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Climate Change and its Impact on Water Requirement and Productivity of Bengal Gram Over Different Agro-climatic Zones of Tamil Nadu

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ABSTRACT

Background: The AquaCrop model for Bengal gram successfully matches the biomass and yield of reported crop data under various planting dates, according to results that have been validated. Further this study was carried out in different agroclimatic zones of Tamil Nadu to assess variations in yield and water requirement.

Methods: In order to simulate realistic yields for the Bengal gram in response to planting date impacts in the Guziliamparai Block in the Dindugal District of Tamil Nadu, the study parameterized and verified performance of the AquaCrop model. Four field trials planted in D_1-1st November, D_2-15th November, D_3-1st December and D_4-15th December provided the model calibration data.

Result: Fruit yield and biomass had R^2 values of 0.9 and 0.8, respectively, indicating strong agreement between observed and model-simulated data. Fruit output and biomass were found to have RMSE values of 0.4 and 0.2, respectively. The NRMSE values for fruit yield and biomass were determined to be 0.3 and 0.1, respectively. The AquaCrop model somewhat overestimated fruit production and biomass since the BIAS was less than 0.4 and 0.2 for yield and biomass, respectively. Fruit production and biomass showed less agreement between simulated and actual D levels (0.4 to 0.6). The Aqua Crop model for bengal gram successfully matches the biomass and yield of reported crop data under various planting dates, according to results that have been validated. Further this study was carried out in different agroclimatic zones of Tamil Nadu to assess variations in yield and water requirement. Across Tamil Nadu's ACZ, a 2°C temperature increase decreased the yield by an average of 6%, with minimums of 2% and maximums of 13%. An rise in temperature of 3°C and 4°C, respectively, decreased the yield by 9% and 19% on average.

Key words: AquaCrop, Bengal gram, Biomass, Elevated temperature, Validation, Yield.

INTRODUCTION

Bengal gram (chickpea) is traditionally grown in other parts of the country; not Tamil Nadu. However, the state's chickpea crop has increased dramatically. The area rose by around 251.24% from 1941.7 hectares in 1950-51 to 6820 hectares in 2014-15, Nasir and Sidhu (2012). Production climbed by about 472.24%, from 730 tonnes to 4177 tonnes and productivity improved by about 71.56%, from 376 to 645 kg ha^{-1}. This would have been achievable as a result of the creation of suitable types with shorter growing seasons, the availability of high-quality seeds from better cultivars, government initiatives to provide the essential infrastructure for agriculture and efficient technology transfer (Raile *et al.*, 2021). To further expand the crop's productivity and area, these initiatives must be expanded up (Narayan and Sandeep Kumar, 2015).

Bengal gram would be a great crop for farmers in the current climate of unpredictable rainfall since it can endure drought conditions and is thus well suited for growing in colder places (using the dew water) with lesser rainfall. But too much water will make it exceedingly sensitive. In Tamil Nadu, the North East Monsoon season of October to November, which falls with the *rabi* sowing of Bengal Gram, is a crucial agricultural season for rainfed farming, accounting for roughly 48% of the annual rainfall. The three major elements that affect the moisture availability to these *rabi* rainfed crops and their abundant yields are residual

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moisture at the conclusion of the *kharif* season, rainfall during the North-East monsoon period (October-December) and dew deposition throughout October-January. Given that black clayey soils have a high water-holding capacity, it may grow successfully in sandy soils as well as in those with adequate drainage. It is therefore essential to conduct some solid study on how to improve irrigation and increase the water usage efficiency of crops that are climate resilient. In this study, the Dindugal district of Tamil Nadu's AquaCrop model was developed.

The FAO's Land and Water Division created the water-driven model AquaCrop to simulate how various herbaceous crops respond to water in terms of production. It is specifically geared to solve situations where water is a major limiting element in agricultural productivity. It is meant to balance simplicity, precision and resilience. The user interface of AquaCrop, a menu-driven software, is very nicely designed. The infiltration of water, the outflow drainage of the root zone, the development of the canopy and root zone, the rate of evaporation and transpiration, the production of biomass and the yield formation are all modelled using algorithms and calculation processes that are provided. It is easier for the user to understand the underlying processes when only a few parameters are used to describe the mechanisms of crop response to water shortage. The model is especially well suited for constructing deficit irrigation plans and doing scenario analysis since the user may use the whole simulation process at each time step to investigate the influence of changes in water-related inputs (Steduto *et al.*, 2009). AquaCrop is a companion tool that enumerates the ideas and guiding ideas of the AquaCrop model and may be used for a variety of users and applications, such as yield prediction under climate change scenarios. Using data from field experiments, the AquaCrop model was validated and calibrated in this work.

