Gonbad Kavous University

Journal of New Approaches in Water Engineering and Environment

Online ISSN: 2981-0280

Homepage: https://nawee.gonbad.ac.ir

The effect of climate change on sorghum's Yield (Case Study: Zanjan province, Abhar Plain)

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Article Info

Article type:
Research Article

Article history:
Received 21 February 2025
Revised 29 February 2025
Accepted 20 June 2025
Published online 26 June 2025

Keywords:
Climate Change
Temperature
Simulation
Aqua Crop
Abhar

ABSTRACT

Objective: The most important climate variable, closely related to other variables, is temperature, whose changes trigger a series of chain reactions in the environment. Also temperature is a key factor influencing plant growth. Therefore, in this study, future temperature trends in the Abhar region, affected by climate change, are analyzed over upcoming periods and compared with the historical observation period. Crop yield in future and various planting periods is predicted using the AquaCrop crop simulation model and climate change models.

Material and Methods: The observation period spans from 1986 to 2010 AD, with near, middle, and far horizons projected for 2011-2045, 2046-2079, and 2080-2100, respectively. LARS-WG software is employed alongside the NorESM1-M model under RCP8.5 and RCP4.5 emission scenarios to downscale the results of the general circulation model. Additionally, a scenario file is created in this study.

Results and Discussion: Results show that the highest yield of 4.64 tons per hectare occurs on September 27, while the lowest yield of 0.65 tons per hectare is on September 16. Moving the traditional planting date from October 7 to September 27 results in a yield increase of 0.15 tons per hectare. In the distant future horizon, the maximum yield 6.39 tons per hectare will be achieved on October 27. Furthermore, sorghum yields are projected to increase in future timelines, likely due to its involvement in the C3 photosynthetic system.

Conclusions: Consequently, the average annual temperature during the near, middle, and far future periods are expected to rise by 0.26, 0.72, and 1.46 degrees Celsius, respectively. Rainfall data indicate that November rainfall has increased to 37.61 mm with an upward trend at the 95% confidence level, while March rainfall has decreased to 32.25 mm, also at the same confidence level.

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Cite this article: Khani, Temeliyeh, Zabihollah., Mirabbasi, Rasoul., Shirdeli, Azim., Shadmehr, Shahab., Khani Temeliyeh, Sakineh., Fakhimi, Parisa. (2025). The effect of climate change on sorghum's Yield (Case Study: Zanjan province, Abhar Plain). Journal of New Approaches in Water Engineering and Environment, 4(2), 107-130. https://doi.org/10.22034/nawee.2025.508033.1141.

Publisher: Gonbad Kavous University. DOI: https://doi.org/10.22034/nawee.2025.508033.1141

1.Introduction

Climate change is one of the most important global issues of the 21st century, and it has serious economic consequences (Redsma et al, 2009). And it affects various economic sectors such as agriculture, forestry, water, industry, tourism, energy and even financial and insurance markets. But since the production of crops is directly dependent on the climatic conditions and the climate is the main determinant of the location, sources of production and productivity of agricultural activities, the agricultural sector is one of the first sectors to be affected by climate change (Reilly,1999). Climate change and its variability have formerly affected the world food crop yield (Ray et al., 2020). The effect of climate change on the agricultural sector, especially in the production sector, indicates adverse consequences that will affect this sector in the future (Ackerman and Stanton,2013). The phenomenon of climate change can affect the demand for water as well as the yield in agriculture by changing evaporation and transpiration of the plant, duration, intensity and time of the rainfall (Bates et al. 2008). We can consider yield a function of restrictive environmental sources to analyze the effect of climate change (Soltani and Gholipour, 2007). Growth length change is the most profitable climate index which has several climate applications (Robeson, 2002). The net special impact of vigorous changes in rainfall patterns is the disruption in crop yield leading to food insecurity, joblessness, paucity of economic or poverty, and societal displacement (Kyei-Mensah et al., 2019).Amin et al, (2012), evaluated the effects of climate change on the yield and cropping area of major food crops in Bangladesh, The results of their research showed that the effects of all the climate variables have had a significant and considerable impact on the yield and cropping area of main food crops, with distinct changes among them. Maximum temperature, from a statistical point of view, has had a significant effect on the yield of all food products except Aus rice. Also, the minimum temperature slightly affected the cultivation area of all crops, and so did the maximum temperature. For all crops, the maximum temperature also had an insignificant effect on them. For the Aman rice type, the minimum temperature insignificantly affected them, but for this type of rice, compared to other crops, yield and cropping have benefited. Moisture or humidity, from a statistical point of view it has a considerable positive effect on the Yield of Aus and Amman rice types, but it has a negative effect on the cultivation area of Aus rice.Bocchiola (2015), evaluated the impact of potential climate change on crop yield and water footprint of rice in the Po valley of Italy. For this purpose, he used the hydrological model based on the product model. (PC), In order to investigate crop productivity and water use (i.e., water footprint) of rice (Oryza sativa L.), in the study area of Landriano, in the Po Valley, Italy, they were used. In order to investigate the potential impacts of future climate change on rice production and water use, climate scenarios from two GCM models (CCSM4, ECHAM6) from IPCC panels, and three RCP emission scenarios (RCP2.6, 4.5, 8.5) were used. The results showed that in half a century, an increase in CO2 concentration may lead to an increase in rice yield (especially under CCSM4), at the expense of an increase in WFB (blue water footprint), and WFI (irrigation water footprint), under a decrease in rainfall and an increase in summer temperature. Under the ECHAM6 scenarios, rice yield remains practically constant, or declines (RCP2.6), due to increased temperatures during the spring season, and projected harvest dates, again with a major increase in WFB. Under the ECHAM6 scenarios, rice production remains practically constant, or declines (RCP2.6), due to increased temperatures during spring, and projected harvest dates, again with a major increase in WFB. Yazdi et al

