ha^{-1} during 2080–2100 (Alsafadi et al., 2023) ought to remain at pace with the projected population expansion. Climate change has made this goal more difficult to attain (Ahmad et al., 2023).

Emerging worldwide affluence imposes an additional strain on agricultural production by raising the need for premium agricultural products, livestock forage, and fiber. Whilst increased CO_2 levels may boost wheat yield and growth in certain wheat-producing territories in the coming years, this is only if there is an abundant accommodate with water and nitrogen (Hernandez-Ochoa et al., 2018). Moreover, wheat yields are anticipated to fall in the majority of wheat-producing countries (Osman et al., 2022) when global temperatures rise by 1-4 °C by 2100 (IPCC, 2018).

Wheat is an essential crop for the world's food stability, but boosting wheat production on present cultivating areas is unlikely to meet the larger portion of projected worldwide demand for food predictions (Kettlewell et al., 2023). Wheat holds the distinction of being the most extensively cultivated crop and produced cereal crop in the world for human consumption. This is due to the broad adaptability of the wheat plant. In addition, the wheat grain is the staple food of approximately 50 countries due to its favorable nutritional value, ease of storage and processing. Wheat provides about 20% of the total calories derived from plant-based foods to the world population and it is 53% for Türkiye (TÜİK, 2022). According to TÜİK (2022), wheat yield reached to 335 kg da^{-1} in Konya. Wheat is used in many food and industrial sectors, including baked goods (Republic of Turkey Ministry of Agriculture and Forestry, 2023). However, climate change is allowing wheat to be produced on formerly uncultivated ground at upper northern latitudes. There are various issues with producing wheat in these areas, the most serious of which being its emission of greenhouse gasses (Kettlewell et al., 2023). Konya, located in the Türkiye's Central Anatolian Plateau, plays a pivotal role in the nation's wheat production (Özensel, 2023). Ranked second only to Şanlıurfa in terms of cultivation area, the region boasts fertile soil and a temperate climate – seemingly ideal conditions for nurturing this vital crop. However, the challenges and opportunities presented by Konya's unique ecological environment must be carefully evaluated, as maximizing both wheat yield and quality has become crucial (Akman & Topal, 2011).

Wheat is a high yield-drought sensitive (Zahra et al., 2023) that drought including other abiotic factors can reduce wheat yield by up to 71%, particularly in rainfed areas (Rana et al., 2013). Drought stress impacts wheat at different stages of growth, including jointing, tillering, and anthesis (Thapa et al., 2020). These critical stages are particularly vulnerable to water deficits (Dhakal, 2021). Drought stress causes a number of biochemical and physiological changes in wheat plants. These changes include decreased water content, reduced stomatal closure, stunted growth, and leaf water potential (Jaleel et al., 2009). Drought stress also disrupts nutrient and water relations, throws phenological timing off kilter, and stifles respiration and photosynthesis (Farooq et al., 2009). To mitigate the impacts of drought stress on wheat, it is important to understand the complex nature of this stress. Various management practices, such as drought-resistant cultivars, developed irrigation techniques, and techniques of soil conservation, can help wheat to withstand drought stress (Dhakal, 2021).

As evidenced by the IPCC report, the ever-increasing threat of climate change poses significant challenges to global wheat production (Pachauri et al., 2014). The years 1980 to 2012 has been identified as the warmest in the past 1400 years, leading to adverse effects on crop yields, particularly for vital fundamental foods like wheat (Dettori et al., 2017). The effects of climate change on wheat development and yield is location-dependent, influenced by temperature thresholds and variations in heat and drought stress (Porter & Gawith, 1999).

