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Impact assessment of climate change on yield of wheat crop by using aqua crop model: A case study for Pilibhit district, Uttar Pradesh, India

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Abstract
Climate change has become very important for farming sector in Pilibhit region. The study was conducted to analyze the wheat crop yield at Pilibhit district. Thirty years (1990-2019) of seasonal climatic data of temperature, rainfall, evapotranspiration while twenty years (2000-2019) of data wheat yield was analyzed to find the trend of climatic variable at the district. The calibrated AquaCrop model has simulated the wheat yield ranging from 4.182 to 4.496 t/ha from the year 2016-2018.

Keywords: AquaCrop, climate, water productivity, yield, Pilibhit

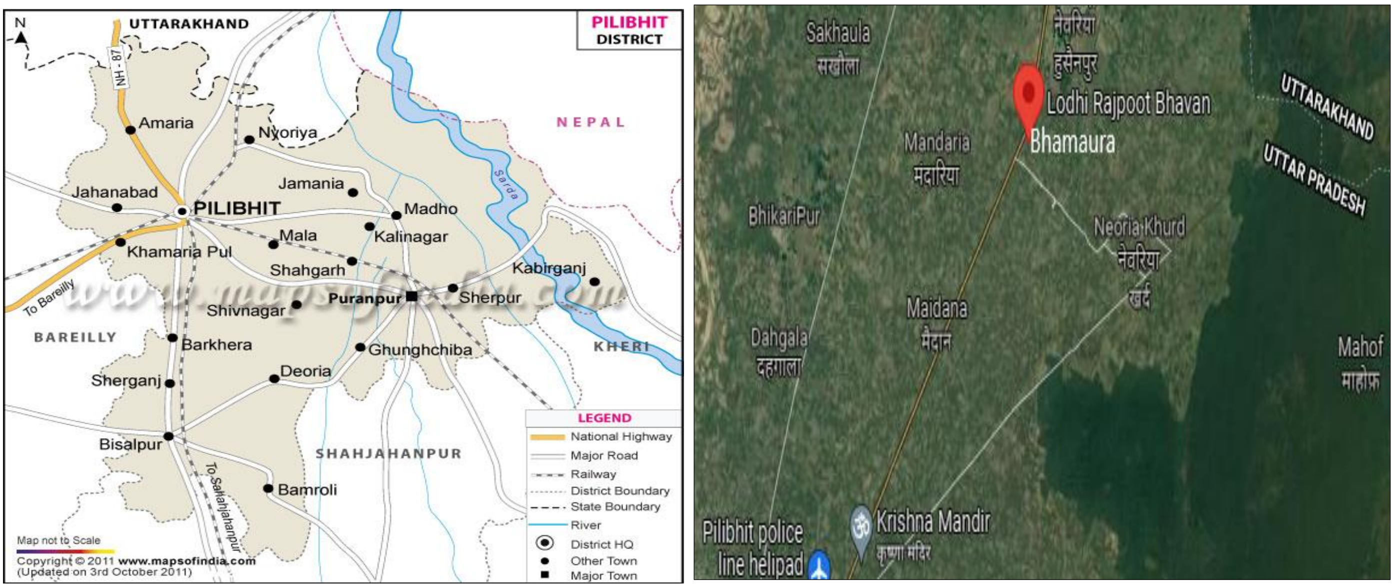
1. Introduction

Climate change threatens global food security, making it one of the most severe concerns of the twenty-first century to feed a growing population while preserving an already stressed ecosystem. Changes in temperature and precipitation as a result of global climate change could have a significant impact on hydrologic processes, water availability, and irrigation water demand, influencing agricultural production and productivity (Kang *et al*., 2009) [5]. Wheat is a winter crop. Wheat requires cool temperatures for vegetative development, and warmer conditions at maturity are considered optimum. Wheat growth requires a minimum temperature of 3-4 °C, an optimal temperature of 25 °C, and a maximum temperature of 30-32 °C. Climate elements such as solar radiation, precipitation, and temperature have a significant impact on crop growth, development, and grain yields (Qian *et al*., 2008) [10]. Wheat (Triticum aestivum), which grows on 200 million hectares of farmland globally (http://www.fao.org), provides around 21% of the world's food. Singh *et al*., (2013) [14] stated that the AquaCrop model explains how water affects crop productivity and is a useful tool for improving farm-level water management and maximizing water efficiency. In simulating wheat yields with full irrigation, AquaCrop achieved good agreement. Several crops, including cotton, maize, wheat, sun flower, tomato, and potato, were simulated using the Aquacrop model. On a daily time step, AquaCrop models the soil water balance and crop growth processes as a function of crop, soil, weather, and management input data. AquaCrop also directly mimics soil evaporation and crop transpiration as separate processes. Jensen (1981) defined irrigation scheduling as "a planning and decision-making activity that the farm manager or operator of an irrigated farm is involved in for each crop that is grown before and during the majority of the growing season." Irrigation schedule is critical for increasing water productivity. Climate change may have a negative impact on water supply and distribution. A crop's potential crop evapotranspiration (ETc) is the amount of water it needs to meet its evapotranspiration needs. The crop irrigation water need is equal to potential crop evapotranspiration (ETc) minus effective rainfall. Wheat, as a winter cereal, requires certain environmental conditions for emergence, growth, and flowering and is more vulnerable during reproductive periods when exposed to high temperatures. In the context of extreme event effects on crop processes for climatic impacts studies, outlining the general effects of climatic variability and temperature extremes on wheat yields (Porter and Gawith (1999) [9]. SR *et al*., (2019) [15] Changes in important climate factors such as temperature, precipitation, and humidity could have long-term consequences for water quality and quantity. Climate change, such as fluctuation in monsoon rainfall and temperature changes within a season, affect food production in India. AquaCrop To develop and assess different deficit irrigation strategies, identify various environmental and management strategies, separate evaporation and transpiration from evapotranspiration to assess beneficial use of water by crops, and aid decision-making for improved irrigation and cultivation management, a combination of field experimentation and analysis based on crop water productivity models can be helpful. AquaCrop's simplicity and adaptability for application in regions where extensive datasets may be unavailable are confirmed by the relatively acceptable simulations produced by the minimum data input calibration. Because of the biomass and yield overestimation caused by using the minimum data input calibration, further parameters (water productivity, canopy sensitivity to water stress, and water stress coefficient) are needed to improve sorghum genotype canopy and yield predictions.

2. Material and Methods

2.1 Study Area

Pilibhit is a district of Uttar Pradesh state. While Pilibhit is the north-easternmost district of Bareilly division, situated in of the sub-Himalayan Plateau belt next to foothills of Sivalik Range on the boundary of Nepal, known for the origin of river Gomati and one of the most forest-rich areas in North India. It lies between the parallels of 28°6′ and 28°53′ north latitude and the meridians of 79°57′ and 80°27′ east longitude. Pilibhit district in the soil of mainly made up of transported and deposited material of aluminum dominated rocks of Tarai region having pH 7.0 to 8.1. Pilibhit district is total geographical area is 377775 ha, with a net cultivated area of 235092 ha. The total irrigated area is 2.25 lakh ha. Irrigation covers 96 percent area of the land. Normal rainfall is 1256 mm and temperature between 4.5 to 47.0 °C in Pilibhit district. Bhamaura is a village panchayat located in the Pilibhit district of Uttar-Pradesh state, India.