(2022), investigated the effects of climate change, drought, and agricultural sector policies on the trend of the water poverty index in Iran. To achieve this purpose, the present study selected the Fasa plain in Iran and calculated its water poverty index (WPI) from 2008 to2018 using parametric and nonparametric statistical tests. Also, in this study, the correlation coefficient between WPI and climate change and drought in the study area was evaluted. The results of their research showed that water consumption in Fasa plain has the most weight in WPI calculation. So that the WPI level in this plain is between 0.297 and 0.678 per year and the worst case of water poverty occurred in 2013. Although insignificant, the decreasing trend of WPI indicated that water resource management has become more unfavorable over time. Finally, it was concluded that WPI in Fasa Plain is more dependent on drought than climate change in the short term.Plant models can be used to assess the effects of climate change on crop production. First, weather data of the previous years in accordance with general circulation models (GCM) when CO_2 concentration would increase are changed in these studies. Then, the model's reaction towards these changed data is investigated (Soltani, 2009). Raes et al. (2009) evaluated the AquaCrop model on corn production in different conditions. This study aimed to examine the effects of deficit irrigation strategies before flowering and complete sets of watering after flowering on crop production. Based on the results, the maximum error between simulated and actual yield was estimated as 24 percent. Garcia-Villa et al. (2007), in a similar study, showed that the AquaCrop model was able to properly simulate yield, canopy cover growth, biomass, and water use efficiency for linen yield. Abraha and Savage (2006) investigated the potential effect of climate change on corn yield in South Africa. They showed that changing the planting dates in the current situation will have little effect on grain yield, but putting the planting date forward under climate change conditions would result in a yield increase. Reduction of the length of growing season due to the temperature rise which is caused by climate change, results in, for example, cropping calendar change and yield loss of crops which has not yet fully matured and reached their final growth. Increasing the length of the growing season may bring more opportunities to start planting earlier, ensure the final growth and maturation, and have as much harvest as possible (in case of water availability). Also, this index is one of the most important criteria for identifying climate change (Chen et al., 2000). Maneta et al (2009), evaluation of the economic effects of climate change in Brazil exploited the integration of hydrological and economic models. The results of their studies showed that the impact of climate change on farmers varies and depends on factors such as access to groundwater resources and the farm's position in the catchment area. also other studies have been done, the following studies can be mentioned(Karimi et al, 2018 ; Lang et al, 2018; Maia et al, 2018 ; Guillermo et al, 2018 ; Arora et al, 2019 ; Malhi et al, 2021 ; Takacs et al, 2021; Habib-ur-Rahman et al, 2022 ; Hossain et al, 2022 ; Bekuma Abdisa et al, 2022, Stricevic et al, 22023).Simulation models are one of the cheapest methods for estimating sorghum's yields under different and arbitrary conditions. A particular crop's yield, water requirement, etc., in different conditions, as well as climate change conditions, can be estimated through the implementation of the (calibration) yield, water requirements, etc., of that crop in real conditions of the area. Given that the Abhar region has significant trends in climate parameters, the AquaCrop model can be used to estimate the available sorghum yield in the area under climate change conditions. Considering all the above-mentioned issues, studying climate change in future periods is essential. Through these studies, we can identify the onset of the growing season, the amount of thermal energy needed to complete the product development cycle, and the best cultivation time. Furthermore, we can decide on a replacement product if necessary. We can use second crop products by properly planning the cultivation time if possible. The Necessity of Herbaceous Models use**:** Agriculture can be defined as the science of product management which is achieved through better forecasting and performance management techniques for maximum profit. Nowadays, production increases mostly depend on the efficient use of resources. Many factors, including climate, soil, plant, and production management, affect the planted herbs' responses toward irrigation, fertilization and other cultivation operations. Herbaceous models are widely and commonly used to evaluate land indirectly. Thus, they are used to answer the questions that are raised in scientific research, product management and policy (Boote et al. 1996). Herbaceous models provide opportunities for predicting the crop yield and potential productivity of places where the plants do not grow. Although models cannot substitute for field experiments, they have a major advantage that they save money and time. Otherwise, it is necessary to conduct exhausting field experiments in multiple locations with different soil characteristics and climate for several years. Computer models play a valuable role in further understanding of the process of growth and the anticipated plant response to different circumstances at different levels of yield and productivity by means of soil system, product and atmosphere simulation. A lot of user-centered models are produced to simulate various as a result of computer hardware and software technologies' advancement and their wide accessibility. These models can be used in product improvement, nutrient management, as well as, proposing theories of wide herbaceous management. Furthermore, they can also be used to research environmental issues and plants' tolerance of agricultural ecosystems (Monteith, 1996). Bagheri Khaneghahi et al (2024), Evaluating the accuracy of AquaCrop 7.1 crop model and investigating the effect of changing the planting date on the performance of rainfed wheat in different climates of Iran. The results of rainfed wheat yield simulation indicated the acceptable accuracy of the model (with high R^2 values and low NRMSE values) in crop yield modeling. Also, the yield of the model crop in the mentioned cities was from 2.52, 1.09, 1.28, 0.83, 1.53 and 1.29 tons per hectare in the date of conventional cultivation to 2.721, 1.349, 1.45, 1.217, 1.742 and 1.683 tons per hectare in the early planting date. Therefore, based on the planting dates, the highest yield was related to the early planting date. Rahemi et al (2024), Evaluation of yield and morphological traits of New Wheat varieties (Triticum aestivum) under rainfed conditions (Late-season drought stress) in Golestan Province in Galikesh region. The mean comparison results showed that the shortest and longest spike lengths belonged to the Aramesh variety with 9.60 cm and UR-93-15 variety with 15.6 cm, respectively. Additionally, the Aramesh variety with 592 spikes per square meter and the Euclide variety with 251 spikes per square meter had the highest and lowest number of spikes per square meter, respectively. The lowest number of grains per spike was observed in the Paya variety, and the highest value for this trait was observed in the Gaboos, Mihan, and UR-95-15 varieties with 43 grains per spike. Furthermore, the Wiener and Paya varieties had the highest and lowest biological yield (3.11 and 1.53 kg per square meter, respectively). Correlation results showed that the harvest index and the number of spikes had a positive correlation above 80% and played the most significant role in grain yield. Other studies include (Haghighati etal, 2024; Hajiabadi et al,2024).The main purpose of herbaceous models are their applicability as an analytical tool to study the effect of cultivation systems management on the fertility of crops and the environment. For this purpose, most of the herbaceous models deal with the simulation of soil and water balance, humus nitrogen balance, phenology, root growth, the amount of biomass, crop yield, production and analysis of residue, soil erosion, and fate of the pesticide. The cases affected by climate, soil, and plant characteristics are cultivation system management options such as crop shift, irrigation, fertilization, etc. In this research, in order to investigate the effect of climate change on sorghum yield in Abhar Plain (In Zanjan province located in Iran country), using RCP4.5 concentration pathway scenario and RCP4.5 concentration pathway scenario, data and general circulation models (using the NorESM1-M climate model) for historical data (1986-2010) for three near (2011-2045), middle (2046-2079) and far (2080-2100) horizons were simulated and produced and the results of the RCP8.5 concentration pathway scenarios, considering the worst and most extreme conditions was selected to analysis. Then, using the AquaCrop model, the performance of the sorghum crop was investigated for the mentioned horizons with the climate change approach.

2.Material and Method

2.1. Area of study

The current study investigated current and future sorghum yield by estimating changes in minimum, average, and maximum temperature over future time in the Abhar region. It also tried to simulate this yield using the AquaCrop plant growth simulation model. We needed at least 20 years' data to conduct the current study. So, we used synoptic stations in Khoramdeh, which was located a very short distance from Abhar (6 km) in the central part of the region and had a climate similar to Abhar. Khoramdeh synoptic station's name and geographic coordinates are shown in Figure1.