MATERIALS AND METHODS

Validation and calibration

To evaluate Bengal gram production and water usage efficiency under various climatic conditions, field experiment data from the Guziliamparai Block of Dindigal District, Tamil Nadu, was gathered using the AquaCrop model as a tool. The experimental site is situated at 10.6809°N latitude and 78.1130°E longitude, 120 m above mean sea level.

Climate and weather

Guziliamparai Block in Dindigal District has a moderate climate, with typical maximum temperatures ranging from 29.0 to 37.3°C. The average amount of precipitation each year is 840.5 mm, with most of it falling during the North-East monsoon season as well as some in the summer. The majority of the agricultural areas have red sand soil.

Soil

The soil on the experimental field is a sandy loam that drains well. The physical and chemical parameters of the original composite soil sample were investigated and the findings are shown in Table 1. The soil is a sandy clay loam with a low availability of N and medium availability of P and K.

Variety

Co-4 was used in the study.

Details of field experiment

Crop period-2018, 2019, 2020, 2021, 2022

Treatment details

i. Dates of sowing: 4

D1- 1st November

D2- 15th November

D3- 1st December

D4 -15th December

Irrigation methods: Ridges and furrows.

Input requirement for setting up AquaCrop

The AquaCrop model relies on a very small set of explicit parameters and mostly obvious input variables that are either widely used or can be derived using simple processes. The input consists of weather data, crop and soil characteristics and management practices that define the environment in which the crop will grow (Fig 1).

Validation of aquacrop model for bengalgram

The AquaCrop model was validated using field experimental data from the Guziliamparai Block in the Dindigal District, Tamil Nadu. Dates from four seeding experiments were collected.

Climate data

In this study, maximum and minimum air temperatures (C), rainfall (mm) and relative humidity (%) using IMD gridded data were employed for the study period (2018-2022).

Crop data

The crop's rooting depth, initial canopy, canopy expansion, flowering and yield output were all simulated using the AquaCrop model.

Soil data

The model requires a comprehensive dataset for each soil texture, including the wilting point, field capacity, bulk density, hydraulic conductivity, saturation, totally accessible water (TAW), nutritional status and initial soil water content. These essential soil characteristics were identified by inspecting the soil of the experimental field.

Irrigation application

The four sowing experiment dates were used to establish the experimental plots and irrigation was done in accordance with the crop's water needs.

For model validation, a number of statistical indicators are utilized, including: The experimental plots were established using the four sowing experiment dates and irrigation was carried out in line with the crop's water requirements.

For model validation, a variety of statistical indicators are used, including:

Root mean square error (RMSE)

$$\text{RMSE (Root mean square error)} = \left[\sqrt{\frac{\sum_{t=1}^{n}(Si - Oi)^2}{n}}\right]$$

Where,

Si and Oi = Simulated and actual values of the study's variables, respectively. Consider grain yield and total biomass.

Where,

n = Mean of the measured variables.

Normalized RMSE provides a measurement (%) of the relative difference between simulated and real data (RMSEn). The simulation is deemed excellent if the normalised root-mean-square error (RMSE) is less than 10%. It is regarded as good if it is between 10% and 20%. It is regarded as fair if it is between 20% and 30%. It is harmful if it is greater than 30% (Loague and Green 1991). The RMSEn was calculated using an equation:

$$\text{NRMSE (Normalized root mean square error)} = \frac{\text{RMSE} \times 100}{\bar{O}}$$

BIAS (BIAS) was calculated as

$$\text{Bias} = n^{-1}\sum_{i=1}^{n}(Si - Oi)$$

Oi stands for observed yield, n for the number of observations and Si for simulated yield. BIAS calculates the average tendency of simulated data to be larger or smaller than their genuine counterparts (Gupta *et al.,* 1999). It is advised to use BIAS values of small magnitude. Positive values point to a model bias toward overestimation, whereas negative values point to a bias toward underestimation (Gupta *et al.,* 1999).