Source: https://www.mapsofindia.com/maps/uttarpradesh/districts/pilibhit.htm

Fig 1: Geographical map of Pilibhit district

2.2 Data Collection

Present study is based on the secondary data and data related to the climate etc. We are collecting two types of data primary and secondary data. Primary data is related to the crop, type of soil, crop, production, irrigation and yield of crops is collected by farmer.

Table 1: Primary data collection of wheat crop at Pilibhit

Crop Name	Wheat (*Triticum aestivum* L.)
Soil Type	Sandy Loam
Variety	PBW-343
Duration	150 Days
Seed Rate	120 kg/ha
Date of sowing	1st November 2018
Method of sowing	Broadcasting
Rooting Depth	1-1.2 (m)
Growing stage	Germination Tillering (after 20-25 days) Stem Elongation (after 25-50 days) Flowering (after 50-75 days) Ripening (after 75-100 days)
Method of irrigation	Border irrigation
Irrigation scheduling	1st irrigation after 20-25 days of sowing
Source of Irrigation	7 H.P. Submersible Pump
Date of Harvesting	30th March 2019
Production of last year	4.2 t/ha
Total wheat cultivable land in Pilibhit	148303 ha

2.2.1 Secondary Data

Secondary data is related to the climate required for the crop such as temperature, wind speed, relative humidity, precipitation and shortwave radiation etc. It will be taken from (https://power.larc.nasa.gov/data-access-viewer/) in the form of daily from 1990 to2019. The wheat crop yield data for the year 2000 to 2019 was collected from crop production statistics for Pilibhit district (https://aps.dac.gov.in/APY/Public_Report1.aspx).

2.3 Analysis of Data

A large number of tests are performed for trend detection of long term time series of meteorological and hydrological records. For the detection of significant trends in climatologic time series these tests can be classified as parametric and non-parametric methods. Parametric trend tests require data to be independent and normally distributed, while non-parametric trend tests require only that the data be independent. In this study, non-parametric methods were used to detect the trend, its magnitude and shift. Following non-parametric tests are mostly used for trend analysis of temperature time series.

2.3.1 Statistical Analysis

In the statistical analysis for the calculation data of Mean, Standard deviation, Covariance, Correlation of climatic parameter and observed yield.

Mean

It is the sum of a collection of numbers divided by the count of numbers in the collection. The collection is often a set of results of an experiment or an observational study, or frequently a set of results from a survey.

$$\bar{X} = \frac{\sum X}{N} \qquad \text{.... eq. (1)}$$

Standard Deviation

The standard deviation of a random variable, sample, statistical population, dataset, or probability distribution is the square root of its variance.

$$\text{SD} = \frac{\sqrt{\sum(X-X)^2}}{N-1} \qquad \text{…. eq. (2)}$$

Covariance

In probability theory and statistics, covariance is a measure of the joint variability of two random variables.

$$\text{Cov (x,y)} = \frac{\sum(X_i - x)(Y_i - Y)}{N-1} \qquad \text{…. eq. (3)}$$

Correlation

Correlation is a statistical measure that expresses the extent to which two variables are linearly related.

$$\text{Cor (x,y)} = \frac{n(\sum xy)-(x)\sum y)}{\sqrt{[n\sum x^2-(\sum x)^2]\,[n\,\sum y^2-(\sum y)^2]}} \qquad \text{…. eq. (4)}$$

2.4 FAO AquaCrop Model Description

The complexity of crop response to water deficits led to the use of empirical production functions as the most practical option to asses crop yield response to water among the empirical function approaches**,** FAO Irrigation and Drainage Paper n. 33 (Doornbos and Kassam, 1979) represented an important source to determine the yield response to water of field, vegetable and tree crops, through the following equation.

$$\left(\frac{Y_x - Y_a}{Y_x}\right) = k_y \left(\frac{ET_x - ET_a}{ET_X}\right) \qquad \text{….. eq. (5)}$$

Where, Yx and Y are the maximum and actual yield, ETx and ET are the maximum and actual evapotranspiration and Ky is the proportionality factor between yield loss and reduction in evapotranspiration.

The actual evapotranspiration (ET) in to soil evaporation (E) and crop transpiration (Tr):

$$\text{ET = E+Tr} \qquad \text{…. eq. (6)}$$

The final yield (Y) into biomass (b) and Harvest Index (HI):

$$\text{Y = B x HI} \qquad \text{…. eq. (7)}$$

The changes described leads to the following equation at the core of the AquaCrop growth engine:

$$\text{B = WP} \sum T_r \qquad \text{…. eq. (8)}$$

Where Tr is the crop transpiration (in mm) and WP is the water productivity. Estimation of crop water productivity (WP).

$$\text{CWP} = \frac{Y}{ET} \qquad \text{…. eq. (9)}$$

2.4.1 Input Data in FAO AquaCrop model

The following data were collected from January 1990 to December 2019 for the period of crop growing season October to April.

2.4.2 AquaCrop 6.1 Model Calibration

The calibration involved fine-tuning then on conservative parameters for the wheat crop. Table presents conservative and non-conservative values derived from the experiment. Other input parameters were minimum rooting depth at 95% emergence (5 cm) and maximum rooting depth at harvesting. The calibration involved adjusting the non-conservative parameters harvest index, initial canopy cover, and canopy growth coefficient until the simulated crop canopy cover, biomass, and yield closely matched the observed data.

Table 2: Conservative and Non-conservative parameter of wheat crop

Parameter	Input Value
Climatic parameter	Temperature (Max. and Min.), Relative humidity, solar radiation, rainfall, wind speed all climatic parameter value monthly mean of 1990-2019.
Crop sowing timing	01st Nov 2018
Seed rate	120 kg/ha
Plant density	5 cm square/plant
Emergence	7 days after sowing
Maximum canopy cover	85% after 70 days of sowing
Flowering	80 days after sowing
Maximum rooting depth	1.0 m 70 days after sowing
Simulation period	150 days (1st November 2018 to 30th March 2019)
Irrigation method	Border method
Soil profile	Sandy loam Number of horizon (1) Thickness 1.5 m
Harvest index	50%

2.4.3 AquaCrop6.1 Model Validation

Model validation was based on data obtained from field experiments. Model performance was evaluated using the following statistical parameters:

(a) Prediction of Error

$$Pe = \frac{(S_i - O_i)}{O_i} \times 100 \qquad \text{.....eq. (10)}$$

Where, S_i and O_i are observed and simulated values.