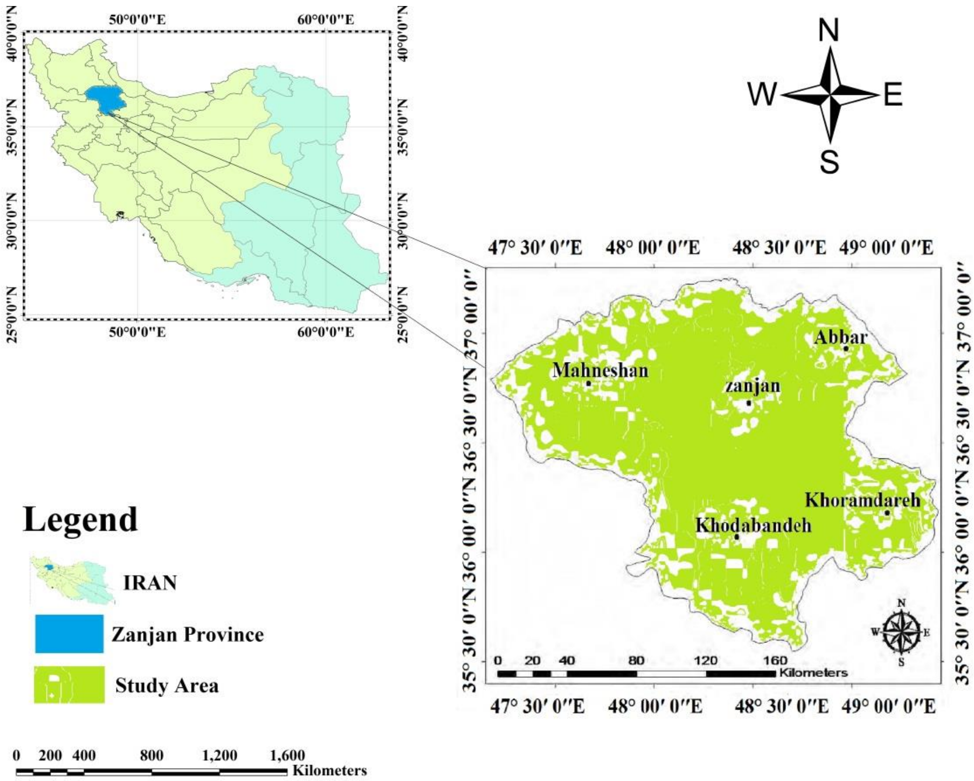

Figure 1- The location of the study area

We needed a reference period as the base one to estimate changes in minimum, average, and maximum temperature in the Abhar region according to the future perspective affected by climate change. The Mann-Kendall nonparametric test was used to investigate the minimum, average, and maximum temperature change process in the past. In addition, Sen Slope Process method was used to calculate the amount of these changes. For this purpose, the required data were obtained from the establishment date of the intended stations up to 2014. Fakhimi et al. (2014) published the results. A proceeding and accuracy test was done on these data. According to the results of the Mann-Kendall test, the minimum temperature time series in February, March and April to September and all seasons of the year as well as in annual terms has had a significant ascending trend. Except for February and fall which had significant trends at 95 percent confidence level, the rest of the months and seasons have had a significant ascending trend in confidence level of 99 %. The average monthly temperature time series during July, August, February and March had significant. To put it eloquently, the significant trend in February was at 90% confidence level and in July and March was at 99% confidence level. The seasonal scale showed that other seasons except autumn have had a significant ascending trend. Moreover, the summer had 99% significant confidence level. The maximum temperature during July and February at 95% confidence level and 99% in March has had a significant ascending trend. At the 95 % confidence level, summer and winter have had a significant ascending trend. Annual maximum temperature at a confidence level of 99% has also had an ascending trend. The effects of climate change on the minimum, average, and maximum temperature of the Abhar region in the next three time horizons, including the near horizon (2011-2045), middle horizon (2046-2079) and the distant horizon (2080-2100) have been studied.

2.2. Concluding the Results of Simulation Models for Average Atmospheric Circulation Based on the Likely Scenarios of Future Climate:

General circulation models are three-dimensional models that are developed on the basis of different climate simulations in order to simulate the effects of greenhouse gases on the current climate of the earth. They are also able to predict future climate change (Xu, 1999). General atmospheric circulation models provide the best studies on climate change which is due to greenhouse gases. One of the main constraints on the output of general circulation climate models is that the accuracy of spatial and temporal analysis does not correspond with the required accuracy of regional and hydrological model. Location accuracy of these models is for networks with a length of 200 kilometers. This amount of accuracy is not especially suitable for studying mountainous areas and climatic factors such as temperature and precipitation. Outputs of these models can be converted into surface variables according to the study zone's scale by creating a small scale. In fact, making small-scale refers to moving from large-scale predictors toward instant predictions on a local scale (Wilby and Dettinger, 2000). The output of general atmospheric circulation models are generally produced based on scenarios of greenhouse gas emissions. The researchers use the coupled three-dimensional models of ocean-atmosphere (AOGCMs) as the most common climate output. Among these concentration pathway scenarios, RCP 8.5greenhouse gas emissions scenario has a wide scope of applicability in the studies due to its similarity to real and available conditions of the world. LARS model has the NorESM1-M model's output according to RCP 8.5 scenario in its

DataBase. This model extracts the related data by determining the latitude, longitude and altitude of the study area.

2.3. Downscaling

There are different styles for downscaling, including the use of original cell info, adjacent cells' interpolation data, statistical methods, and dynamic methods which are used to create climate scenarios. The statistical downscaling (productive climate model) is used in this study. Related details are provided in the following part. LARS-WG is one of the most famous climate random data producer models. This model is used to generate daily precipitation, light, maximum, and minimum daily temperatures at a station under the terms of the present and the future climate. Moreover, it uses the observed daily information at a specific station to calculate a set of parameters that are related to probable distributions of the climatic variables and their correlation. These parameters are used to make artificial time series of the climatic variables. A daily climate scenario can be created for a weather station by adjusting the parameters of the obtained distributions for a given weather station based on the predicted climate changes which are obtained from regional or global climate models. This scenario can be used to assess climate change and build information (Semenov and Stratonovich, 2010). There are different ways to evaluate and calibrate the model, such as comparing the generated data according to the base model and the period of the station, or drawing charts related to various parameters. Furthermore, different formulas are used in most studies on climate change (Naseri et al. 2014).

2.4. Weather Data Generation in The Future

Two fundamental requirements of the model in this stage are: two files which characterize the climate behavior in the past (* .wgx) and climate change scenarios (* .sce) extracted from GCM models' output. The generator menu is used for this purpose. The name of the desired station is chosen. The baseline option is suitable for generating the base period's data. Moreover, future periods can be chosen from the climate scenario section in order to generate climate data. The output of this step is stored as a text file in a folder named output, which is located in the section where you have installed the software. A NorESM1-M model is used in this study. Output data of the minimum and maximum temperature as well as daily data related to the aforementioned climate data and some of these models are available in the database software. The RCP 8.5 concentration pathway scenario of the NorESM1-M model was the basis for the rest of the study.