Studies in different regions, such as France and Italy, indicate accelerated flowering dates and reduced yields due to climate-induced changes (Gouache et al., 2012; Dettori et al., 2017). Nevertheless, the complex relationship between temperature and wheat development offers opportunities for mitigation through agronomic management strategies. One such strategy involves leveraging crop models to predict and adapt to climate change influences (Lobell & Burke, 2010). The use of crop models, like the one employed by Wang et al. (2015) in Australia, allows for the simulation of various scenarios, enabling farmers to adjust critical developmental stages by manipulating sowing dates that is altered resulted in a viable strategy to counteract yield decline and adapt to changing climatic conditions. Similarly, Nouri et al. (2017) proposed the postponement of rainfed wheat cultivation’s sowing dates in Northwest Iran to align with favorable precipitation periods. As an adaptive alternative, this approach enhances precipitation during crucial growth phases, thus mitigating the adverse impacts of climate change on wheat production. These studies demonstrate that employing crop models in wheat cultivation offers a proactive approach to anticipate and manage the impacts of climate change. By strategically adjusting sowing dates based on model predictions, farmers can optimize developmental stages, ensuring suitable phenology for the changing climate (Ahmad et al., 2023; Wang et al., 2015; Nouri et al., 2017).

The Lintul Model, inspired by studies in Middle Asia (Sommer et al., 2013), provides a comprehensive assessment of the influences of climate change on wheat developmental stages and yield. Notably, the model indicates an overall favorable influence on wheat yield in Middle Asia, attributed to a reduction in the risk of late spring cold stress and a rise in thermal stress (Sommer et al., 2013). The Light INTerception and UtiLization (LINTUL) models (Spitters & Schapendonk, 1990) or in other named “Lintul Model”'s strength lies in its ability to simulate various climate scenarios, offering insights into the dynamic relationship between temperature changes and wheat development (Ahmed et al., 2013). The initial adaptation of the model (LINTUL 1) was established to estimate potato crop development using daily collected photosynthetically active radiation (PAR) and light utilization efficiency within optimum development circumstances. LINTUL 2 was evolved further to model crop growth in water-stressed environments (Spitters & Schapendonk, 1990). Winter oilseed rape (Habekotté, 1997), banana (Nyombi, 2010; Taulya, 2015), corn (Farré et al., 2000), and rice (Shibu et al., 2010) have all advantageous crops that were simulated by this model. Adopting Monteith (1977), the model anticipates that biomass rate of development is directly related to the quantity of light intercepted with a fixed light or radiation consumption effectiveness. The LINTUL model is a beneficial instrument for understanding the impact of climate change and other factors on wheat production. It can be used to develop strategies for adapting to these changes and guaranteeing food security in the future. Therefore, this work aimed to assess climate change's possible effects on the cultivation of wheat and wheat phenology alteration in Konya by applying the LINTUL-MULTICROP Model.

MATERIAL and METHOD

Model Explanation

The LINTUL-MULTICROP model, originally developed in Fortran and converted to MS-Excel by Linus Franke of the University of Bloemfontein, South Africa, was used for crop simulations. The model was first employed in scientific studies by Haverkort et al. (2013) and Franke et al. (2013).

Three key data types are required for model simulations: climate, crop, and soil. Climate data includes average minimum and maximum temperatures (°C), precipitation (mm), solar radiation (MJ m^{-2} day^{-1}), and monthly evapotranspiration values (mm). These data form the first input set. Crop data, the second input set, includes planting and harvesting dates (days), planting and effective rooting depth (cm), dry matter concentration (%), harvest index (%), sprout growth rate (mm degree day^{-1}), effective temperature sum between emergence and 100% ground cover (GC) (0-100% GC, degree day), radiation use efficiency (RUE, g MJ^{-1}), minimum and maximum photosynthesis temperatures, and optimal photosynthetic temperatures. Soil data, the final input set, allows users to choose from a pre-defined list of nine soil types with varying bulk densities, water capacities, wilting points, and accessible water contents. The LINTUL-MULTICROP model generates various outputs. By calculating the growing time (days), days between planting and emergence, days between emergence and 100% GC, and days between 100% GC and harvest, the model suggests potential adaptation strategies for climate change. Additionally, the model uses precipitation and ETP data to determine irrigation water requirements. Finally, the model predicts yield (t ha^{-1}) under both irrigated and dry conditions.