Coefficient of determination (R^2) was calculated as follow

The squared value of the coefficient of correlation is what Bravais-Pearson refers to as the coefficient of determination (r2). It is predicated on:

$$\left| r^2 = \left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}}\right) \right|$$

Utilising O real-world data and S simulations. R^2 may also be expressed as the squared ratio between the covariance and the multiplied standard deviations of the observed and simulated values. As a consequence, it contrasts the single dispersion of the observed and simulated series with their combined dispersion. R^2 measures how much of the observed dispersion can be explained by simulation and ranges from 0 to 1.

Index of agreement (d)

Lack order to overcome E and r^2's insensitivity to changes in the observed and simulated means and variances, Willmot (1981) created the index of agreement d. (Legates and McCabe, 1999). Willmot (1984) said that the ratio between the mean square error and the potential error is the index of agreement.

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

Where,

n = Number of observations,

O_i = Observation.

S_i = Simulation.

The bigger the difference between the index value and one and vice versa, the higher the agreement between the two variables under comparison, according to the D-statistic.

Impact of varied climatic conditions on Bengal gram productivity and water requirements across these distinct agro-climatic zones

Location

Tamil Nadu is characterized by a varied topography, encompassing coastal plains, hilly regions and plateaus, contributing to a rich agro-climatic diversity. The state is divided into several Agro-Climatic Zones (ACZ) (Fig 1), each exhibiting unique environmental characteristics influencing agricultural practices. These zones include the Western zone (WZ), Northwestern zone (NWZ), Northeastern zone (NEZ), Cauvery delta zone (CDZ), Southern zone (SZ). The selection of these specific zones for the study was based on their prominence in bengal gram cultivation and their representation of the diverse agro-climatic conditions prevalent in Tamil Nadu. The research aimed to provide comprehensive insightsinto the impact of varied climatic conditions on Bengal gram productivity and water requirements across these distinct Agro-Climatic Zones.

Input requirement for setting up the AquaCrop model

The AquaCrop model employs a concise set of parameters and input variables that are commonly used or can be determined using simple methods. Input consists of weather data, crop and soil characteristics and management practices that define the environment in which the crop will be developed.

Weather

Comprehensive data on rainfall and temperature spanning from 1980 to 2022, sourced from the India Meteorological Department (IMD), were incorporated into the AquaCrop model.

Soil data

A digital soil map of Tamil Nadu at a scale 1:50,000 obtained from Department of Remote Sensing and Geographical Information System, Tamil Nadu Agricultural University (TNAU) were used to define the soils of Tamil Nadu portion of the basin.

Assessing the impact of climate change on water requirement, WUE and yield of bengal gram in different agro-climatic Zones of Tamil Nadu

Cropping districts with high efficiency were delineated across various agro-climatic zones (ACZ) in Tamil Nadu (Fig 2), prioritizing regions with the largest bengal gram cultivation areas, as reported in the Season and Crop Report

Table 1: Physico-chemical characteristics of the experimental field.

Character		Values
Mechanical analysis		
Sand (%)	:	62
Silt (%)	:	14.7
Clay (%)	:	15.6
Texture	:	Red sandy
Physical properties		
Bulk density (g cc^{-1})	:	1.01
Hydraulic conductivity (cm hr^{-1})	:	2.0
Infiltration rate (mm hr^{-1})	:	10.3
Field capacity (%)	:	26.2
Permanent wilting point (%)	:	12.1
Chemical properties		
pH (Jackson, 1973)	:	7.52
Electrical conductivity (dS m^{-1})	:	0.03
Organic carbon (%)	:	0.30
Available nitrogen (kg ha^{-1})	:	65.4
Available phosphorus (kg ha^{-1})	:	16.1
Available potassium (kg ha^{-1})	:	659.25

by the Department of Economics and Statistics, Government of Tamil Nadu Seasonal Crop Report, (2016). This model was employed to simulate both the crop water requirements and bengal gram yields over the past 43 years. The simulations were conducted with temperature variations of 2°C, 3°C and 4°C, enabling a detailed analysis of the impact of elevated temperatures on bengal gram crops.

RESULTS AND DISCUSSION

Validation of aquacrop model

Table 2 provides information on fruit production, biomass and water usage efficiency (WUE) as predicted and observed by AquaCrop. Where, D1, D2, D3 and D4 are the different date of sowing.