(b) Root Mean Square Error Normalized

$$RMSEN = \frac{1}{O}\sqrt{\frac{\Sigma(S_i - O_i)}{N}} \times 100 \qquad \text{.....eq. (11)}$$

Where, S_i and O_i are the observed and simulated yield and N is the no of year.

(c) Mean Absolute Error

$$MAE = \sqrt{\Sigma_{i=1}^{N}\frac{(S_i - O_i)}{N}} \qquad \text{.....eq. (12)}$$

Where, S_i and O_i are the observed and simulated yield and N is the no of year.

Prediction error, RMSEN and MAE approach zero, they represent positive indicators of model performance. The simulation is considered excellent if RMSEN is less than 10%; it is good if it comes between 10% and 20%; reasonable when it comes between 20% and30%; and poor when it is greater than 30.

3. Results and Discussion

3.1 Statistical analysis of seasonal climatic parameter and wheat yield

Table 3 Shows the analysis of data shows that in past 30 years the seasonal maximum temperature and seasonal minimum temperature shows that there is a variation of 9.948 ºC and 7.448 ºC in maximum and minimum temperature values in crop season November to March with a mean of 26.759 ºC and 12.106 ºC, and standard deviation of 3.956 ºC and 3.067 ºC and covariance of 0.147 ºC and 0.253 ºC from 1990-2019 respectively. The analysis of data shows that in past 30 years the seasonal precipitation shows the variation of 28.164 mm and 3.711 mm in maximum and minimum precipitation values with a mean of 15.466 mm and standard deviation of 9.272 mm and covariance of 0.599 mm from 1990-2019 respectively. The seasonal evapotranspiration shows that there is a variation of 5.3 mm and 2.4 mm in maximum and minimum potential evapotranspiration values in crop season November to March with a mean of 3.28 mm and standard deviation of 1.207 mm and covariance of 0.368 from 1990-2019 respectively.

The analysis of data shows that in past 20 years the wheat yield has also shows high variation from lowest of 2.57 t/ha in year 2015 followed by 4.44 t/ha in year 2019 with a mean of 3.524 t/ha and standard deviation of 0.468 t/ha and covariance of 0.132 t/ha from 2000-2019 respectively.

Table 3: Statistical analysis of seasonal climatic parameter and wheat yield

Climatic parameter	Maximum	Minimum	Mean	S.D.	Covariance
Seasonal of Max Temperature (°C)	32.942	22.994	26.759	3.956	0.147
Seasonal of Min Temperature (°C)	16.11	8.662	12.106	3.067	0.253
Seasonal of Precipitation (mm)	28.164	3.711	15.466	9.272	0.599
Seasonal of ETo (mm)	5.3	2.4	3.28	1.207	0.368
Yield (t/ha)	4.44	2.57	3.524	0.468	0.132

3.2 Seasonal of climatic variable at Pilibhit region

Figure 2 shows seasonal mean maximum temperature & mean minimum temperature from 1990-2019 at Pilibhit region. In this figure it is observed that there is low variation in maximum temperature from January (1990-2019) which high variation in maximum temperature from March 1990-2019.

The analysis of data shows that in past 30 years the seasonal maximum temperature of mean is 26.759 °C, standard deviation is 3.956 °C and covariance 0.147 °C. In this figure it is observed that there is low variation in minimum temperature from January 1990-2019 which high variation in minimum temperature from March 1990-2019. The analysis of data shows that in past 30 years the seasonal maximum temperature of mean is 12.106 °C, standard deviation is 3.067 °C and covariance 0.253 °C.

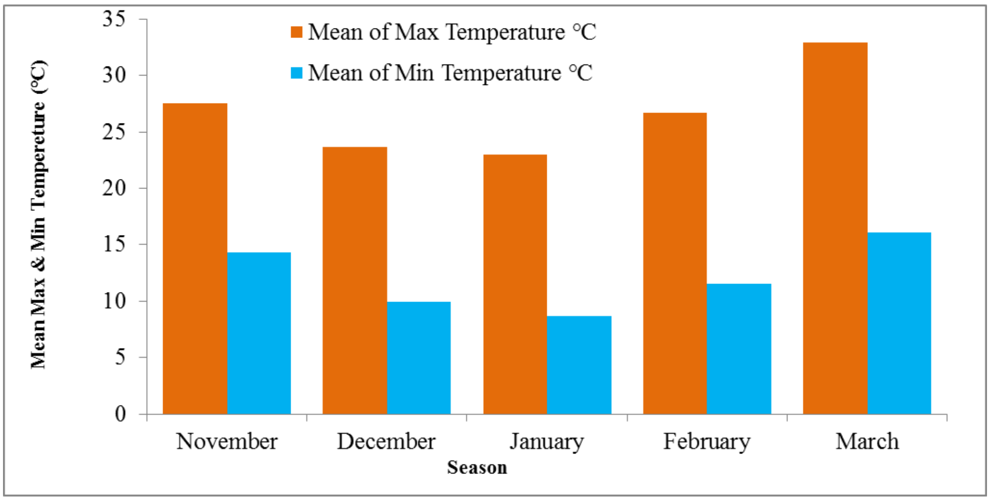


Fig 2: Seasonal Max Temperature & Min Temperature from 1990-2019 at Pilibhit region

Figure 3 shows seasonal mean precipitation data from 1990-2019 at Pilibhit region. The lowest seasonal precipitation 3.711 mm in November 1990-2019 and highest seasonal precipitation 28.164 mm in February 1990-2019. The analysis of data shows that in past 30 years the seasonal precipitation of mean is 15.466 mm, standard deviation is 9.272 mm and covariance is 0.599 mm.

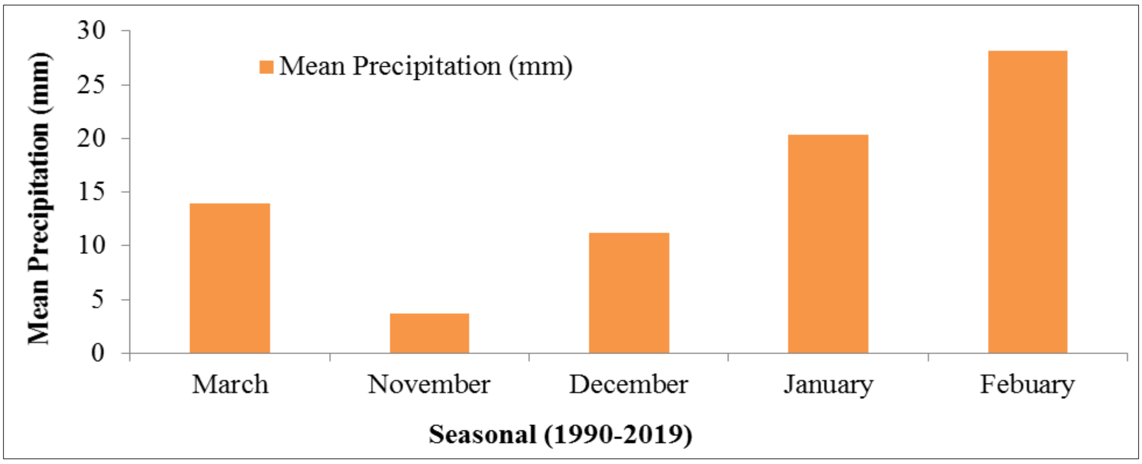


Fig 3: Seasonal Precipitation data from 1990-2019 at Pilibhit region

Figure 4 shows seasonal mean evapotranspiration from 1990-2019 at Pilibhit region. The lowest seasonal evapotranspiration 2.4 mm in December 1990-2019 and highest seasonal evapotranspiration 5.3 mm in March 1990-2019. The analysis of data shows that in past 30 years the seasonal evapotranspiration of mean is 3.28 mm, standard deviation is 1.207mm and covariance is 0.368 mm.