Study Site

The research was carried out in the Konya Province, located in Central Anatolia, Turkey (37°41' 29" N, 33°14' 39" E; altitude 1016 m) because of Konya Province (Figure 1) is a part of the Konya Plain that as the second-largest plain and is accounting for 17% of all agricultural areas in Türkiye. A semi-arid climate prevails in the region and the average climate data from 1929 to 2022 and the monthly crop evapotranspiration data (ETP) are given in Figure 2 (TSMS, 2022).

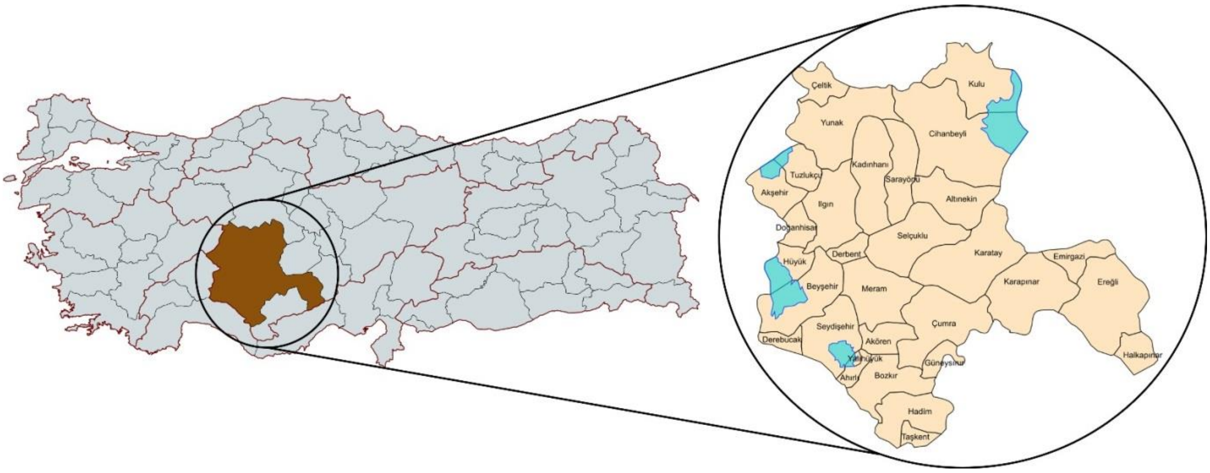

Figure 1. Study Site (Konya)

Plant Material

Wheat, perfectly adapted to the region's ecological landscape and holding significant economic importance, was chosen as the plant material for this research due to its major production and consumption cereal in Türkiye. The LINTUL-MULTICROP model was apply to model the impacts of climate change on the cultivation of wheat, utilizing input crop data meticulously collected from diverse, and reliable sources, as presented in Table 1.

Climate Change Scenarios

To comprehensively examine the impacts of climate change on wheat cultivation in the semi-arid Konya Region, four scenarios were devised; Scenario (a): Current climate conditions, simulated for the Konya Province to serve as a reference point; scenario (b): Current conditions, augmented by a 2°C temperature raise; scenario (c): Current conditions, augmented by a 4°C temperature raise; scenario (d): Current conditions, augmented by a 200 ppm increase in atmospheric CO_2. By varying the temperature and atmospheric CO_2 levels, these scenarios enable us to evaluate the most likely effects of climate change on wheat farming in the Konya Region.

Table 1. Factors for the model input

Parameter	Value	Reference
Month of planting	10	Ministry of Agriculture and Forestry, 2017
Day of planting	15	Purucker, 2020
Planting depth (cm)	4	
Month of harvest	6	Balaghi et al., 2008
Day of harvest	7	
Rooting depth (cm)	90	Fan et al., 2016
DM concentration (%)	87	Fang et al., 2010, Papakosta & Gagianas, 1991, Zhang et al., 2008
Harvest index (%)	33	Tari, 2016
The days between emergence and 100 GC	177	Hoogendoorn, 1985
RUE (g MJ^{-1})	1.2	Sandaña et. al., 2012
Min. photosynthesis temp. (°C)	0	Khan et al., 2020
Min. photosynthesis temp. (optimal) (°C)	14	
Max. photosynthesis temp. (optimal) (°C)	25	
Max. photosynthesis temp. (°C)	30	
Actual yield (kg da^{-1})	335	TÜIK, 2022