Table 2 showed that the AquaCrop model's predicted yield and biomass production for all planting dates closely matched the observed yield and biomass (Fig 3 and 4). Similar to this, the effectiveness of the validation was examined using statistical measures including the Root Mean Square Error (RMSE), Normalized Mean Square Error (NRMSE), Bias (PBIAS), coefficient of determination (R^2) and index of agreement (d), with the findings shown in Table 3.

According to the model statistics (Fig 5 and 6), the R^2 values for fruit yield and biomass, respectively, are 0.9 and 0.8, which show high agreement between observed and model-simulated data. Root mean square error (RMSE) evaluation tests were employed to assess the accuracy of the calibration and validation steps in the surface water as a portion of the coupled model (Wang and Yanmin, 2018).

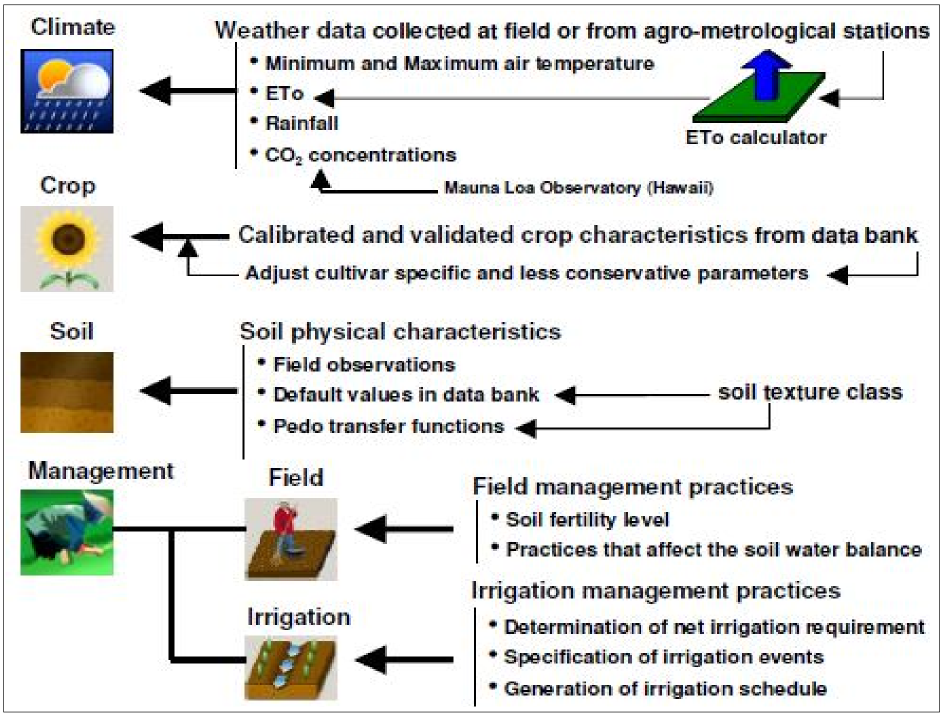

Fig 1: Input data defining the environment in which the crop will develop.

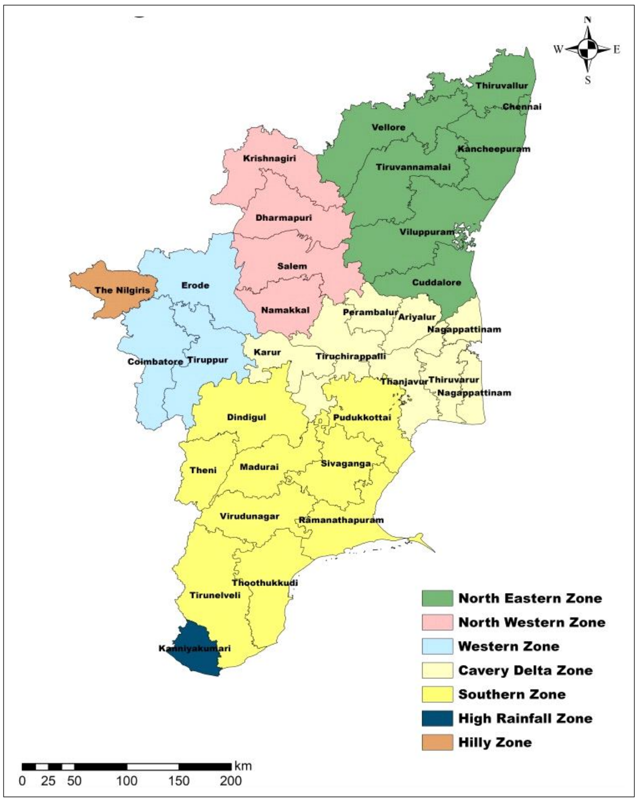

Fig 2: Agro climatic zones of Tamil Nadu.