This section is a part of the Generator menu. In this section, we can generate the climate data through selecting the NorESM1-M scenario and the desired period for generating the data (near, middle and far periods). Then we press the generate button and the output is stored in the OutPut folder. This file contains data on simulated temperature and precipitation under climatic conditions. The light parameters would also be generated if the process of sundial parameter (light) is significant and we enter data of the sundial (Partovi, 2013).

2.5.Scenario file generation

The LARS-WAG model needs a special kind of climate change scenario file.We should use the climate change scenario of climate variables and two output file of the model as (*.wgx) and (*.dat), which contain daily data. These variables contain coefficient variance of average precipitation parameters, minimum and maximum temperature, variation of monthly wet and dry periods in the future compared to the base period (Eq. 1), relative variation of the standard deviation related to the average daily temperature for each month in the future compared to the base period (Eq. 2), and absolute variation of light in the future compared to the base period (Eq. 3). These variables are extracted from output of AOGCM models and entered in file as (*.sce) file. Moreover, data on the standard deviation of average daily temperature and the rest of the data are extracted from the files (*.dat) and (*.wgx).

Calculation of the variability of rainfall, during of wet and dry periods, and minimum and maximum temperature: Average empirical distribution of periods' length is done by (* .wgx) file for the base and future period. For this purpose, the center of each histogram is obtained by averaging the first and last values. The calculated averaging amount is multiplied with the number of occurrences of this period in order to calculate the duration for this interval of the histogram. This process is performed for all Histograms. Now, all values are summed to achieve an approximation of the total number of wet days (or dry). The total number of events are obtained through the sum of all events (or density of distribution) in each histogram. Furthermore, the total number of wet days (or dry) is divided by the total number of events to calculate the average distribution. This process is taken for two periods, all 12 months. Finally, the average duration of the future series is divided to the average duration of the other month's base period in order to calculate the relative change of the wet (or dry) monthly period.

$$RC = \frac{\overline{X}_f}{\overline{X}_b} \qquad (1)$$

$$RC_{std} = \frac{std_f}{std_b} \quad (2)$$

$$RC_{rad} = \overline{X}_f - \overline{X}_b \quad (3)$$

B and F are base and future, respectively.

2.6. Simulation of the growth period by AquaCrop

AquaCrop is a model to evaluate the efficiency of water use in plants. It is designed by the water and soil department of the World Food Organization (FAO) and revised in the 33rd issue of the FAO. It is introduced in January 2009 for the first time. In fact, the Aquacrop model is a water consumption-based plant growth simulation model that needs fewer parameters for simulation in contrast to the other models. It uses the revised version of an equation which is published in the 33rd issue of the World Food Organization (FAO) (Equation 4).

$$\left(1-\frac{Y_a}{Y_m}\right) = K_y\left(1-\frac{ET_a}{ET_m}\right) \quad (4)$$

Where: Y_a is the actual yield (ton. Ha^{-1}), Y_m is the maximum yield (ton. Ha^{-1}), K_y is the yield response factor (dimensionless), ET_a is the actual evapotranspiration (Cm), ET_m is the maximum evapotranspiration (Cm).

The required parameters for this model are divided into two categories: constant and variable parameters. The input of this model is information about climate, soil, management, and plant characteristics. Important parameters examined in this model are crop yield, water use efficiency (WP) and harvest index (HI).

$$WP = \frac{Yield}{ET} \quad (5)$$

$$HI = \frac{Yield}{Biomass} \quad (6)$$

Where, yield and biomass are in units of Kg and ET is water consumption (cubic meters). Eq. (7) is the main core of the Aquacrop model for yield estimation.

$$Biomass = WP * \sum_{i=1}^{n}\left(\frac{Tc}{ET_o}\right)_i \quad (7)$$

Where, WP is water use efficiency ($gm^{-2}.mm^{-1}$), TC is plant evaporation ($mm.day^{-1}$), ET_0 is reference evapotranspiration ($mm.day^{-1}$), and $\sum_{i=1}^{n}$ refers to daily steps of the model.

2.7. Model Calibration and Validation According to The Study Area

Herbaceous data of the AquaCrop model is available for a certain number of products in limited areas of the world. Certain varieties of the product may show different responses in different regions. On the other hand, each product has varieties. Due to these facts, the herbaceous data calibration needs to be done in the intended area with the real numbers and yield. For this purpose, the current study used the herbaceous data of similar research that was conducted in areas (whether in our country or abroad) with a climate similar to Abhar. Then, data from the Agriculture Organization of Abhar city, including planting density, yield, planting time, and NETWAT software's data were used to have an accurate calibration of the model.

2.8. Cultivation Time Period

The unit (degree-days) is used here because of the need to involve climate change conditions in the growing season. Some of them are changed according to the other studies' data and calibrated using Abhar's planting and harvesting time. Moreover, other parameters of growing time are altered according to these data. For instance, if ten days is added to the harvest time, the result of dividing the calibrated harvest time by the previous harvest time is added to the flowering period of the crop after harvest. A maximum of one week was added to the conventional harvest time due to use of the highest yield and also to prevent frostbite. AquaCrop version 6.0 (2019) (Sandhu and Irmak,2019) was used; the model was run in calendar days, and the sorghum's annual fodder crop file was taken as a reference. The standard window version 6.0, Similar to version 7.0(2022), the user interface included a database of annual and perennial herbaceous forage crops, with multiple harvests, the amount of biomass, and crop yield harvested at each cut during the growing cycle in case of multiple cuttings; these data were stored in a 'harvests' output file. In this study, the calibration and validation guidelines described by Hsiao et al. were followed (Qian and Engelke, 1999); data from the non-limiting soil water regime treatment (C1-Irrigation: full irrigation treatment in the first cropping season of sorghum and other crops, C3 photosynthetic system of sorghum plant) were used to calibrate AquaCrop. The calibration process was performed by running the model with the specific input information of weather conditions, soil characteristics, field management practices, and crop parameters. The calibration also involved adjusting the non-conservative parameters, including initial canopy cover CCo (%), maximum canopy cover (CCx), time from sowing to start of senescence (day), and maximum effective rooting depth (m), until a close match between observed and simulated biomass was obtained.For the first stage, from sowing to first germination, the soil surface cover of an individual seed at 90% emergence observed in the field and the final yield at the time of germination were taken into account. For germinating after the first germination, the canopy cover after cutting (CCini) was specified at a value of 40% according to field measurements.

The goodness-of-fit of the AquaCrop model for sorghum was evaluated using the following five statistics: the coefficient of determination (R^2) (Eq 8), the Willmott index of agreement (d-index) (Eq 9), the root mean square error (RMSE) (Eq 10), the normalized root mean square error (NRMSE) (Eq 11), and the Nash-Sutcliffe model efficiency coefficient (EF) (Eq 12). The evaluations of simulation results were recorded in statistics output files. The output files contain statistics on the evaluation of the simulation results for canopy cover, biomass, and soil water content.

$$R^2 = \left(\frac{\sum_{i=1}^{n} (O_i - \bar{O}) * (P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n} (O_i - \bar{O})^2} * \sqrt{\sum_{i=1}^{n} (P_i - \bar{P})^2}} \right)^2 \quad (8)$$

$$d = 1 - \frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} \left(|P_i - \bar{O}| + |O_i - \bar{O}| \right)^2} \quad (9)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{n}} \quad (10)$$

$$NRMSE = \frac{1}{\bar{O}} \sqrt{\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{n}} \quad (11)$$

$$EF = 1 - \frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2} \quad (12)$$

where O_i = is the observed data; $\bar{O}$ = is the average of observed data; P_i = is the simulated data; $\bar{P}$ = is the average of simulated data; and *n* is the observation number.