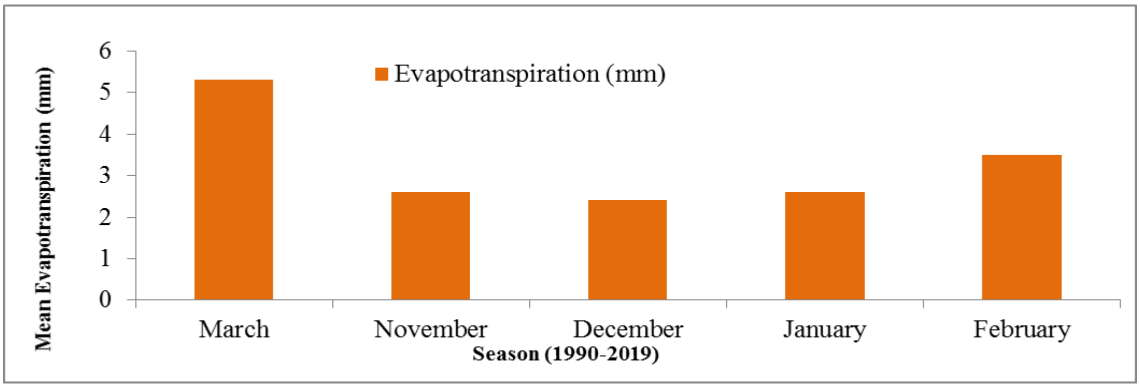


Fig 4: Seasonal Evapotranspiration from 1990-2019 at Pilibhit region

Figure 5 shows yearly wheat crop yield from the year 2000-2019 at Pilibhit region. The lowest wheat yield 2.57 t/ha in year 2015 and highest wheat yield 4.44 t/ha in year 2019. The analysis of data shows that in past 20 years, the wheat yield of mean is 3.524 t/ha, standard deviation is 0.468 t/ha and covariance is 0.132 t/ha.

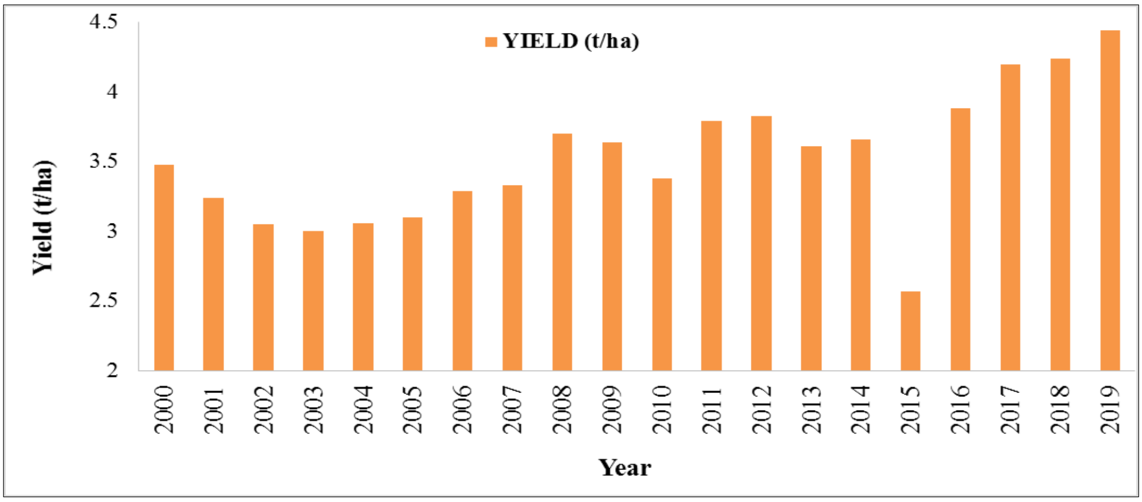


Fig 5: Yearly Trend Wheat Crop Yield from the year 2000-2019 at Pilibhit region

3.3 Trend test of seasonal climatic parameter at Pilibhit region

Trend Analysis of Pilibhit district has been done with 30 years maximum temperature, minimum temperature, precipitation data from 1990-2019.

Fig 6 represents seasonal mean maximum temperature for the study period. Fig 6 revealed that the hottest year 1990-2019 in the season month is March with a correlation (R^2) of 0.0027 °C while the coldest year 1990-2019 in the season month is January with a correlation (R^2) of 0.22 °C.