RESULTS and DISCUSSION

The current wheat yield is 5.5 t ha^{-1} while actual yield is 3.35 t ha^{-1} (Turkish Data Portal for Statistics, 2022) due to may not reflect real-world variability such as unexpected weather events, localized pest and disease outbreaks, or differences in soil quality and/or more accurate or generalized input data, assume advanced technologies and practices not fully adopted by all farmers, and not account for the variability in actual farming techniques and if the temperature increases by 2°C, the yield increases to 6.9 t ha^{-1}. If the temperature increases by 4°C, the yield further increases to 8.0 t ha^{-1}. With an increase of 200 ppm in atmospheric CO_2 levels (RUE 1.56), the yield reaches 7.1 t ha^{-1}. The growth season length was simulated by the LINTUL- MULTICROP for different scenarios.

In scenario (d), if 200 ppm is added to the existing atmospheric CO_2 amount, the new RUE value is determined as 1.56 g MJ^{-1}. Tang et al., 2018 examined the potential yield and water requirements of winter wheat in the Huang-Huai-Hai Plain under the RCP4.5 and RCP8.5 scenarios. The results showed that potential yield increased from the northwest inland to the southeast coast under both scenarios, while evapotranspiration (ETc) decreased from the Shandong Peninsula to the surrounding areas. Under the RCP4.5 scenario, potential yield, ETc, and effective precipitation increased, leading to a decrease in irrigation water requirements. In contrast, under the RCP8.5 scenario, potential yield, ETC, and irrigation water requirements first increased and then decreased. These findings provide valuable insights for mitigating the impacts of climate change on agricultural production and water use.

On the other hand, Yeşilköy and Şaylan (2020) ‘s study assessing the future impacts of climate change on winter wheat in the Thrace region of Turkey, results indicated that increasing temperatures and atmospheric CO_2 concentrations could significantly boost wheat yields by up to 46.8% by the late 21st century under the RCP 8.5 scenario. Consequently, the water footprint (WF) of winter wheat is projected to decrease by as much as 82.5% due to increased yields and changing precipitation patterns.

Since harvesting dates were input of the model, the total growing period was not changed for all scenarios (Table 2). Days between emergence and 100% GC scenarios a and d remained the same in this evaluation criterion and were determined as 177 days. However, although there is a difference in scenarios b and c, there was a 38-day decrease in scenario b. For scenario c, there was a decrease of 84 days. Thus, the germination times of the plants decreased in scenarios b and c. Considering the climate data of Konya, 600-700 mm of precipitation, distributed in accordance with the growing period of wheat, is sufficient for maximum yield in wheat cultivation (Dündar & Topak., 2021). Irrigation water requirements were determined as 25.19 mm for scenario a, and these values were calculated as 20.66 mm and 16.90 mm for scenario b and c, respectively. It is calculated as 19.38 mm for scenario d where +200 ppm increase is added. Alexandrov & Hoogenboom (2000) reported that modification of the sowing date can decrease the adverse influence of climate change on wheat cultivation. The cultivation period of wheat in the semi-arid environment of Konya has been established as 235 days and it does not change under any scenarios.

Table 2. Growing stages of wheat grown in different scenarios

Growing stages	**Climate Change Scenario**			
	a	**b**	**c**	**d**
Days between planting and emergence	4	3	3	4
Days between emergence and 100% GC	177	140	93	177
Days between 100% GC and harvest	54	92	139	54
Growing period (days)	235	235	235	235

In scenario a, the potential yield is 5.5 t ha^{-1} for potential yield and yield irrigated. The irrigation water requirement is 25.19 mm. In scenario b, the potential yield increases to 6.9 t ha^{-1} for potential yield and yield irrigated. The irrigation water requirement decreases to 20.66 mm. In scenario c, the potential yield further increases to 8.0 t ha^{-1} for potential yield and yield irrigated. The irrigation water requirement decreases to 16.90 mm. In scenario d, the potential yield is 7.1 t ha^{-1} for potential yield and yield irrigated.

