

**CALIBRATION AND VALIDATION
AQUACROP MODEL FOR IRRIGATED
CHILLI CROP**

THESIS

**Submitted to
Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola
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**MASTER OF TECHNOLOGY
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DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation of the thesis entitled '**CALIBRATION AND VALIDATION OF AQUACROP MODEL FOR IRRIGATED CHILLI CROP**' or part thereof has neither been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis/publication of any university or scientific organization. The sources of material used and all assistance received during the course of investigation have been duly acknowledged.

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CERTIFICATE

This is to certify that the thesis entitled '**CALIBRATION AND VALIDATION OF AQUACROP MODEL IRRIGATED CHILLI CROP**' submitted in partial fulfilment of the requirement for the degree of '**Master of Technology in Agricultural Engineering (Irrigation and Drainage Engineering)**' of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola is a record of bonafide research work carried out by **GARDE VAIBHAV BABASAHEB** under my guidance and supervision.

The subject of thesis has been approved by the Student's Advisory Committee.

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C) ABBREVIATIONS

Abbreviation	Description
%	: Percent
/	: Per
@	: At the rate of
°C	: Degree Celsius
A	: Area
Agri.	: Agriculture
Agril.	: Agricultural
ASAE	: American Society of Agricultural Engineering
ASCE	: American Society of Civil Engineering
C.A.E.T.	: College of Agriculture Engineering and Technology
Cm	: Centimeter
Div.	: Division
Drain.	: Drainage
Engg.	: Engineering
ET _o	: Reference Evapotranspiration
ET _c	: Crop Evapotranspiration
<i>et al.</i>	: And others
FAO	: Food and Agricultural Organization
FC	: Field capacity
Fig.	: Figure
Ha	: Hectare
Hrs	: Hours
I.A.R.I.	: Indian Agriculture Research Institute
<i>i.e.</i>	: That is

Irrig.	: Irrigation
<i>J</i>	: Journal
LAI	: Leaf Area Index
Obs	: Observed
PDKV	: Dr. Panjabrao Deshmukh Krishi Vidyapeeth
PGI	: Post Graduate Institute
Sci.	: Science
IDE	: Irrigation and Drainage Engineering
etc.	: Etcetera
Fig	: Figure
dSm-1	: Deci Siemen per meter
EC	: Electrical conductivity
m ³	: Cubic meter
Kg	: Kilogram
Int.	: International
Ltd.	: Limited
M	: Metre
m ³ hr ⁻¹	: Cubic metre per hour
mg l ⁻¹	: milligram per litre
min.	: Minute
mm	: Millimeter
MS	: Maharashtra State
mm ³	: Million Cubic Metre
MSL	: Mean sea level
No.	: Number
PWP	: Permanent wilting point

Res. : Research
Resour. : Resource
WUE : Water Use Efficiency
CropSyst : Cropping Systems Simulation Model
DSSAT : Decision Support System for Agrotechnology
: Transfer
EPIC : Environmental Policy Integrated Climate
SWAP : Soil, Water, Atmosphere and Plant
WOFOST : World Food Studies
viz. : Namely

D) Thesis Abstract

- a) **Title of the thesis** : **CALIBRATION AND VALIDATION OF AQUACROP MODEL FOR IRRIGATED CHILLI CROP**
- b) **Full name of student** : **GARDE VAIBHAV BBASAHEB**
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ABSTRACT

Predicting attainable yield under water limiting condition is an important goal in rainfed agriculture. Proper irrigation planning is not only essential for water saving, but also for yield enhancement and it is only possible when

an accurate and reliable decision-making tool has been adopted. AquaCrop is one of the models extensively used for irrigation planning purposes. To evaluate its performance, a study entitled 'Calibration and Validation of AquaCrop model for irrigated chilli crop' was undertaken, with objective to calibrate and validate this AquaCrop model and also to verify the field results with the simulated outputs. Experimental study on chilli crop was carried out during 2014-15, 2015-16 and 2016-17. AquaCrop model was calibrated using chilli production data for the period 21st July 2014 to 19th January 2015. The harvest index was observed as 77 % for the chilli whereas, water productivity were 18 g/m². Thus, validation was carried out without any further adjustment to the calibrated parameters. The model validated for the period 21st July 2015 to 19th January 2016. Two statistical parameters *i.e.* root mean square error (RMSE) and Nash Sutcliffe coefficient of efficiency (R²Ns) were used as performance indicator. Results indicated that both statistical parameters were in acceptable limit for both calibration and validation period. Using calibrated model different irrigation schedules were tested for the year 2016-17 and it was found that S1 (80 % ET with PM) irrigation schedule was best as compare to other irrigation schedule in terms of yield and water saving.