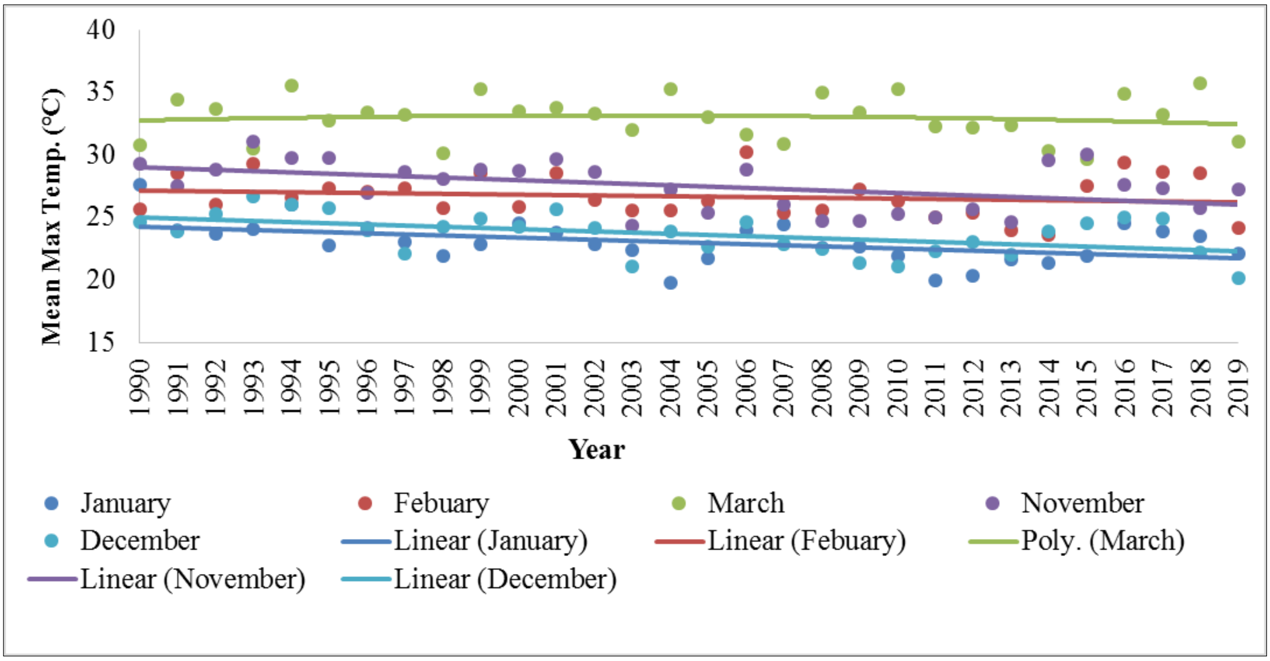


Fig 6: Seasonal Mean Maximum Temperature Trend (°C) from Nov, Dec, Jan, Feb, March year 1990 to 2019

Fig 7 represents seasonal mean minimum temperature for the study period. Fig 7 revealed that the hottest year 1990-2019 in the season month is March with a correlation (R^2) of 0.0162 °C while the coldest year 1990-2019 in the season month is January with a correlation (R^2) of 0.1247 °C.

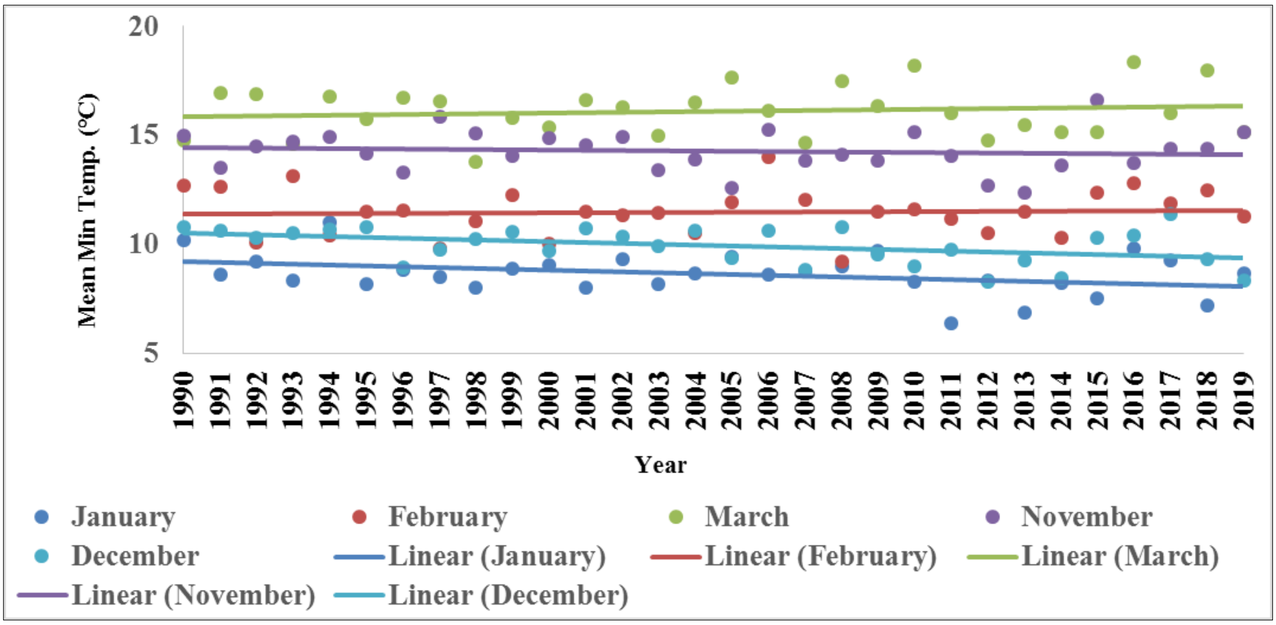


Fig 7: Seasonal Mean Minimum Temperature Trend (°C) from Nov, Dec, Jan, Feb, March year 1990 to 2019

Fig 8 represents seasonal mean precipitation for the study period. Fig 8 revealed that the highest year 1990-2019 in the season month is February with a correlation (R^2) of 8E-05 (mm) while the lowest year 1990-2019 in the season month is November with a correlation (R^2) of 0.0117 mm.

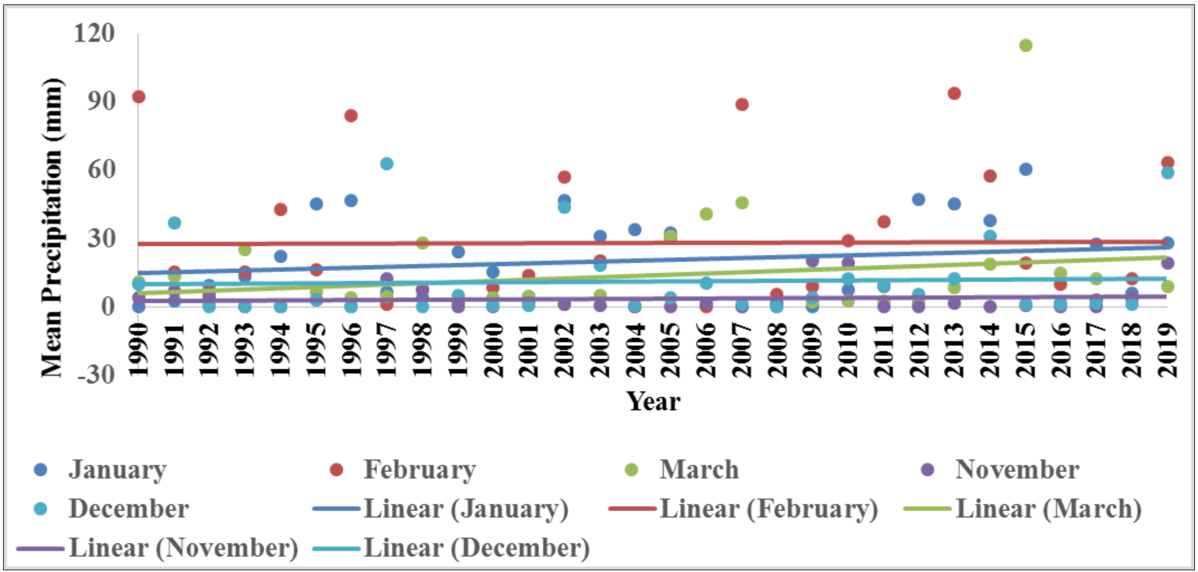


Fig 8: Seasonal Mean Precipitation Trend (°C) from November to March from 1990 to 2019

3.4 AquaCrop model to schedule irrigation for optimum yield of wheat crop

3.4.1 Model Calibration

The observed collected wheat seasons (2012–2014) were used for model calibration, and the validation was conducted for the last three wheat seasons (2016–2018). The wheat season included the measured moisture contents for a soil depth of 1.0 m. The model was calibrated against observed CC, above ground biomass and grain yield from the field experiment during 2012-2014. We elected to run the model separately for each replicate since there was a slight variation in the amount of applied irrigation water as shown in Table 4 as well as the day at which maturity was reached, CC and biomass production. The calibrated model was subsequently validated against the experimental results from the 2016–2018 seasons using the same model parameterization.