2.9. Crop's water requirement

Data of the NETWAT software is used for accurate calibration of crop' water requirement in real conditions of the region. For this purpose, we can use two parameters as Kc_{TR} (transpiration rate) and WP* (water productivity which is normalized and adjusted by reference evapotranspiration and carbon dioxide concentration). The transpiration coefficient is used because of its simplicity. The WP* parameter is not used due to the limited amount of the parameter value as well as the involvement of the carbon dioxide and food processors.

2.10. Corp yield

The Jihad of Construction provides the required data for accurate calibration of crop yield in Abhar City. Again, we can use two parameters as WP* و HI (Harvest Index). We assumed the WP* parameter was stable in the previous step, so we used the harvest index in this section. The water requirements influence crop yield. So, first, water requirement and then crop yield must be calibrated.

2.11. Cultivation Time Change

The aims of this study is to study the created changes in crop yield during future time series as well as to study yield changes during the cultivation time change. In order to see the aim of this study, 10 days before and 20 days after the real cultivation day are added to the model. In other words, five different cultivation times is considered for the crop (Sandhu and Irmak, 2019; Takács et al, 2021).

3. Result and Discussion

Tables (1-3) demonstrate the correction factors for creating the climate change scenario file of the LARS-WG model, climate change scenario, and climate variables as follows:

Column 1: coefficient of variation for average of precipitation parameters, 2: minimum temperature, 3: maximum temperature, 4 and 5: variation of monthly duration of wet and dry series in the future compared to the base period (Eq. 1), 6: relative variation of the standard deviation related to the average daily temperature for each month in the future compared to the base period (Eq. 2), and 7: absolute variation of light in the future compared to the base period (Eq. 3).

Table 1- Scenario file modified coefficients period 2011-2045

Parameter / Month	[1]	[2]	[3]	[4]	[5]	[6]	[7]
March	1/01	1/01	0/99	0/96	0/99	0/97	1
April	1	1/01	1	1/01	1	1/02	1/01

May	1	1/01	1	1/02	1/02	1	1/01
June	1/01	1/38	1/17	1/01	1	1/01	1/01
July	1/1	1/04	0/99	1	1	1/02	1/01
August	1/01	1/54	1/16	1/01	1/01	1	1
September	1	1/01	1/03	0/98	1	1	0/98
October	1/01	1	1/01	0/89	0/99	1/02	0/97
November	1	0/99	1	1/93	0/98	1/03	0/98
December	1	0/99	1/02	0/94	0/89	1	0/99
January	1	0/99	0/99	2/18	0/97	1/06	1
February	1/01	0/99	1/01	1	0/98	1/03	1

Table 2- Scenario files are modified coefficients for the period 2046-2079

Parameter / Month	[1]	[2]	[3]	[4]	[5]	[6]	[7]
March	1	1/01	1	0/91	0/98	0/97	1
April	1/01	1/01	1	0/98	0/99	1/04	1/02
May	1	1/01	1	1	1	1/01	1/02
June	1/01	1/4	1/17	0/98	0/99	1/02	1/01
July	1/1	1/04	0/98	1	1	1/02	1
August	1/01	1/54	1/16	1	1	1/02	0/99
September	1	1/02	1/02	0/95	0/99	1/03	0/97
October	1/01	1	0/99	0/77	0/98	1/01	0/97
November	1	1	1	1/26	0/92	1/02	0/97
December	1	0/99	1	1/37	0/74	1	0/98
January	1	1/01	0/99	1/43	0/92	1/06	0/99
February	1	1/01	1	1/64	0/97	1/04	0/99

Table 3- Scenario files are modified coefficients period 2080-2100

Parameter / Month		[1]	[2]	[3]	[4]	[5]	[6]	[7]
March		1/01	1/01	1/01	0/85	0/97	1	1/07
April		1/02	1/01	1	0/95	0/98	1/09	1/09
May		1/03	1/01	1	0/97	0/99	1/02	1/07
June		1/04	0/99	1/02	0/98	0/99	1/05	1/03
July		1/05	0/97	0/98	0/98	0/99	0/98	1/01

August		1/06	1	1/02	0/97	0/99	1/05	1/01
September		1/07	1/01	1/01	0/91	0/98	1/06	0/98
October		1/08	0/99	1/01	0/61	0/95	1/04	0/95
November		1/09	1	0/99	2/94	0/87	1/05	0/94
December		1/10	1	1/01	2/75	0/65	0/93	0/97
January		1/11	1/01	1/01	2/99	0/86	1/03	1/01
February		1/12	0/99	1/01	3/42	0/93	1/08	1/04

[1] Relative variation of the average monthly precipitation

[2] Relative variation during dry periods

[3] Relative variation during wet periods

[4] Absolute variation of the average monthly minimum temperature

[5] Absolute variation of the average monthly maximum temperature

[6] Relative variation of the standard deviation related to the average daily temperature

[7] Relative variation of the average monthly light

Numbers of two series (GCM PREDICTIONS and LARS-WG PARAMETERS) are considered as on series in creating the scenario file, and this action is taken for three future time periods as near, middle and distant horizons.

Temperature variation in future periods

Checking the model quality for base period simulation, we created the simulated data for near (2011-2045), middle (2046-2079) and far(distant) (2080-2100) horizons of the future. Tables 5 and 6 and Figures 2, 3, 4 show the comparison between simulated data of the future period and observed data of the base period in Khoramdeh station.