Keywords: AquaCrop, Chilli, Calibration, Validation, Harvest index, Water productivity.

CHAPTER I

INTRODUCTION

1.1 Background information

Water is the vital source for crop production and is the most limiting factor in Indian agricultural scenario. The great challenge of the agricultural sector is to produce more food from less water. With rapidly growing population, the pressure on limited fresh water resources increases. Agriculture is the largest water-consuming sector and it faces competing demands from other sectors, like industrial and domestic. Increasing demand and scarcity of water makes it important to use available water in most economic ways. Management practices for conservation of water have been increasingly emphasized because of limited natural precipitation, high evapotranspiration and excessive depletion of limited ground water resources. Higher crop productivity can only be attained by proper soil, water and crop management. Thus, an assessment of the potential for reducing water needs and increasing production is the need of time. It requires an understanding of basic biological and hydrological crop-water relations.

Estimation of water requirement of crop is essential for crop planning on farm and, for designing and monitoring irrigation projects. Prediction methods for crop water requirements are used owing to difficulty of obtaining accurate field measurements. Food and Agriculture Organisation (FAO) (1977) has given guidelines to calculate crop water requirements of crop under different climatic and agronomic conditions. Methods often need to be applied for such climatic and agronomic conditions, which are different from those under which they were originally developed. Testing the accuracy of methods under a new set of conditions is labourious and time consuming. Therefore, use of available computer software with appropriate modifications to suit the site conditions may be a better option.

Small-scale irrigation initiatives are expanding rapidly in Maharashtra. However, in many cases optimal yields are not being obtained despite the available water and required nutrient applications. Local stakeholders need an easy-to-use decision-support tool to assess irrigation water use and its impact

on yield. A very powerful option to identify potential yields and possible crop cultivation constraints of particular areas are crop modeling tools (Droogers and Hunink, 2012). Use of models can assist in evaluating and reducing time intensive and expensive field tests (Whisler *et al.* 1986). Model results with regards to crop performance, management and yield estimates will help decision makers to decide which management system is suited best for a particular field, by estimating the optimum yield and crop water productivity. Frequently applied crop yield models are: CropSyst, CERES, DSSAT, EPIC, CropWat, SWAP/WOFOST and AquaCrop.

Accurate crop development models are important tools in evaluating the effects of water deficits on crop yield or productivity. Food and Agricultural Organization (FAO) of United Nations addresses this need by providing a yield response to water simulation model (AquaCrop) with limited sophistication. It simulates crop yield response to water, and is particularly suited to address conditions where water is a key limiting factor in crop production. AquaCrop is developed from revision of 'FAO Irrigation and Drainage Paper No. 33 Yield Response to Water' (Doorenbos and Kassam, 1979). AquaCrop attempts to balance accuracy, simplicity, and robustness. AquaCrop is the successor of CropWat featuring new adjustment options to reproduce crop environment in more detail. The capacity of AquaCrop model in simulating the yield in response to water is proved by various researchers (Araya *et al.* 2010a, Heng *et al.* 2009; Stricevic *et al.* 2011; Abedinpour *et al.* 2012, Andarzian *et al.* 2011 etc).

Chilli (*Capsicum annuum* L.), the most widely used and universal spice of India, belongs to the Solanaceae family. This has high medicinal value especially anti cancerous and instant pain relief. The popularity of chilli for spice, vegetable and other uses increases every year. In this regard, chilli is principal component of curry and chilli powder. It can be used to make pepper sauce, red pepper and paprika. It can also be used in the medical field with pungency being an important pharmacological property. These are also extremely good sources of many essential nutrients and richer sources of vitamin 'A' and 'C'. In India the area under chilli during 2017-2018 was 3.09 lakh hectares and in Maharashtra the area of chilli was 30590 hectares and

production of Chilli was 35.92 lakh MT and 342480 MT in India and Maharashtra, respectively (Horticultural Statistics at a Glance 2018, Horticulture Statistics Division, Department of Agriculture, Cooperation & Farmers' Welfare Ministry of Agriculture & Farmers' Welfare Government of India). In Maharashtra, Akola district production of chilli is 216 metric tonnes with an area 270 hectares (SAO Akola, 2019-20).