Table 4: The rainfall amount, above ground biomass, grain yield, HI under different water treatments during the 2012 to 2014

Year	Actual Yield (t/ha)	Calibrated Yield (t/ha)	Biomass (t/ha)	ETo (mm)	Rainfall (mm)	Net Irrigation Requirement (mm)	Harvest Index (%)	Canopy Cover (%)
2012	3.83	3.953	13.175	416.3	153.3	152.1	30	85
2013	3.61	3.836	12.786	366.9	128.5	105.2	30	85
2014	3.66	4.243	14.142	487.5	224.8	160.2	30	85

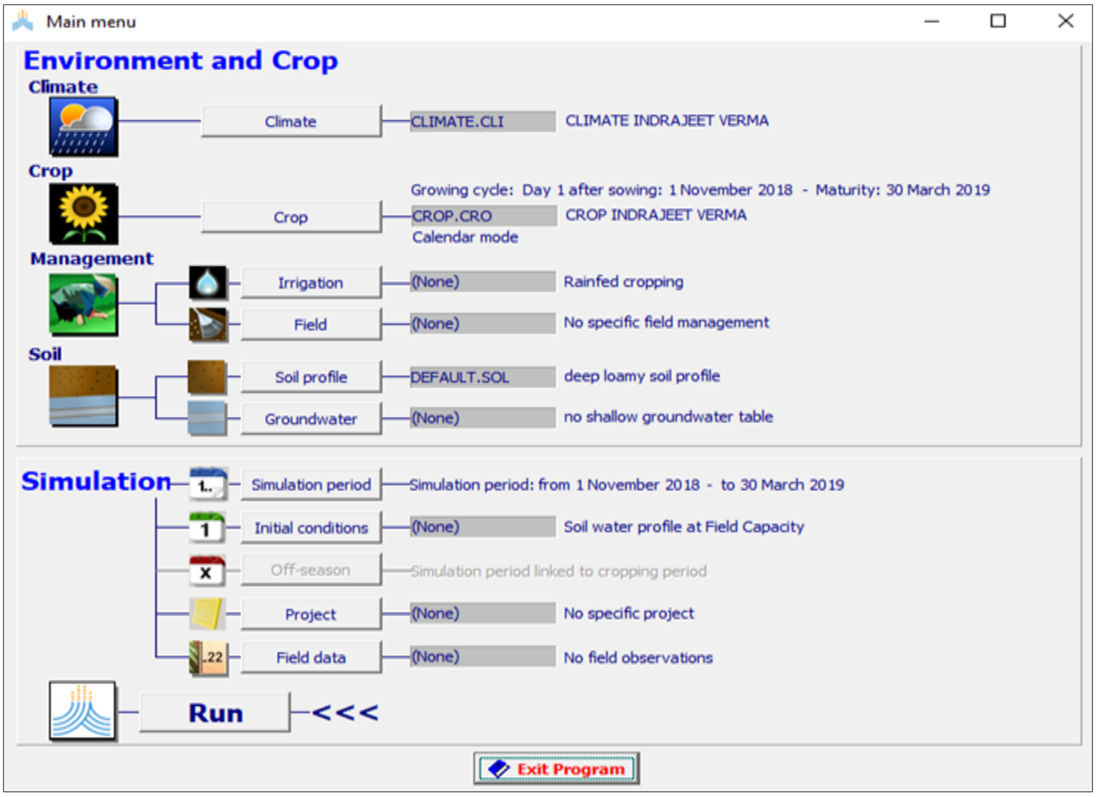


Fig 9: Overview of input data in FAO AquaCrop model

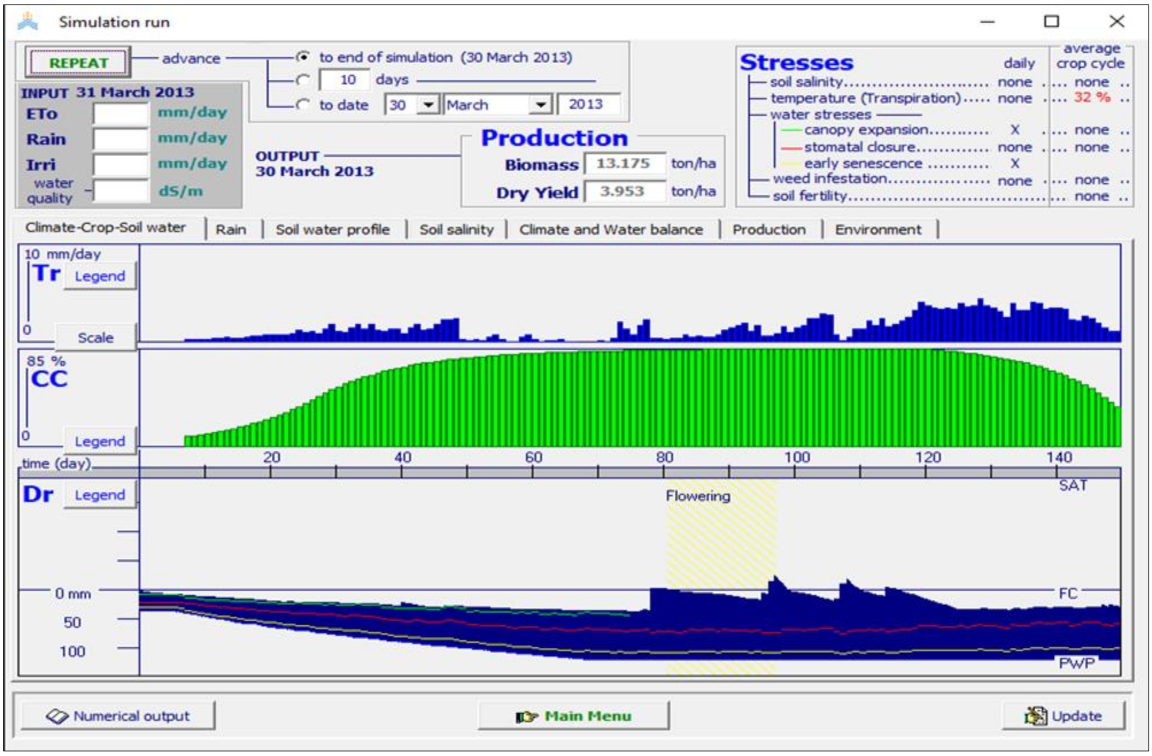


Fig 10: Calibrated result of wheat yield 2012

3.4.2 Model Simulation

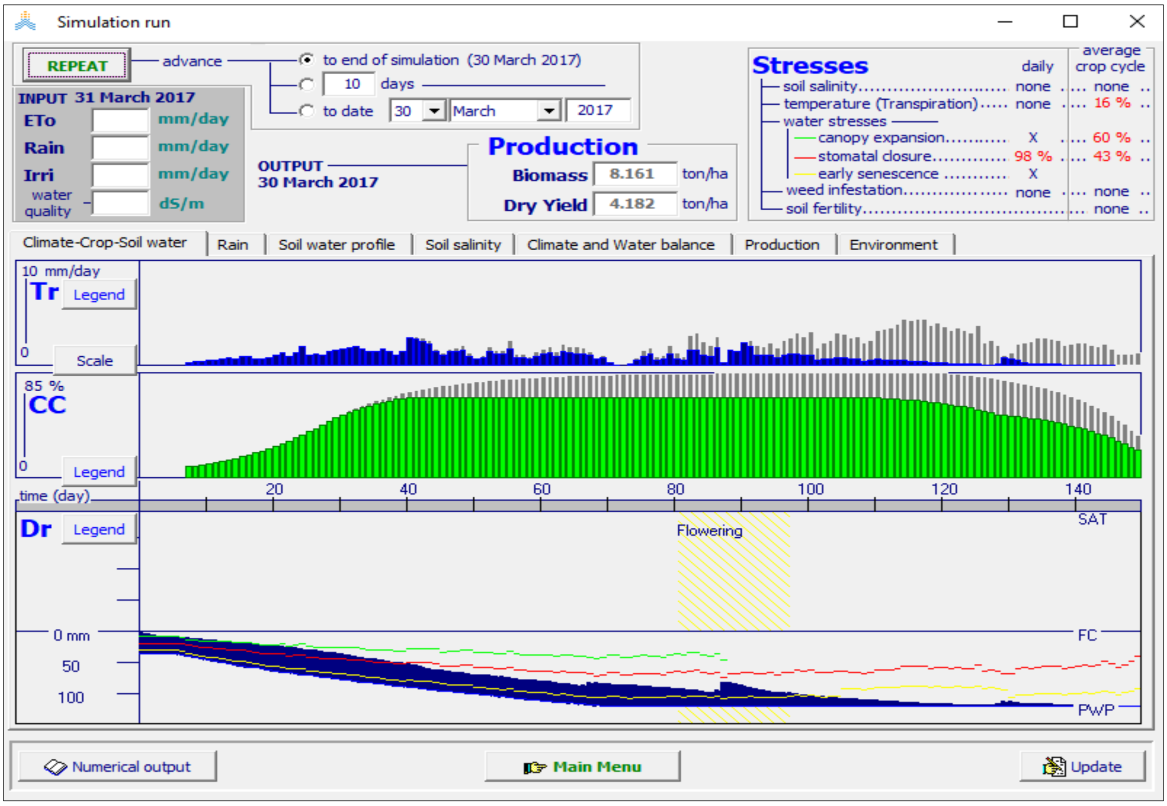


Fig 11: Simulated result of wheat yield of 2016

Table 5 shows the simulated results of aquacrop and prediction error. The simulated values were found to be in close conformity of observed values. A continuous increase in both observed and simulated yields were observed from the year 2016 to 2018. The observe value of shows that these are continuous increasing. Rainfall followed by evapotranspiration and maintained the sufficient moisture in the soil causing increase in yield with schedule irrigation supply.

Table 5: Simulated result of FAO Aquacrop model time period from 2016 to 2018

Year	Actual Yield (t/ha)	Dry Yield (t/ha)	Biomass (t/ha)	ETo (mm)	Rainfall(mm)	Harvest Index (%)	Canopy Cover %)
2016	3.88	5.720	12.268	528.2	44.1	50	85
2017	4.20	5.278	11.449	536.1	24.6	50	85
2018	4.24	7.058	14.133	390.1	105.8	50	85

Table 5 inputs were combined with the observed yield and simulated yield at 6.3% of prediction error for wheat yield simulations, the sowing date was fixed as 01st November, and the AquaCrop irrigation module generated an automatic irrigation schedule with no water stress. Temperature, rainfall and the atmospheric