The irrigation water requirement is 19.38 mm. These values demonstrate the variations in potential yields and irrigation water requirements across different scenarios, highlighting the importance of irrigation for achieving higher yields and managing water resources effectively in agricultural practices (Table 3).

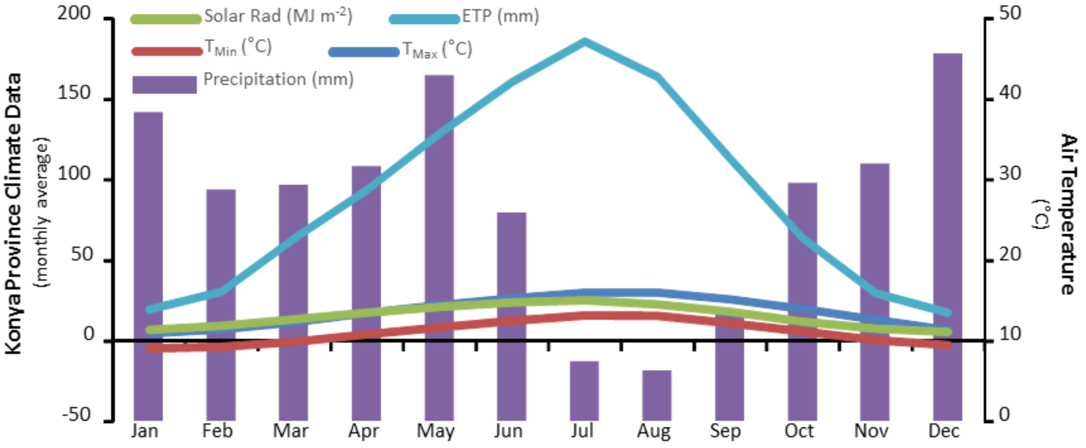

Figure 2. Temperature data according to climate change scenarios for current condition in Konya.

Table 3. Yield and irrigation simulations of different scenarios for wheat

Yield and irrigation requirement	**Climate Change Scenario**			
	a	**b**	**c**	**d**
Potential yield (t ha^{-1})	5.5	6.9	8.0	7.1
Yield irrigated (t ha^{-1})	4.9	6.1	7.2	6.3
Yield not irrigated (t ha^{-1})	3.6	4.4	5.3	4.6
Irrigation water requirements (mm)	25.19	20.66	16.90	19.38

CONCLUSION

The key findings indicate that a 2°C temperature increase (scenario b) significantly modifies the alfalfa growing period, requiring adjustments to seeding and harvesting schedules, while a 4°C temperature increase (scenario c) exacerbates challenges for wheat growers, potentially making current practices unsustainable. Additionally, increased CO_2 levels (scenario d) change sowing and harvesting dates, resulting in longer intervals between 100% Ground Cover (GC) and harvest. These findings highlight the urgency of developing and implementing effective adaptation strategies to mitigate the negative effects of climate change on wheat and alfalfa production in the Konya Region. Precision planting and harvesting can mitigate some adverse effects, but long-term solutions are necessary for sustainable production. The susceptibility of wheat to fluctuating climatic conditions requires a holistic approach to ensure its long-term sustainability.

This involves advancements in agricultural practices, technological innovations, and robust policy frameworks. Future research should focus on developing comprehensive long-term adaptation solutions that integrate the insights from this study, advancing agricultural practices, enhancing technological innovations, and establishing strong policy frameworks to ensure the long-term sustainability and resilience of wheat production amidst a changing climate. By elucidating the intricate relationship between climate change and wheat growth, this study lays bare the vulnerability of this essential crop. This knowledge paves the way for informed decision-making, effective policy formulation, and equitable resource allocation, all crucial for fostering proactive adaptation and sustainable agricultural practices. Ultimately, the development of robust and sustainable wheat production systems is imperative for safeguarding food security, economic stability, and environmental preservation in the face of climate change. Taking decisive action and implementing the solutions outlined in this study will ensure that wheat continues to thrive, providing sustenance and prosperity for generations to come.