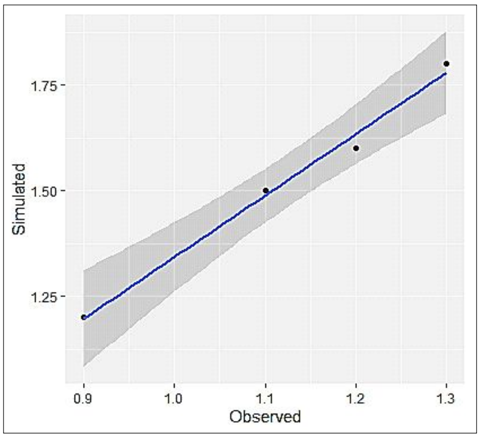

Fig 3: Comparison between observed and simulated values of fruit yield.

Fruit output and biomass were found to have RMSE values of 0.4 and 0.2, respectively. Fruit output and biomass were found to have NRMSE values of 0.3 and 0.1, respectively. As the BIAS was less than 0.4 and 0.2 for yield and biomass, respectively, the AquaCrop model somewhat overestimated fruit output and biomass. Fruit production and biomass exhibited reduced concordance between the simulated and real values for D values (0.4 to 0.6).

The findings of this investigation are comparable to prior studies using quinoa (Geerts *et al*., 2009), winter wheat (Xiangxiang *et al*., 2013) and maize (Katerji *et al*., 2014), independent of the crops utilised. The AquaCrop model was able to identify substantial changes for biomass that were induced by variation in planting date, as evidenced by the high quality of the model simulation results for biomass. Therefore, if the model is used to conduct scenario evaluation of the influence of climate change on chickpea planting dates in the same region of study, yield and biomass fluctuations may also be pretty accurately simulated by the model.

Fig 7 shows that the Bengal gram yield across the different agro-climatic zones in Tamil Nadu. The Northwestern zone (WZ) showed high-yielding potential (1.4 tonnes/ha) with wider annual variability and north eastern zone and western stood next in Bengal gram productivity

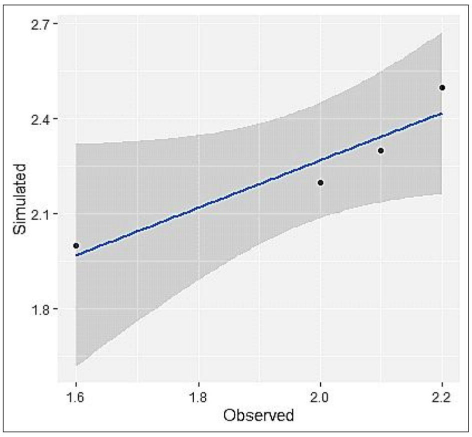

Fig 4: Comparison between observed and simulated values of biomass.

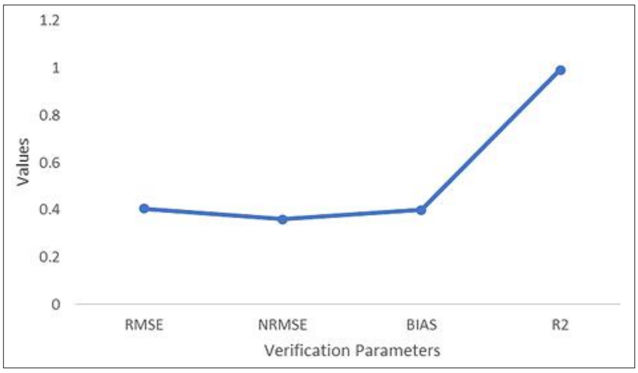

Fig 5: Comparison of verification parameters for fruit yield.

Table 2: AquaCrop simulated and observed fruit yield and biomass.

Treatments	Average fruit yield (2018-2022) (t ha^{-1})		Average biomass yield (2018-2022) (t ha^{-1})	
	O	S	O	S
D_1- 1st November	1.2	1.6	2.1	2.3
D_2- 15th November	1.3	1.8	2.2	2.5
D_3- 1st December	1.1	1.5	2.0	2.2
D_4- 15th December	0.9	1.2	1.6	2.0

Table 3: Comparison between observed and simulated values of fruit yield and biomass.