CO2 concentration are the key determinants of crop yield responses to future climate change. Previous experimental evidence suggested that CO2 enrichment could mitigate the climate warming threats of crop yield reduction. Wheat yield and ET, net irrigation water requirements (NIWR) were also simulated for future climate change scenarios, with and without the inclusion of CO2 enrichment effects. The simulated data were validating for the year 2016 to 2018. The independent data set from the 2016 to 2018 growing season was used to validate the model. Table 5 shows that model validation data from the year 2016 to 2018. The simulated yield has shown in Table 5 with prediction error highest observed yield was 4.24 t/ha in year 2018 and lowest observed yield was 3.88 t/ha in year 2016. The variation was found 0.36 t/ha. Similarly the highest simulated yield was 4.496 t/ha in year 2018 and lowest simulated yield was 4.182 t/ha in year 2016. The variation was found 0.314 t/ha. The final simulation of the AquaCrop model are presented in table observed value and simulated value close for wheat growth during the simulation period at Pilibhit. By (Sandhu & Irmak, 2019), it shows the same variation between observed and simulated yield respectively.

The observed grain yield with RMSE and MAE of 7.41% and 0.287 t/ha in year 2016, respectively Table 5 Model performance was evaluated in terms of prediction error (Pe), coefficient of determination (R^2), the normalized root mean square error (NRSME), the Nash–Sutcliffe model efficiency coefficient (EF) and Willmott's index of agreement (d).

Table 6 shows the validation results of simulated and observed yields. It was observed total yield at all the validated year 2016-2018 in close conformity and the Pe, RMSEN and MAE values are well within the limits.