The important states growing chilli in terms of production are Andhra Pradesh (composite) (60%) followed by Karnataka (11%), West Bengal (7%), Orissa (5%), Madhya Pradesh (3%), Maharashtra (3%) and Tamil Nadu (2.6%) (Source-Spice Board, India).

1.2 Importance and need of the study

Considering the need of increasing population food production needsto be increase with the available water. Thus, increasing demand and limited availability of fresh water makes it important to use available water in most economic ways. To overcome such problem crop planning becomes essential considering the limited availability of water. Also, yield prediction under water-limiting conditions is an important goal in agriculture sector.

To address this task, the research project entitled 'Calibration and Validation of Aqua Crop model for irrigated Chilli Crop' was carried out at Department of Irrigation and Drainage Engineering, College of Agriculture Engineering and Technology, Dr. PDKV, Akola.

1.3 Objectives:

- I. To calibrate and validate AquaCrop model for irrigated Chilli.
- II. To verify the field results with that of validated model.

1.4 Hypothesis

The experiment is proposed & executed with the hypothesis that judicious and sustainable use of water becomes the need of time. In such a case predicting attainable yield under water-limiting conditions is an important goal in agriculture sector. Similarly different irrigation levels with polythene mulch might have significant effect on growth and yield of chilli crop. Simulative models like AquaCrop are effective tools in evaluating & predicting the effect of

water deficit on crop yield & productivity, which will be useful in crop planning and irrigation planning.

1.5 Scope and limitations

India has been well endowed with large freshwater reserves, but the increasing population and over exploitation of surface and groundwater over the past few decades has resulted in water scarcity in some regions. Water has always been the main factor limiting crop production in much of the world where rainfall is insufficient to meet crop demand. However, increasing urbanization and per-capita demand, the water demands of domestic, industrial and other sectors are expected to increase and become highly competitive with the irrigation sector and the country will face water scarcity if adequate and sustainable water management initiatives are not implemented.

Agricultural sector faces the challenge to produce more food with less water by increasing Crop Water Productivity. As such, the question of improving the present level of Crop Water Productivity in general and for irrigation in particular assumes a great significance in perspective water resource planning.

CHAPTER II

REVIEW OF LITERATURE

The main focus of present study was to calibrate and validate the AquaCrop model for the irrigated chilli crop. This chapter deals with brief review of work done by several researchers in the country and abroad related to application of FAO crop water productivity model *i.e.*, AquaCrop for crop production and Crop production under drip irrigation and mulches. This brief review of previous work done is presented in this chapter under following heads

1. AquaCrop model
2. Crop production under drip irrigation and mulches

2.1 AquaCrop model

FAO crop water productivity model *i.e.*, AquaCrop addresses the yield response to water. It simulates crop yield in response to water, and is particularly suited to address conditions where water is a key limiting factor in crop production. A review of past work done in application of AquaCrop for crop production is presented below.

Garcia-Vila *et al.* (2009) determined optimum level of Applied Irrigation Water (AIW) for cotton (*Gossypium hirsutum* L.) production in southern Spain under several climatic and agricultural policy scenarios. To generate yield response to variations in AIW, FAO crop water productivity (WP) model, AquaCrop was used. Model calibration and validation using four experiments conducted in region showed that AquaCrop adequately simulated yield in response to AIW. Model was further used to determine yield–AIW functions for different scenarios, assuming best deficit irrigation (DI) strategy. An economic optimization procedure showed that maximum profits occurred at AIW values between 540 and 740 mm, depending on climatic scenario. However, profits stayed close to maximum (above 95%) for AIW levels exceeding 300-350 mm, indicating that under DI, AIW may be reduced significantly with little impact on profits. The study concluded that AquaCrop is useful tool to assist managers for making decisions in irrigation to cotton

under water supply restrictions.