REFERENCES

Ahmad A., Ashfaq M., Rasul G., Wajid S. A., Ahmad I., Khaliq T.... & Hoogenboom G. 2023. Development of Climate Change Adaptation Strategies for Cotton–Wheat Cropping System of Punjab Pakistan. *In Handbook of Climate Change And Agroecosystems: Climate Change and Farming System Planning in Africa and South Asia: AgMIP Stakeholder-driven Research*, Part 2 pp. 277-327.

Ahmed M., Asif M., Hirani A. H., Akram M. N. & Goyal A. 2013. *Modeling for agricultural sustainability: A review*. Elsevier. Pp 127-147.

Akman H., & Topal A. 2011. General Situation and Problems of Wheat Farming in Province of Konya, *Selcuk Journal of Agriculture and Food Sciences*, 25(4), 47-57.

Alexandrov V. A. & Hoogenboom G. 2000. The impact of climate variability and change on crop yield in Bulgaria, *Agricultural and forest meteorology*, 104(4), 315-327.

Alsafadi K., Bi, S., Abdo H. G., Almohamad, H., Alatrach B., Srivastava A. K., ... & Mohammed S. 2023. Modeling the impacts of projected climate change on wheat crop suitability in semi-arid regions using the AHP-based weighted climatic suitability index and CMIP6, *Geoscience Letters*, 10(1), 1-21.

Asseng S., Ewert F., Martre P., Rötter R. P., Lobell D. B., Cammarano D., ... & Zhu Y. 2015. Rising temperatures reduce global wheat production, *Nature climate change*, 5(2), 143-147.

Balaghi R., Tychon B., Eerens H. & Jlibene M. 2008. Empirical regression models using NDVI, rainfall and temperature data for the early prediction of wheat grain yields in Morocco, *International Journal of Applied Earth Observation and Geoinformation*, 10(4), 438-452.

Dettori M., Cesaraccio C. & Duce P. 2017. Simulation of climate change impacts on production and phenology of durum wheat in Mediterranean environments using CERES-Wheat model, *Field Crops Research*, 206, 43–53.

Dhakal A. 2021. Effect of drought stress and management in wheat—A review, *Food Agribus. Manag*, 2(2), 62-66.

Dündar M. A. & Topak R. 2021. Evaluation of Irrigation Productivity Using Different Irrigation Strategies for Winter Wheat, *Bahri Dağdaş Bitkisel Araştırma Dergisi*, 10(2), 124-137.

Fan J., McConkey B., Wang H. & Janzen H. 2016. Root distribution by depth for temperate agricultural crops, *Field Crops Research,* 189, 68-74.

Fang Y., Xu B., Turner N. C. & Li F.-M. 2010. Grain yield, dry matter accumulation and remobilization, and root respiration in winter wheat as affected by seeding rate and root pruning, *European Journal of Agronomy*, 33(4), 257–266.

Farooq M., Wahid A., Kobayashi N., Fujita D. & Basra S. M. A. 2009. Plant drought stress: effects, mechanisms and management, *Sustainable agriculture*, 153-188.

Farré I., Van Oijen M., Leffelaar P. A. & Faci J. M. 2000. Analysis of maize growth for different irrigation strategies in northeastern Spain, *European Journal of Agronomy*, 12(3-4), 225-238.

Franke A.C., Haverkort A.J. & Steyn J.M. 2013. Climate change and potato production in contrasting south African agro-ecosystems 2. Assessing risks and opportunities of adaptation strategies, *Potato Res*, 56(1): 51-66.

Gouache D., Le Bris X., Bogard M., Deudon O., Pagé C. & Gate P. 2012. Evaluating agronomic adaptation options to increas- ing heat stress under climate change during wheat grain filling in France, *European Journal of Agronomy*, 39, 62–70.

Monteith J. L. 1977. Climate and the efficiency of crop production in Britain. Philosophical transactions of the royal society of London, *B, Biological Sciences*, 281(980), 277-294.