Table 4- Data generation and basis period for the monthly scale Khoramdeh station

	Minimum temperature				Mean temperature				Maximum temperature			
	1	2	3	4	1	2	3	4	1	2	3	4
March	4.92	6.01	7.3	9.24	11.23	11.23	11.23	11.23	17.53	17.53	17.53	17.53
April	8.68	9.91	7.4	14.49	15.44	15.44	15.44	15.44	22.21	22.21	22.21	22.21
May	12.71	13.95	7.5	18.93	20.5	20.5	20.5	20.5	28.29	28.29	28.29	28.29
June	16.06	17.25	7.6	22.48	23.57	24.85	26.93	30.04	31.09	32.45	34.53	37.6
July	15.73	16.35	7.7	21.41	23.69	23.69	23.69	23.69	31.66	31.66	31.66	31.66
August	11.88	12.13	7.8	16.22	20.09	20.31	21.92	24.33	28.31	28.31	28.31	28.31
September	7.26	7.26	7.9	7.26	14.43	14.43	14.43	14.43	21.59	21.59	21.59	21.59
October	2.41	2.41	7.10	2.41	7.98	7.98	7.98	7.98	13.55	13.55	13.55	13.55
November	-2.34	-2.34	7.11	-2.34	2.23	2.23	2.23	2.23	6.8	6.8	6.8	6.8
December	-5.24	-5.24	7.12	-5.24	-0.75	-0.75	-0.75	-0.75	3.74	3.74	3.74	3.74
January	-4.05	-3.51	7.13	-0.8	0.65	1.16	1.96	3.74	5.36	5.83	6.63	8.28
February	-0.06	1.27	7.14	3.92	5.43	6.53	7.53	9.19	10.91	11.8	12.8	14.46

March	4.92	6.01	7.3	9.24	11.23	11.23	11.23	11.23	17.53	17.53	17.53	17.53

Table 5- Data generated and basis period for seasonal and annual scale at Khoramdeh station

	Minimum temperature				Mean temperature				Maximum temperature			
	1	2	3	4	1	2	3	4	1	2	3	4
Spring	8/77	9/96	11/5	14/22	15/72	15/72	15/72	15/72	22/68	22/68	22/68	22/68
Summer	14/55	15/24	17/14	20/04	22/45	22/95	24/18	26/02	30/35	30/81	31/5	32/52
Fall	2/44	2/44	2/44	2/44	8/21	8/21	8/21	8/21	13/98	13/98	13/98	13/98
Winter	-3/12	-2/49	-1/9	-0/71	1/78	2/32	2/91	4/06	6/67	7/13	7/72	8/83
Yearly	5/66	6/29	7/3	9	12/04	12/3	12/76	13/5	18/42	18/65	18/97	19/5

[3] the period1986-2010
[4] the period 2011-2045
[3] the period2046-2079
[4] the period2080-2100

Temperature variation in future periods

Checking the model quality for base period simulation, we created the simulated data for near (2011-2045), middle (2046-2079) and far(distant) (2080-2100) horizons of the future. Tables 5 and 6 and Figures 2, 3, 4 show the comparison between simulated data of the future period and observed data of the base period in Khoramdeh station.

Table 4- Data generation and basis period for the monthly scale Khoramdeh station

	Minimum temperature				Mean temperature				Maximum temperature			
	1	2	3	4	1	2	3	4	1	2	3	4
March	4.92	6.01	7.3	9.24	11.23	11.23	11.23	11.23	17.53	17.53	17.53	17.53
April	8.68	9.91	7.4	14.49	15.44	15.44	15.44	15.44	22.21	22.21	22.21	22.21
May	12.71	13.95	7.5	18.93	20.5	20.5	20.5	20.5	28.29	28.29	28.29	28.29
June	16.06	17.25	7.6	22.48	23.57	24.85	26.93	30.04	31.09	32.45	34.53	37.6
July	15.73	16.35	7.7	21.41	23.69	23.69	23.69	23.69	31.66	31.66	31.66	31.66
August	11.88	12.13	7.8	16.22	20.09	20.31	21.92	24.33	28.31	28.31	28.31	28.31
September	7.26	7.26	7.9	7.26	14.43	14.43	14.43	14.43	21.59	21.59	21.59	21.59
October	2.41	2.41	7.10	2.41	7.98	7.98	7.98	7.98	13.55	13.55	13.55	13.55
November	-2.34	-2.34	7.11	-2.34	2.23	2.23	2.23	2.23	6.8	6.8	6.8	6.8
December	-5.24	-5.24	7.12	-5.24	-0.75	-0.75	-0.75	-0.75	3.74	3.74	3.74	3.74
January	-4.05	-3.51	7.13	-0.8	0.65	1.16	1.96	3.74	5.36	5.83	6.63	8.28
February	-0.06	1.27	7.14	3.92	5.43	6.53	7.53	9.19	10.91	11.8	12.8	14.46
March	4.92	6.01	7.3	9.24	11.23	11.23	11.23	11.23	17.53	17.53	17.53	17.53

Table 5- Data generated and basis period for seasonal and annual scale at Khoramdeh station

	Minimum temperature				Mean temperature				Maximum temperature			
	1	2	3	4	1	2	3	4	1	2	3	4
Spring	8/77	9/96	11/5	14/22	15/72	15/72	15/72	15/72	22/68	22/68	22/68	22/68
Summer	14/55	15/24	17/14	20/04	22/45	22/95	24/18	26/02	30/35	30/81	31/5	32/52
Fall	2/44	2/44	2/44	2/44	8/21	8/21	8/21	8/21	13/98	13/98	13/98	13/98
Winter	-3/12	-2/49	-1/9	-0/71	1/78	2/32	2/91	4/06	6/67	7/13	7/72	8/83
Yearly	5/66	6/29	7/3	9	12/04	12/3	12/76	13/5	18/42	18/65	18/97	19/5

[3] the period1986-2010
[4] the period 2011-2045
[3] the period2046-2079
[4] the period2080-2100

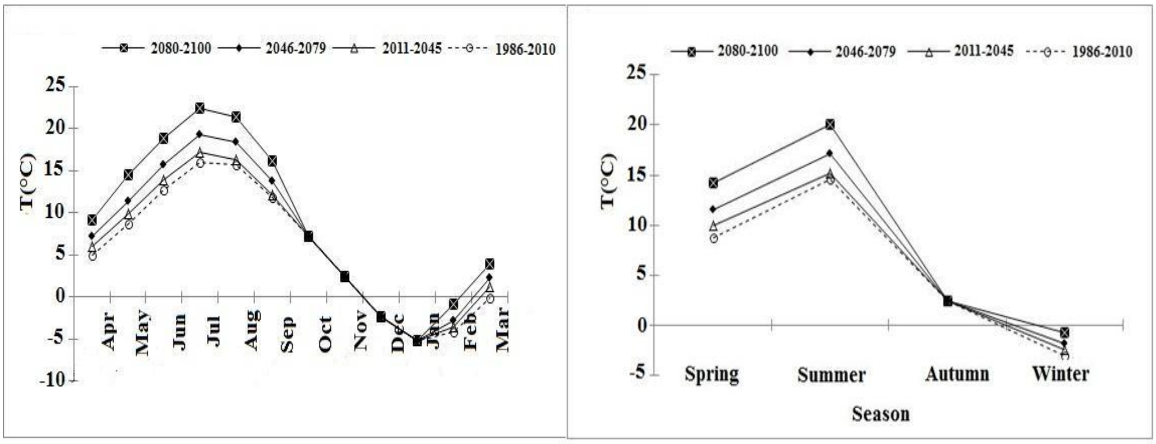

Figure 2- The graph of Observation and prediction of the minimum temperature at the Khoramdeh station