Hsiao *et al.* (2009) parameterized and tested AquaCrop model for maize (*Zea mays* L.). Treatment variable was irrigation with holding water after planting continuously, only up to tasseling, from tasseling onward, or intermittently, and with full irrigation (FI) as control. Conservative parameters included: canopy growth and canopy decline coefficient (CDC), crop coefficient for transpiration (Tr) at full canopy, normalized water productivity for biomass (WP), soil water depletion thresholds for inhibition leaf growth and of stomatal conductance and for acceleration of canopy senescence, reference harvest index (Hlo) and coefficients for adjusting harvest index (HI) in relation to inhibition of leaf growth and of stomatal conductance. With all 19 parameters held constant, AquaCrop simulated final above ground biomass within 10% of measured value for at least 8 of 13 treatments (6 yr of experiments) and also grain yield for at least five of cases. In at least four of cases, simulated results were within 5% of measured for biomass as well as for grain yield. Largest deviation between the simulated and measured values was 22% for biomass, and 24% for grain yield. Possible reasons for discrepancies between simulated and measured results include simplifications in model and inaccuracies in measurements

Todorovic *et al.* (2009) compared performance of AquaCrop, CropSyst and WOFOST, in simulating sunflower (*Helianthus annuus* L.) growth under different water regimes in a Mediterranean environment. Data used in analysis were obtained in field experiments with *hybrid Sanbro MR*, performed in a typical Mediterranean area of Southern Italy in 2005 and 2007. Models were calibrated on data from a full irrigation treatment in 2007, and validated on a full irrigation treatment in 2005 and several deficit irrigation (DI) treatments, including regulated deficit irrigation (RDI) and rain-fed (RF) conditions. Although AquaCrop required less input information than CropSyst and WOFOST, it performed similarly to them in simulating both biomass and yield at harvesting. Use of different numbers of parameters and crop growth modules by tested models did not influence substantially the simulation results.

Araya *et al.* (2010a) simulated biomass and grain yield of barley under various water inputs and planting dates, AquaCrop model, for cropping seasons of 2006, 2008 and 2009 at Mekelle site in northern Ethiopia. The study confirmed the capacity of model to simulate barley biomass and grain yield under various planting dates in the study site. AquaCrop model could be used in evaluation of optimal planting time. Out of tested planting dates, planting on July 4 (early sowing) was found to maximize barley biomass, grain and water use efficiency. Model could also be used in evaluation of irrigation strategies. Barley showed slightly lower performance under mild water stress condition compared to full irrigation condition. However, model has indicated possibility of obtaining more biomass and grain yield from relatively larger barley field under (deficit irrigation) mild stress condition.

Araya *et al.* (2010b) studied AquaCrop model to explore alternative water management strategies in teff crop. To calibrate and evaluate this model, independent data sets of cropping season 2008 and 2009 in northern Ethiopia were used. Teff crop cover, biomass and soil water simulated by model agreed well with observed data. Model revealed that grain water use efficiency of teff increased when supplementary irrigation after start of flowering was increased from 0 to 95 mm. Biomass-water use efficiency showed the opposite trend. Implication of these results is that if land is not a constraint, and if intention is to grow teff for its biomass, best option is to use available water to grow teff with deficit irrigation. But when major intention is to produce grain, best option is an optimum irrigation application. It is concluded that AquaCrop model can be used to explore management options to improved teff water productivity in the area.

Geerts *et al.* (2010) used AquaCrop model to simulate crop development for long series of historical climate data. Subsequently they carry out a frequency analysis on simulated intermediate biomass levels at start of critical growth stage, during which irrigation will be applied. From start of critical growth stage onwards, they simulate dry weather conditions and derive optimal frequencies (time interval of a fixed net application depth) of irrigation to avoid drought stress during sensitive growth stages and to guarantee maximum water productivity. By summarizing these results in

easily readable charts, a ready reckoner for policy, extension and farmer level use.