Table 6: Observed yield and simulated yield at % of prediction error for wheat yield simulations of year 2016 to 2018

Year	Observed Yield (t/ha)	Simulated Yield (t/ha)	Pe (%)	RMSEN (%)	MAE (%)
2016	3.88	4.182	6.391	7.410	0.287
2017	4.20	4.344	3.428	5.216	0.219
2018	4.24	4.496	6.037	6.889	0.292

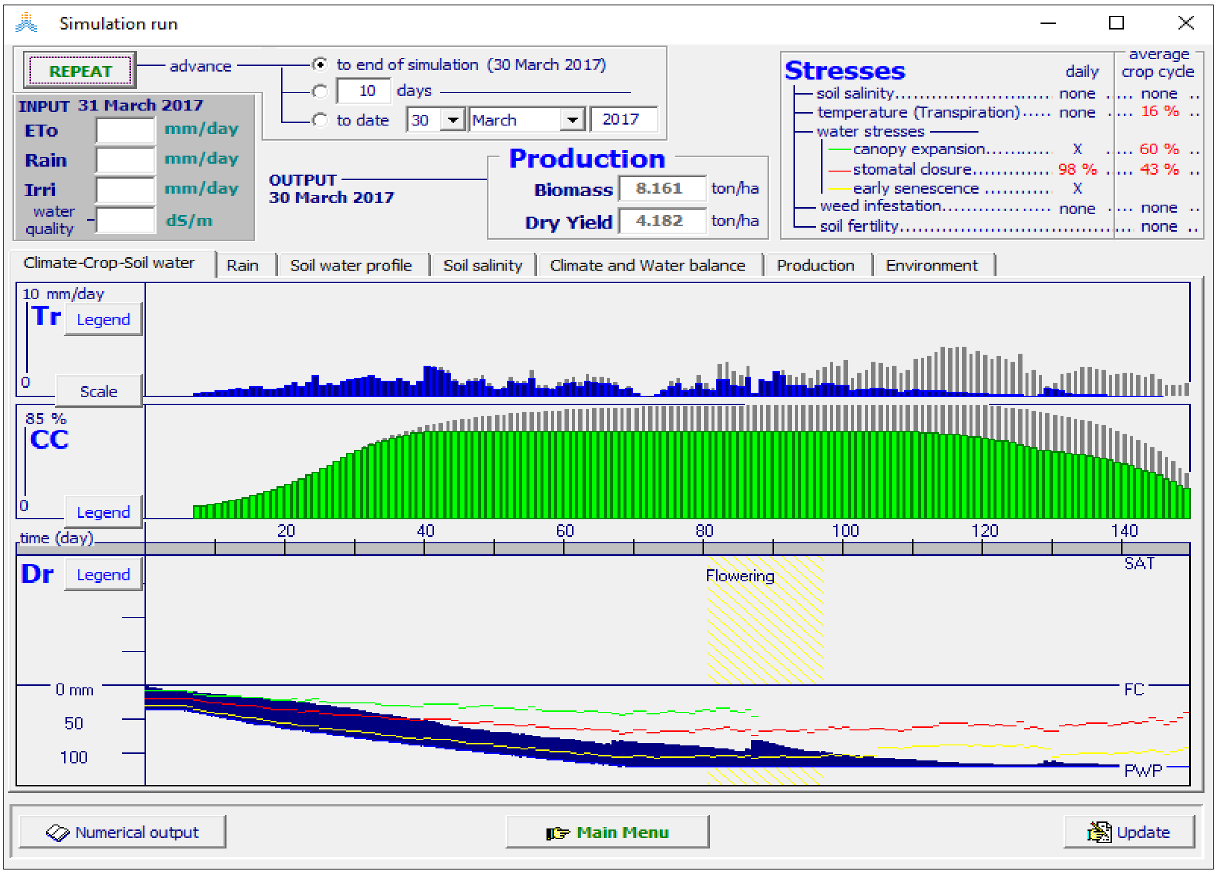


Fig 12: Simulated result of wheat yield of 2016

3.5 Validated the Model
The model was validated against field data collected from the year 2016 to 2018, using the parameterization calibrated on data from 2012 to 2014. The measured and simulated yield and observed yield for the validation season are shown in Table 5**.** The AquaCrop model showed robust performance in the validation. This pattern follows what was observed during calibration, although there is no noticeable difference between the degrees of overestimation of grain yields. The observed differences are acceptably small, and support the good statistical metrics presented in Table 5 Their study also noted the potential effects of imperfect manual harvesting in leaving some of the biomass on the ground inadvertently, thereby reducing the 'observed 'total yield. Despite every effort to prevent that, our study could also have been affected by imperfections in the field assessment of biomass and final grain yield. Recurring reports on slight overestimations in biomass or yield may strengthen the suspicion that imperfect field data collection may indeed be at least partly behind the overestimations.

The fig 12 shows that simulated and observed wheat yield has positive correlation of 0.8 and the model can be well adopted for prediction of yield at an estimated net irrigation schedule.

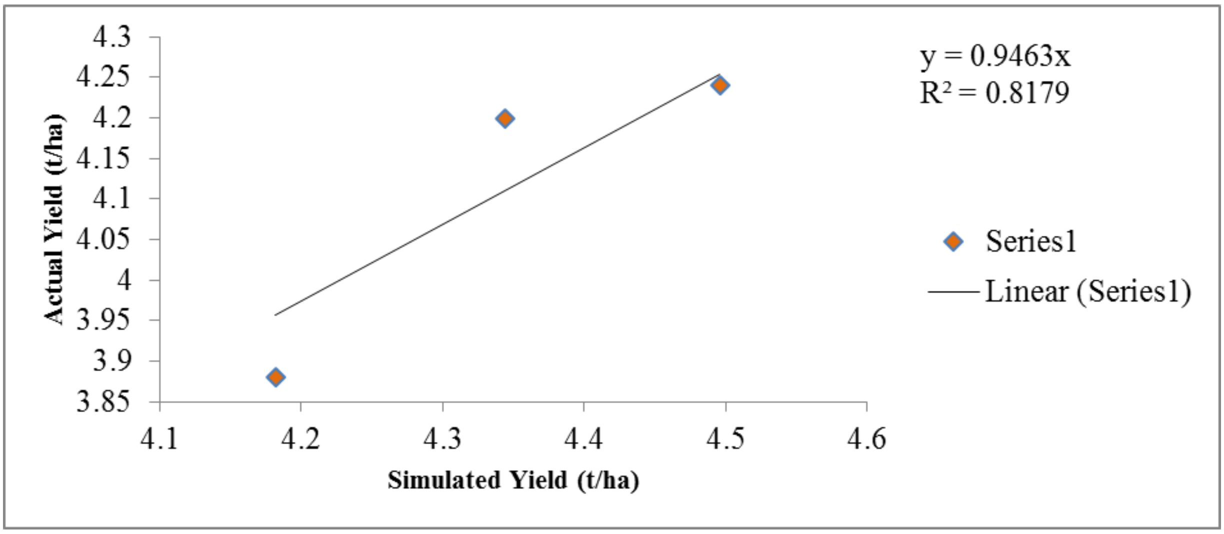


Fig 13: Simulated and observed yield for the validation period 2016 to 2018 model run.

4. Conclusions
The maximum temperature for all the crop season has shows model downward trend in all the temperature where as the minimum temperature has shows minimum downward trend precipitation in the area shared no trend. Simulated yield results based on net irrigation requirements have shows batter correlation with climatic variable. The validated simulated yield of wheat was to correlation with observed yield data.

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