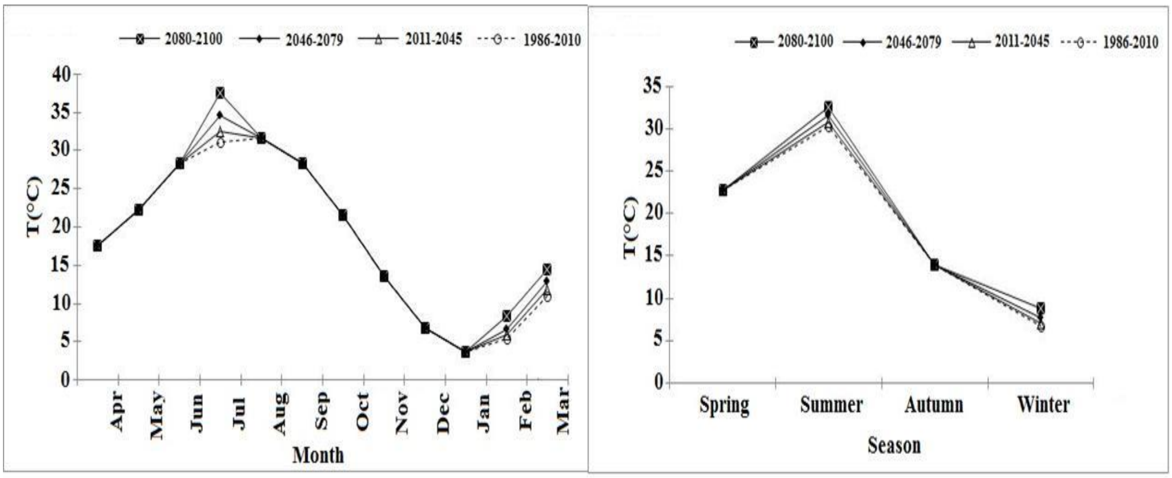

Figure 3- The graph of average temperature observations and predictions at the Khoramdeh station

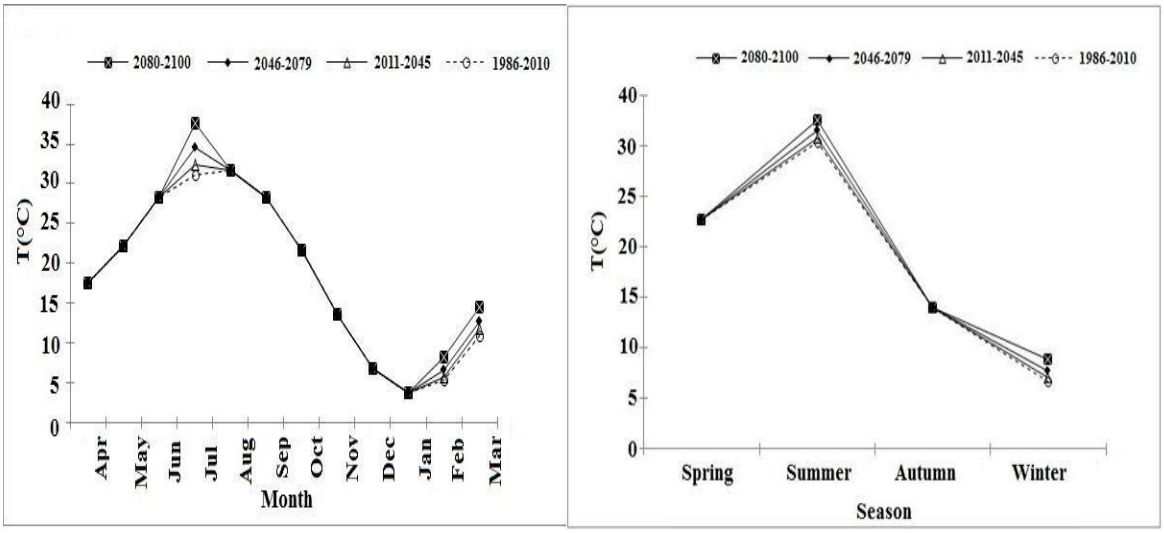

Figure 4- The maximum temperature Observation and predicted graph for the Khoramdeh station

3.1. Calibration of the AquaCrop model

The AquaCrop model is used to evaluate the simulation and yield of the growth period of sorghum in five different cultivation times and four time periods, as present, near, middle, and distant. So, some terms of the model parameters are required. Table 6 presents some of these terms and information. Data from 1986 to 2010 was used for the calibration of the crop file. The simulated biomass growth line of 300 showed a very good fit with the measured growth line (n (normalized for CO2) (RMSE=0.0205, R^2=0.995,d-index= 0.209, NRMSE=0.0615, EF=0.11.Also in the calibration, the parameter values adopted for the canopy cover simulation showed a high tendency throughout crop germination. The relationship between yield response coefficient to irrigation and water stress is shown in Fig(5) for the sorghum's crop, the result show high relationship between yield response and water stress with R^2=1.

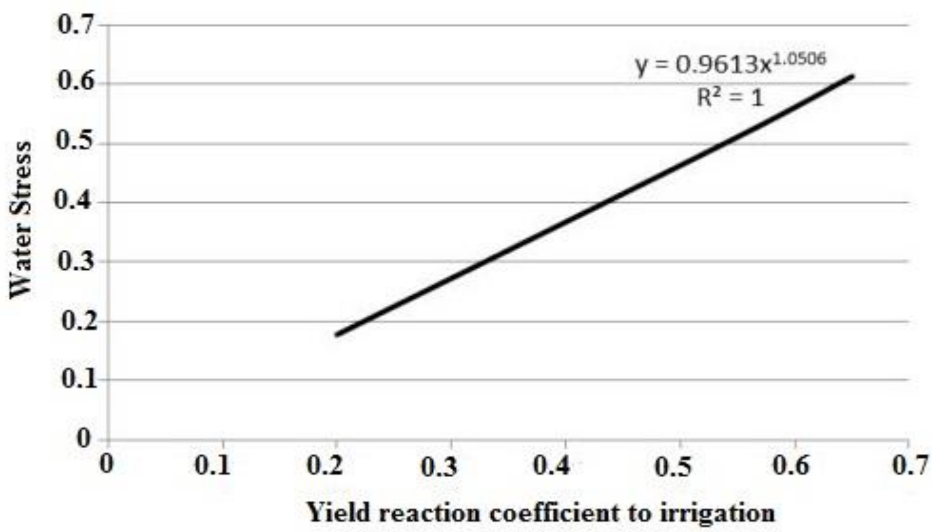

Figure 5 - The relationship between the yield response coefficient to irrigation and water stress of the sorghum crop

Table 6- Cultivation data and some parameters of an AquaCrop plant model.

Parameter	Sorghum
Seed density	Herbs per hectare 10000
Root depth (cm)	100
Kc Tr	0.7
(gr/m^2)* WP	34
Hio (percentage)	237

WP*: water productivity which is normalized and adjusted by reference evapotranspiration and carbon dioxide concentration, Kc_{TR}: transpiration rate, Hi_0: harvest index.