Andarzian *et al.* (2011) evaluated AquaCrop model for its ability to simulate wheat (*Triticum aestivum* L.) performance under full and deficit water conditions in a hot dry environment in south of Iran. AquaCrop model was evaluated with experimental data collected during three field experiments conducted in Ahvaz. AquaCrop model was able to accurately simulate soil water content of root zone, crop biomass and grain yield, with normalized root mean square error (RMSE) less than 10%. Analysis of irrigation scenarios showed that highest grain yield could be obtained by applying four irrigations (200 mm) at sowing, tillering, stem elongation and flowering or grain filling stages for wet years, four irrigations (200 mm) at sowing, stem elongation and flowering stages for normal years and six irrigations (300 mm) at sowing, emergence, tillering, stem elongation, flowering and grain filling stages for dry years. Least amount of irrigation water required to satisfy evaporative demand and to obtain high water use efficiency (WUE) for wet, normal and dry years were 100, 200 and 250 mm, respectively.

Stricevic *et al.* (2011) assessed AquaCrop model to simulate yield and irrigation water use efficiency (IWUE) for three major field crops (maize, sunflower, and sugar beet), under two scenarios: (1) natural water supply and adequate supply of nutrients, and (2) supplementary irrigation and adequate supply of nutrients, during 2000 and 2007 in northern Serbia. Data of 2003 cropping seasons were used for local calibration, whereas remaining years for validation. Model was calibrated by adjusting maize crop coefficient, sunflower harvest index. Simulated sunflower yield levels varied by less than 10% in 8 out of 10 comparisons. Difference between simulated and measured values in case of sugar beet was from -10.2 to 12.2%. Statistical indicators root mean square error (RMSE) and index of agreement (d) for all three crops suggested that model can be used to highly reliably assess yield and IWUE. This conclusion was derived based on low values of RMSE and high values of d (in the case of maize and sugar beet 0.999 for both yield and IWUE, and in case of sunflower 0.999 for yield and 0.884 for IWUE). It is noteworthy that under wet conditions, model suggested that sunflower and sugar beet do not

require irrigation, as confirmed by experimental research.

Saadati *et al.* (2011) explored AquaCrop model for a lowland local rice cultivar (Champa-Kamfiroozi) in Kooshkak area (semi-arid climate), Fars province, Iran, with data from an experiment with five irrigation treatments in two consecutive years. Model efficiency (ME) for canopy cover simulation was 0.34 to 0.82. Simulated grain yield deviated from observed data with a range of 0.1% to 7.8% in 2000 and -19% to 0.2% in 2001. Model efficiency (ME) for grain yield simulation in 2000 and 2001 were 0.98 and 0.5, respectively. Root mean square error (RMSE) for grain yield simulation in 2000 and 2001 were 0.09 and 0.7 tha^{-1} , respectively. AquaCrop model can adequately simulate canopy cover development and grain yield of rice under different irrigation managements. Model can be used to explore management options to improve rice water productivity.

Abrha *et al.* (2012) calibrated and validated AquaCrop model for barley (*Hordeum vulgare* L.). Data sets of field experiments at seven different locations in four countries (Ethiopia, Italy, Syria and Montana, USA) with different climates in different years and with five different cultivars were used for model calibration and validation. Goodness of fit between observed and simulated soil water content, green canopy cover, biomass and grain yield was assessed by means of coefficient of determination (R^2), Nash–Sutcliff efficiency (E), index of agreement (d) and root mean square error (RMSE). Statistical parameters indicated an adequate accuracy of simulations ($R^2=0.95$, $E=0.94$, $d=0.99$, $\text{RMSE}=0.34$). Subsequently, sowing strategies in semi-arid environment of northern Ethiopia were evaluated with validated model. Dry sowing had a probability of 47% germination failure attributable to false start of rainy season. On other hand, delay sowing at start of rainy season to eliminate germinating weeds should be kept as short as possible because grain yields strongly reduce in season due to water stress when sowing is delayed on shallow soils. This research demonstrates the ability of AquaCrop to predict accurately crop performance with only a limited set of input variables, and robustness of model under various environmental and climatic conditions.

Garcia-Vila and Fereres (2012) applied AquaCrop model at farm scale to an area in South-western Spain to assist farmers in pre-season decision making on cropping patterns and on irrigation strategies. Yield predictions were obtained from AquaCrop model which was validated for four different crops. Model simulated impact on farm income of: (a) irrigation water constraints; (b) variations in agricultural policies; (c) changes in product and water prices; and (d) variations in communication to farmers of specific level of irrigation water allocation. Applications of models to study area showed that the changes in cropping patterns induced by agricultural policy will encourage water savings more than an increase in water prices. Under water restrictions, the best strategy combines planting of low water use crops in part of area to release water to grow more profitable crops with greater water needs.