Nouri M., Homaee M., Bannayan M. & Hoogenboom G. 2017. Towards shifting planting date as an adaptation practice for rainfed wheat response to climate change, *Agricultural water management*, 186, 108-119.

Habekotté B. 1997. Description, parameterization and user guide of LINTUL-BRASNAP 1.1: a crop growth model of winter oilseed rape (Brassica napus L.). AB-DLO. ISBN: 9789073384514

Haverkort A. J., Franke A. C., Engelbrecht F. A. & Steyn J. M. 2013. Climate change and potato production in contrasting South African agro-ecosystems 1. Effects on land and water use efficiencies, *Potato Research*, 56, 31-50.

Hernandez-Ochoa I. M., Asseng S., Kassie B. T., Xiong W., Robertson R., Pequeno D. N. L....& Hoogenboom G. 2018. Climate change impact on Mexico wheat production, *Agricultural and Forest Meteorology*, 263, 373-387.

Hoogendoorn J. 1985. The physiology of variation in the time of ear emergence among wheat varieties from different regions of the world. *Euphytica*, 34(2), 559-571.

IPCC 2018. Intergovernmental Panel on Climate Change Report 2018 https://www.ipcc.ch/2018/ (accesed:15 April 2023)

Jaleel C. A., Manivannan, P., Wahid A., Farooq M., Al-Juburi H. J., Somasundaram R. & Panneerselvam R. 2009. Drought stress in plants: a review on morphological characteristics and pigments composition, *Int. J. Agric. Biol*, 11(1), 100-105.

Kettlewell P., Byrne R. & Jeffery S. 2023. Wheat area expansion into northern higher latitudes and global food security, *Agriculture, Ecosystems & Environment*, 351, 108499.

Khan A., Ahmad M., Ahmed M. & Iftikhar Hussain M. 2020. Rising atmospheric temperature impact on wheat and thermotolerance strategies, *Plants*, 10(1), 43.

Lee H., Calvin K., Dasgupta D., Krinner G., Mukherji A., Thorne P. ... & Park Y. 2023. IPCC, 2023: Climate Change 2023: Synthesis Report, Summary for Policymakers. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.

Lobell D. B. & Burke M. B. 2010. On the use of statistical models to predict crop yield responses to climate change, *Agricultural and forest meteorology*, 150(11), 1443-1452.

Nouri M., Homaee M., Bannayan M. & Hoogenboom G. 2017. Towards shifting planting date as an adaptation practice for rainfed wheat response to climate change, *Agricultural water management*, 186, 108-119.

Nyombi K. 2010. Understanding growth of East Africa highland banana: experiments and simulation, *Wageningen University and Research*. ISBN: 978-90-8585-550-7

Osman R., Ata-Ul-Karim S. T., Tahir M. N., Ishaque W. & Xu M. 2022. Multi-model ensembles for assessing the impact of future climate change on rainfed wheat productivity under various cultivars and nitrogen levels, *European Journal of Agronomy*, 139, 126554.

Özensel İ. E. 2023. Evaluation of the Factors Playing an Effective Role in Farmers' Selection of Cereals for Sowing by Dematel Method: (The Case of Konya Province). MSc Thesis, KTO Karatay University, Türkiye.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R. ... & van Ypserle, J. P. 2014. Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change, IPCC, p. 151. Papakosta D. K., & Gagianas A. A. 1991. Nitrogen and Dry Matter Accumulation, Remobilization, and Losses for Mediterranean Wheat during Grain Filling, *Agronomy Journal*, 83(5), 864–870.

Porter J. R. & Gawith M. 1999. Temperatures and the growth and development of wheat: a review, *European journal of agronomy*, 10(1), 23-36.

Purucker S. J. 2020. *Agronomic and Nutrient Management Strategies to Improve Winter Wheat and Sugarbeet Plant Growth, Yield, and Quality*. Michigan State University.

Raihan A. 2023. A review of the global climate change impacts, adaptation strategies, and mitigation options in the socio-economic and environmental sectors, *Journal of Environmental Science and Economics*, 2(3), 36-58.