3.2. Time for the cultivation period of crops

Although the time for the cultivation period of sorghum's crops is impressible to temperature and cultivation time variations as well as variations caused by climate change, we entered it according to degree-day in order to have a stable calendar and changing cultivation period. Table 7 shows the time for the cultivation period.

Table 7- Sorghum crop time cultivation in terms of degree-day parameters and time of traditional cultivation

Sorghum crop	Degree-day	Day
Cultivation period	80	10
Germination time	705	60

Processing times of maximum vegetation	1409	107
Processing times of root depth	1500	113
The onset of senility	1700	129
Processing Times of Maturity	880	72
Processing the flowering time	750	52
Productivity Period of time	180	12
Processing times into the flowering period	80	10

3.3. Crop yield simulation

Sorghum's crop yield is simulated by the AquaCrop model. Tables(8and9) and Figure(6) demonstrate the result of crop yield simulation.

Table 8- Sorghum simulation results by the AquaCrop model

	1986-2010					2010-2045				
Time cultivation	April 24	May 4	May 14	May 25	June 4	April 24	May 14	May 4	May 25	June 4
yeild	46/03	46/06	46/01	46/29	40/6	45/68	45/26	45/48	45/49	45/51

Table 9- Sorghum simulation results by AquaCrop model

	2046-2079					2080-2100				
Time cultivation	April 24	May 4	May 14	May 25	June 4	April 24	May 14	May 4	May 25	June 4
yeild	44/07	43/59	43/37	43/22	43/63	41/42	41/26	40/41	39/9	40/32

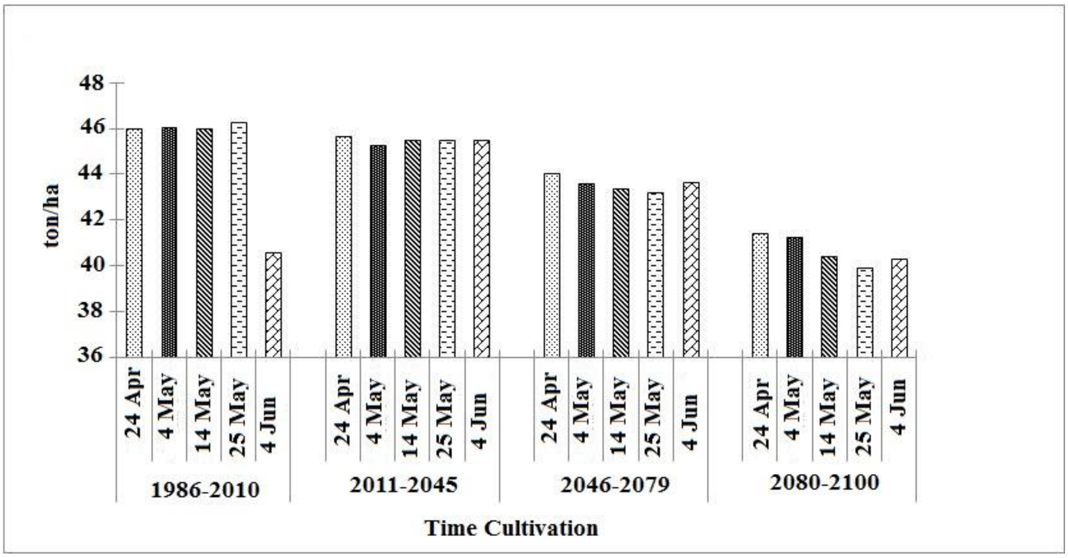

Figure 6- The simulation yield of sorghum cultivation conditions under different times of climate change

Figure 6 shows the sorghum crop yield simulation. The maximum yield is on May 25 at 46.29 tons per hectare and the minimum yield is on June 4 at 40.6 tons per hectare. If we change the traditional cultivation time from May 14 to May 25, an increase of 0.28 tons per hectare will occur. As climate change affects, sorghum's crop yield would decrease. The highest yield will be on April 24 in the future.

Sorghum's crop yield will decrease in the future. Due to temperature increase in the future, the degree-day parameter will increase as well. Moreover, as the plants' thermal requirements are fixed, growth periods will be shortened. As the growth days decrease, the plant is less exposed to light and solar energy. Consequently, food processors, photosynthesis, and the absorption of nutrients and micronutrients from the soil decrease plants' dry weight and cause plants to lose dry weight (Farokhi and Ghorbani Kahriz Sangi, 2012). Furthermore, sorghum's reaction to the increase of carbon dioxide will decrease in the future due to C4 photosynthetic systems. Conversely, the corn will not have a remarkable yield increase due to the increase in carbon dioxide.

4.Conclusion

In this research, in order to model the results of the climate change scenario, first, the time series of monthly temperature and precipitation using the NorESM1-M climate model and the RCP8.5 and RCP4.5 pathway scenarios of data and general circulation models of the historical data (1991-2010) for three The near (2011-2030), middle (2046-2065) and far (2080-2099) horizons were simulated and generated. According to the results obtained in the prediction of minimum, average and maximum temperature, it showed an increasing trend in the region in the future. So that these increased values in the middle horizon will be more than the near horizon and in the far horizon, more than the average horizon compared to the observed historical period. Then, by simulating the yield of sorghum's crop in the study area using the AquaCrop model, it was simulated and estimated in future periods and at different cultivation times. This study considers the observation period of 1991-2010 AD, the near horizon of 2011-2030, the medium horizon of 2046-2065, and the distant horizon of 2080-2099. In order to show the results of the general atmospheric circulation simulation model from the LARS-WG software and the NorESM1-M model, the RCP.8.5 scenario was chosen from among the two mentioned scenarios. According to the obtained results, the highest yield is cultivated on September 27 with 4.64 tons per hectare and the lowest yield is produced on September 16 with 0.65 tons per hectare. If we change the traditional cultivation time from October 7 to September 27, a 0.15 tons per hectare growth will be seen. Therefore, the experts and planners of the agricultural sector must pay attention to the issue of risk management, so that by adopting appropriate policies, on the one hand, they reduce the risk for farmers' production, and on the other hand, appropriate solutions such as climate change forecasts and adapt to it in order to adjust the fluctuations caused by the effects of climate change. It is suggested that, in future studies, the parameters of wind speed and relative humidity should be calculated using the SDSM model. Plant modeling (AquaCrop) should be investigated on other crops such as potatoes, barley, legumes and garden crops. Due to the inappropriate allocation of water resources in the region's agricultural sector, a study should be conducted in line with the optimal allocation of water resources. In order to deal with the effects of climate change, it is necessary to design a suitable cultivation pattern compatible with the economic and climatic conditions of the region. The AquaCrop model was able to simulate biomass with acceptable accuracy under both irrigation practices, but the simulated results were observed to be slightly better suited to full irrigation practices. Full irrigation practices compensate for any lack of water from precipitation, which enables the model to quantify results with reasonable certainty. Also, the result showed that AquaCrop can estimate soil moisture with acceptable precision. The soil water content was reasonably simulated, albeit simulated values tended to have greater variability than observed value.

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