Heidariniya *et al.* (2012) tested performance of AquaCrop model for cotton to decrease costly and long-time field experiments. So, statistical indicators RMSE, Average Absolute Deviation (AAD) and R^2 were calculated to evaluate model accuracy and deficit irrigation scenarios were also assessed. Value of R^2 is 0.7381 and 0.7638 for 2004 and 2005, respectively. Possible reasons for discrepancies between simulated and measured results include simplifications in model, inaccuracies in measurements and different varieties. Also, results show that stress before flowering increases yield.

Mkhabela and Bullock (2012) tested ability of AquaCrop model (v3.0) to simulate spring wheat yield and total soil water content (0–120 cm layer) on Canadian Prairies. Crop yield and soil water content data collected from five experimental sites across the Canadian Prairies from 2003 through 2006 were used in the study. Results showed that the AquaCrop model can be used to model both wheat grain yield and soil water content on Canadian Prairies with acceptable accuracy. Overall, relationship between observed and modelled wheat grain yield for all sites combined, yielded R^2 of 0.66, slope of 0.96, index of agreement (d) of 0.99, root mean square error (RMSE) of 743 kg ha⁻¹ and mean absolute error (MAE) of 611 kg ha⁻¹. Similarly, the comparison between observed and modelled soil water content yielded R^2 of 0.90, slope of 0.73, d of 0.99, RMSE of 49 mm and MAE of 40 mm. The difference between observed

and modelled grain yield was only 3%, while that between observed and modelled total soil water was 2%. Consequently, AquaCrop can be a valuable tool for simulating both wheat grain yield and soilwater content on Canadian Prairies, particularly considering the fact that model requires a relatively small number of explicit and mostly intuitive input data which can be readily available or easily collected.

Nazeer *and Hussain* (2012) modelled the response of onion crop to deficit irrigation. Proper irrigation planning is not only essential for water saving, but also for yield enhancement and it is only possible when an accurate and reliable decision-making tool (DMT) has been adopted. A best agriculture model is that which has dynamic climatic, soil and crop components. AquaCrop is one of the models extensively used for irrigation planning purposes. To evaluate its performance an experimental field was laid down in Agricultural Research Institute (ARI) Tarnab, Peshawar, Pakistan, during 2011, using onion as a test crop. Four different irrigation treatments of 100, 80, 60 and 40% of crop water requirements (CWR) were applied on each growth stage. Two statistical parameters including root mean square error (RME) and Nash Coefficient of efficiency (NCE) were used as performance indicators. Results indicated that the biomass and yield estimated through model showed overestimation for all irrigation treatments; similarly, underestimation was observed for water productivity without any discrimination among full and severe water stress conditions. The performance of model to estimate biomass, yield and water productivity was not satisfactory, confirmed by performance indicators. The unreliability and differences in results may be due to other factors including crop structure and phenology, rather than climatic, soil and water supply parameters. For better performance of water productivity model adopted for global agriculture estimation, focus should also be given to underground stems and bulb like crop along with cereals and cash crops to obtain more realistic results.

Kiptum *et al.* (2013) studied potential of AquaCrop to simulate growth of cabbages in Keiyo Highlands under nine different irrigation treatments in dry season between December to February. Statistical comparisons of observed and simulated biomass $R^2 = 0.96$, Root mean square error (RMSE)

= 0.38 tons and coefficient of residuals = -0.17. Results cleared that model overestimated biomass of cabbages. Model also provided excellent simulation of canopy and yield. In this study water productivity of 17 gcm⁻² and harvest index of 76% were found for cabbages.