Rana R. M., Rehman S. U., Ahmed J. & Bilal M. 2013. A comprehensive overview of recent advances in drought stress tolerance research in wheat (Triticum aestivum L.), *Asian Journal of Agriculture and Biology, 1*(1), 29–37.

Republic of Türkiye Ministry of Agriculture and Forestry 2017. Serin İklim Tahılları Çeşit Tescil Raporu, Tarım Ürünleri Piyasa Raporu, TEPGE. https://www.tarimorman.gov.tr/BUGEM/TTSM/Belgeler/Yay%C4%B1nlar/2017%20Faliyet/Serin%20%C4%B0klim%20Tah%C4%B1llar%C4%B1%202017%20Tescil%20Raporu.pdf (accessed 17 April 2023).

Republic of Turkey Ministry of Agriculture and Forestry 2023. Buğday Tarımı. https://arastirma.tarimorman.gov.tr/ktae/Belgeler/brosurler/Bu%C4%9Fday%20Tar%C4%B1m%C4%B1.pdf (accessed 18 October 2023)

Sandaña, P., Ramírez, M. & Pinochet, D. (2012). Radiation interception and radiation use efficiency of wheat and pea under different P availabilities. Field crops research, 127, 44-50.

Shibu M. E., Leffelaar P. A., Van Keulen H. & Aggarwal P. K. 2010. LINTUL3, a simulation model for nitrogen-limited situations: Application to rice, *European Journal of Agronomy*, 32(4), 255-271.

Sommer R., Glazirina M., Yuldashev T., Otarov A., Ibraeva M., Martynova L., Bekenov M., Kholov B., Ibragimov N., & Kob- ilov R. 2013. Impact of climate change on wheat productivity in Central Asia, *Agriculture, Ecosystem and Environment*, 178, 78–99.

Spitters C. J. T. & Schapendonk A. H. C. M. 1990. Evaluation of breeding strategies for drought tolerance in potato by means of crop growth simulation, *Genetic aspects of plant mineral nutrition*, 151-161.

Tari A. F. 2016. The effects of different deficit irrigation strategies on yield, quality, and water-use efficiencies of wheat under semi-arid conditions, *Agricultural Water Management*, 167, 1-10.

Tang X., Song N., Chen Z., Wang J. & He J. 2018. Estimating the potential yield and ETc of winter wheat across Huang-Huai-Hai Plain in the future with the modified DSSAT model, Scientific Reports, 8(1), 15370.

Taulya G. 2015. *Ky'osimba Onaanya: Understanding productivity of East African highland banana.* PhD thesis, Wageningen University. ISBN 9789462575615 - 167

Thapa S., Xue Q., Jessup K. E., Rudd J. C., Liu S., Devkota R. N. & Baker J. A. 2020. Soil water extraction and use by winter wheat cultivars under limited irrigation in a semi-arid environment, *Journal of Arid Environments*, 174(March), 104046.

TSMS. 2022. Turkish State Meteorological Service, climate data of long term period. URL: https://mgm.gov.tr (accessed 17 April 2023).

TÜİK 2022. Wheat yield for Konya province in 2022. https://biruni.tuik.gov.tr/medas/?kn=92&locale=tr (accessed 17 November 2023).

Wang B., Li Liu D., Asseng S., Macadam I. & Yu Q. 2015. Impact of climate change on wheat flowering time in eastern Australia, *Agricultural and Forest Meteorology*, 209, 11–21.

Yeşilköy S. & Şaylan L. 2020. Assessment and modelling of crop yield and water footprint of winter wheat by AquaCrop, Ital J Agrometeorol, 3, 3-14.

Zahra N., Hafeez M. B., Wahid A., Al Masruri M. H., Ullah A., Siddique K. H. & Farooq M. 2023. Impact of climate change on wheat grain composition and quality, *Journal of the Science of Food and Agriculture*, 103(6), 2745-2751.

Zhang X., Chen S., Sun H., Pei D. & Wang Y. 2008. Dry matter, harvest index, grain yield and water use efficiency as affected by water supply in winter wheat, *Irrigation Science*, 27(1), 1–10.