	Fruit yield	Biomass
RMSE	0.406	0.287
NRMSE	0.361	0.145
BIAS	0.4	0.275
R^2	0.991	0.891
D	0.436	0.653

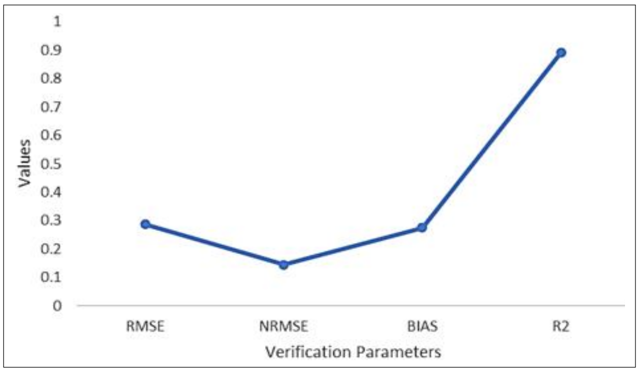

Fig 6: Comparison of verification parameters for biomass.

(1.3 tonnes/ha). Bengal gram yield was about 1.1 tones/ ha in Cauvery delta zone may be due to the presence of the sandy loam soils may added up the nutrient and retains the soil moisture inside the soil (Pradipa, 2018). Relatively low yield was noticed in the western region (1.0 tones/ha). There are several elements that are responsible for its low production. Unbalanced nutrition is one of them and it has a significant impact on Bengal gram yield. Application of organic manures including rock phosphate, phosphorus-solubilizing bacteria and rhizobium seed treatment are highly beneficial for increasing the production of this crop (Saravanan and Panneerselvam, 2014).

Fig 8 shows that the water requirement of Bengal gram across the different agro-climatic zones in Tamil Nadu. The north western zone (WZ) showed Highest water requirement (270.1 mm) with wider annual variability and western zone stood next in water requirement (256.3 mm). In terms of water requirement, bengal gram was about 225.7 mm in southern zone and 213.5 mm in the Cauvery Delta Zone. Relatively low water requirement was noticed in the north eastern zone (195.2).

Fig 9 shows that the Water use efficiency (WUE) of Bengal gram across the different agro-climatic zones in Tamil

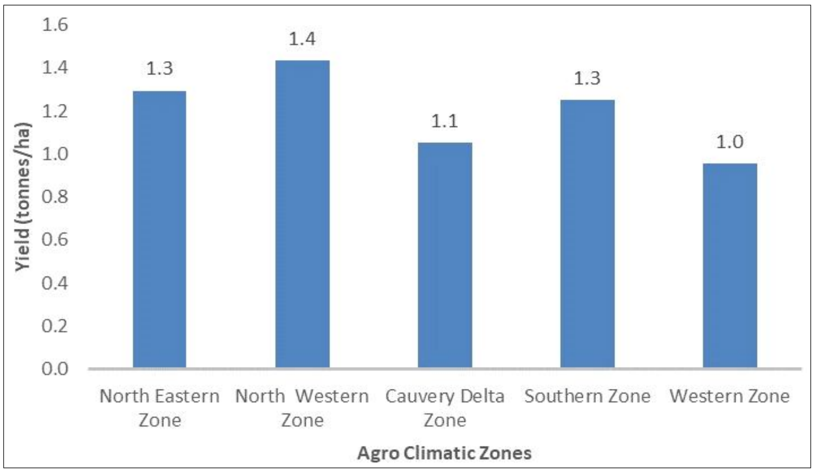

Fig 7: Yield of Bengal gram over different agro climatic zones.