Singh *et al.* (2013) conducted experiment with 10 varieties (DBW 17, RAJ 4120, PBW 621, K 0307, HD 2733, HD 2687, CBW 38, DBW 39, HD 2985 and PBW 343) of wheat during 2008–2009 and 2009–2010 at farm of Uttar Banga Krishi Viswavidyalaya at Majhian located in Dakshin Dinajpur District of West Bengal, India, during December to April. The production was simulated using AquaCrop model for best variety. Model simulated wheat yield as 4.16 tha⁻¹ as compared to the actual yield of 4.10 tha⁻¹ in year 2008–2009. Model was validated in 2009–2010 for simulating wheat yield and performance of the model was quite satisfactory. Model simulated 4.01 tha⁻¹ as compared to actual yield of 3.90 tha⁻¹. Simplicity of AquaCrop in its requirement and minimum input data, which were readily available or could easily be collected, makes it user-friendly. It is also a very useful model for planning purposes to be used by economists, water administrators and managers working in West Bengal, India.

Sam-Amoah *et al.* (2013) calibrated and tested AquaCrop for hot pepper grown under full and deficit irrigation in a tropical humid coastal savanna zone in south-central Ghana (Cape Coast). Calibrated AquaCrop model concentrated on its performance to predict crop yield and seasonal crop water requirement (ETc). Four treatments were investigated: T1 (100% ETc), T2 (90% ETc), T3 (80% ETc) and T4 (70% ETc). AquaCrop could not simulate yield of hot pepper accurately for all treatments with the exception of treatment T2 which was simulated with lowest deviation of 4%. On the other hand, model was able to simulate the seasonal water requirements to an appreciable degree in both experiments. It must be pointed out that calibration of AquaCrop suffered from a lack of data on progress of crop canopy cover which is a very important parameter used in developing the model.

Wellens *et al.* (2013) studied AquaCrop for cabbage (*Brassica oleracea* L.) using a limited dataset and leave-one-out cross-validation (LOOCV). This

experiment was conducted in south-western Burkina Faso on small irrigated farmer plots, where optimal managerial conditions could not always be guaranteed. Statistical indicators *viz.* normalized root mean square error (nRMSE) and index of agreement (d) suggested that model was very reliable for simulating cabbage biomass yield and soil water content. Relationship between observed and simulated yield produced d-index of 0.99 and an nRMSE of 1.39% (or 0.59 tha^{-1}). Comparison between observed and modelled soil water content gave d-index of 0.90 and an nRMSE of 4.38% (or 9.13 mm). It was concluded that AquaCrop was a very useful tool for enabling local end-users to evaluate and optimize cabbage yield and irrigation water use.

Casa *et al.* (2013) stated AquaCrop model estimates crop productivity decrease in response to water stress, determining biomass (B) based on water productivity (WP) and accumulated transpiration (ΣTr) and yield (Y) was calculated according to B and harvest index (HI). AquaCrop was evaluated considering different WP values for 2010 late growing season to simulate crop yield of potato (*Solanum tuberosum* L.) cv. Spunta, in a commercial production field of 9 ha located in green belt of Cordoba city (31°30'S, 64°08'W, 402 msl), while monitoring in 2009 was used to verify model. Canopy cover estimation by AquaCrop was adjusted using observed field data obtained from vertical digital photo- graphs acquired at 2.5 m height. WP values of 15.8 and 31.6 (for C3 and C4 species, respectively) and two intermediate values 21 and 26.3 $\text{g}\cdot\text{m}^{-2}$ were considered to evaluate model performance. While linear function between observed tuber yields and estimated by AquaCrop had always correlation coefficient greater than 0.94 ($p < 0.001$), using $\text{WP}=26.3$ and $\text{WP}=31.6$ $\text{g}\cdot\text{m}^{-2}$ presented overestimation, whereas with 15.8 $\text{g}\cdot\text{m}^{-2}$ had an opposite behaviour, while $\text{WP}=21$ $\text{g}\cdot\text{m}^{-2}$ was value that produced lowest estimation error. In addition, soil moisture from this estimated value of WP was highly correlated with measured water content in different areas of production field. Verification test shows that while model slightly underestimates canopy cover, biomass was overestimated. After setting coefficients of canopy cover development, AquaCrop crop model estimated adequately potato yield for high production values that are less

affected by lack of water, but in both years showed a tendency to overestimate lowest yields, as was observed for other crops. Meanwhile, dispersion between observed and estimated yield was higher in verification test because sampling this year was more random.