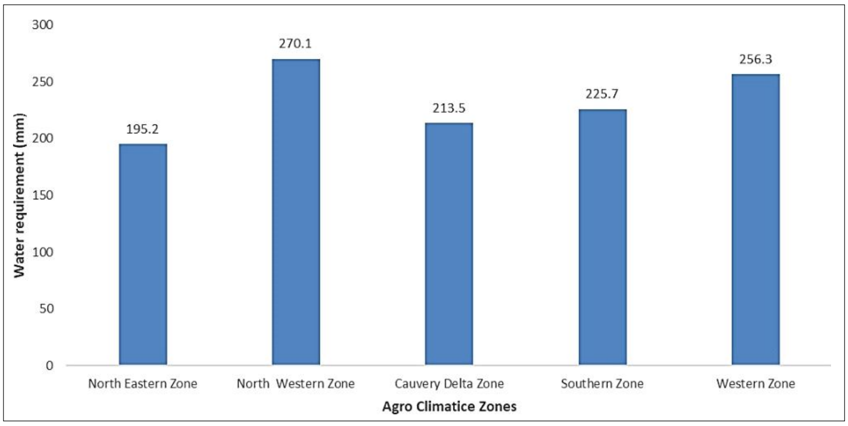

Fig 8: Water requirement of Bengal gram over different agro climatic zones.

Nadu. The north eastern zone showed Highest WUE (6.6 Kg $ha^{-1}mm^{-1}$) with wider annual variability and southern zone stood next in WUE (5.5 Kg $ha^{-1}mm^{-1}$). Bengal gram was about 5.3 Kg $ha^{-1}mm^{-1}$in north western zone and 4.9 Kg ha^{-1} mm^{-1} in the Cauvery Delta Zone. Relatively low WUE was noticed in the western zone (3.2 Kg $ha^{-1}mm^{-1}$). Understanding the combined response of climate influences on carbon absorption and water usage will be crucial implications, as Yoo *et al.* (2009) summarized the importance of altering transpiration on crop water use.

Fig 10 shows the effect of elevated temperature on Bengal gram yield in different agro-climatic zones in Tamil Nadu. The increase in temperature hurts Bengal gram yield in all agro-climatic zones. Reductions in Bengal gram yield due to elevated temperature are predicted to be more for Nort eastern zone as well as North western Zone and less in western zone. A temperature increases of 2°C reduced the yield on an average by 6% with a minimum of 2 and a maximum of 13% across the ACZ of Tamil Nadu. A temperature increases of 3°C and 4°C reduced the yield on an average by 9% and 19%. Because of the higher average daily temperature, more heat units accumulated over shorter times, accelerating the start of flowers and pods and shortening the crop's total lifespan (Banerjee *et al.,* 2021).

Fig 11 shows the changes in water requirement (WR) for bengal gram cultivation in different agro-climatic zones (ACZ) in Tamil Nadu under elevated temperatures (Fig 10). The elevated temperature increased the water requirement in all the ACZ at varying magnitudes. An increase of 2°C tends to lift the WR by an average of 5%. The elevated temperature by 3°C resulted in a 10 % increase in WR and

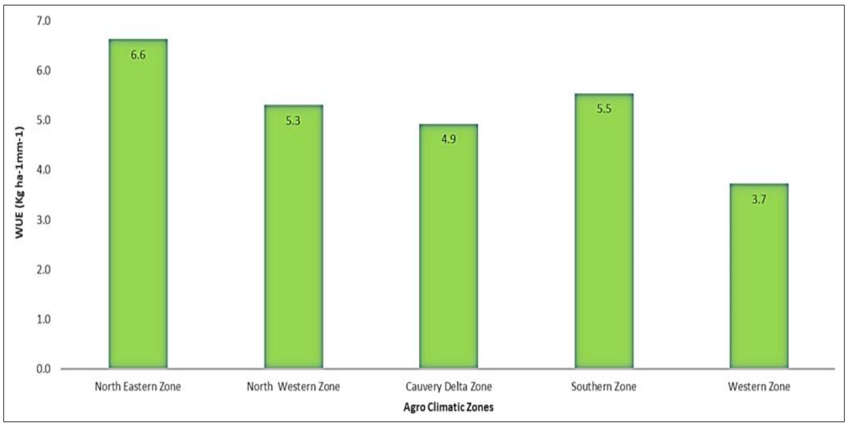

Fig 9: Water use efficiency of Bengal gram over different agro climatic zones.

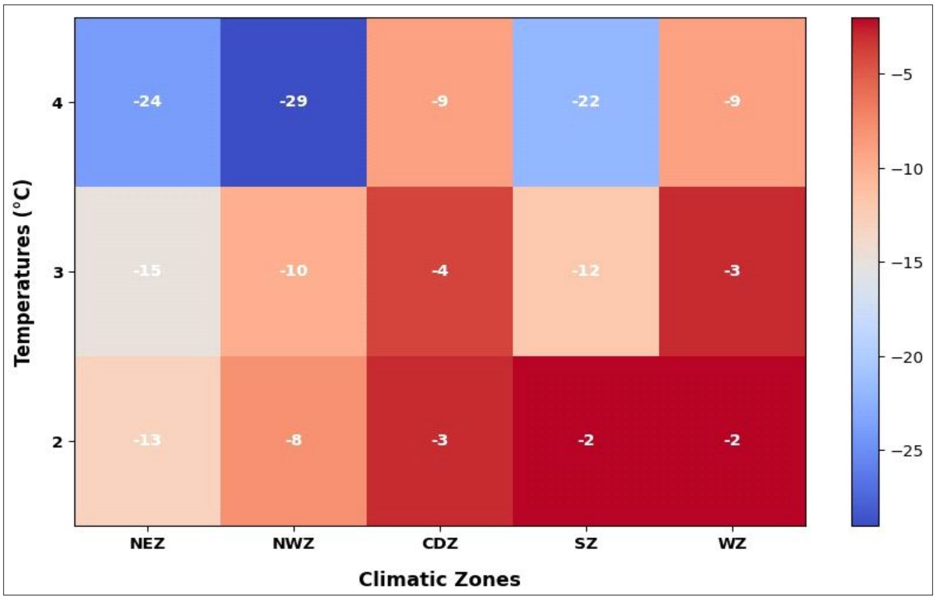

Fig 10: Effect of elevated temperature on Bengal gram yield.

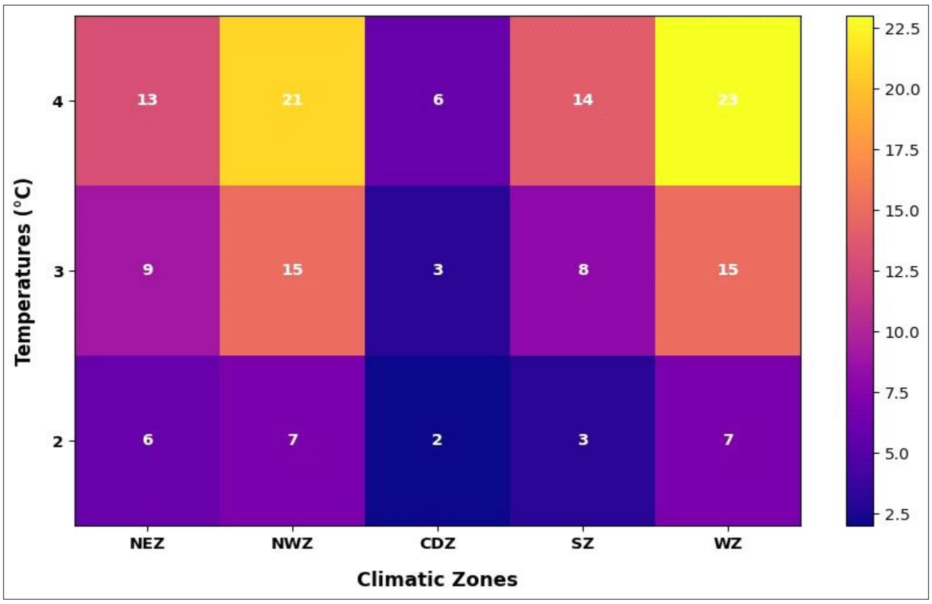

Fig 11: Changes in water requirement under elevated temperature.

the 4°C temperature rise increased the WR by 15% as suggested by Kaur *et al.* (2012).

CONCLUSION

According to the confirmed results of the AquaCrop model for Bengalgram, this model successfully mimics the biomass and yield of reported crop data under various planting dates. Across Tamil Nadu's ACZ, a 2°C temperature increase decreased the yield by an average of 6%, with minimums of 2% and maximums of 13%. A rise in temperature of 3°C and 4°C, respectively, decreased the yield by 9% and 19% on average. The rising temperature raised the water need in all ACZs to variable degrees. A rise of 2°C tends to raise the WR by 5% on average. A 3°C temperature increase resulted in a 10% increase in WR, whereas a 4°C temperature increase resulted in a 15% increase in WR. As a result, the model may be used to anticipate crucial crop phases and to optimise water requirements and irrigation schedules as well as yield responses to water. As a result, the model is a useful tool for making decisions on efficient irrigation management tactics.

Conflict of interest

The authors declare that there are no conflicts of interest.

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