Kumar *et al.* (2014) evaluated AquaCrop model for predicting wheat yield and water productivity under irrigated saline regimes. In this study four different wheat varieties, including three salt-tolerant (i.e., KRL-19, KRL-1-4, KRL-210) and one salt non-tolerant variety (i.e. HD-2894) grown under different salinity levels were evaluated. The experiment was conducted at the research farm of water technology center (WTC), IARI, New Delhi, during *rabi* 2009-10 and 2010-11. The model was calibrated using experiment data of *rabi* 2009-10 and validated with data of *rabi* 2009-2010. Saline water of 4, 8 and 12 dSm⁻¹ and groundwater were used for irrigation. The result predicted statistics error, i.e. model efficiency (ME), index of agreement (d) and coefficient of determination (R²) for grain yield, were 0.85, 0.96, 0.94 and for biomass 0.7, 0.95, 0.95 respectively for all varieties and salinity levels. It was observed that the AquaCrop model good for predicting water productivity and wheat yield.

Thokal *et al.* (2014) evaluated the AquaCrop model, developed by FAO, for its ability to simulate crop performance under full and deficit irrigation in a humid environment in Kokan region of Maharashtra. Different irrigation (depth of irrigation) scenarios on crop yields grown in the irrigation command and their effects on sustainability and project benefit were also tested in the study. Panchnadi Minor Irrigation Project was selected as a case study. The management scenarios were developed for improving irrigation efficiency and were compared in terms of monetary benefits with present status of irrigation project. The possibility of deficit irrigation was also explored for light texture soil in command area. Project net benefit for 10, 30 and 50 percent scenarios was Rs.23.67, 12.20 and -0.74 lakh respectively. The results suggested that 10 per cent deficit strategy could be beneficial for irrigation command under study. The net water allocation for 10 per cent deficit scenario was 0.31 mm³ for the live storage in the reservoir of 1.461 mm³. The canal could be run from 1st October to 31st May of the year i.e. for 243 days. The overall efficiency of

the lined and unlined sections of canal and unlined field channel under existing condition was observed as 75, 52 and 35 per cent, respectively. The total loss from lined and unlined main canal sections and unlined field channels was observed as 0.184, 0.61 and 0.183 mm³, respectively. The gross water allocation for 10 per cent deficit irrigation strategy was 1.43 mm³.

Ahmadi *et al.* (2015) modelled the maize yield and soil water content with AquaCrop under full and deficit irrigation managements. The AquaCrop model was used to simulate maize growth and soil water content under full and deficit irrigation managements as 1.2, 1, 0.8, and 0.6 of the potential crop water requirement. Generally, the RMSEs in simulating soil water content in calibration and validation were 0.01–0.039 and 0.012–0.037 m³m⁻³, respectively, that overall corresponds to 3–14 % error. For the in-season biomass development, the RMSEs in calibration varied between 2.16 and 2.73 Mg ha⁻¹, while they varied between 1.97 and 5.19 Mg ha⁻¹ in validation for the four irrigation managements. The model showed poor performance for simulating biomass late in the season under deficit irrigation managements. The RMSEs of final grain yield simulation were 0.71 and 1.77 Mg ha⁻¹ that corresponded to 7 and 18 % error in calibration and validation, respectively. Likewise, the RMSEs for simulating the final biomass in calibration and validation were 1.29 and 2.21 Mg ha⁻¹ that equals to 6 and 10 % error, respectively. Results demonstrated that AquaCrop is a useful decision-making tool for investigating deficit irrigations and maize growth in the region. However, in agreement with the findings in earlier studies on AquaCrop, the model showed insufficient accuracy in simulating final grain yield and biomass under moderate to severe water stresses. It is suggested that AquaCrop would benefit of including some calibrating parameters about the root distribution pattern in the soil because it is a water-driven model and highly depends on the accurately simulated water uptake from the soil profile.

Sandhu *et al.* (2015) implemented AquaCrop model in irrigation scheduling for rice under northwest India. The model was calibrated and validated using the experimental data of field experiments conducted during 2009 and 2010, respectively. The model underestimated the above ground dry biomass at 30 days after transplanting (DAT) in the range of 21.60 to

24.85 %. At the time of harvest the model overestimated the above ground dry biomass within the range 11.58 to 14.34%. At harvest the values of normalized root mean square error (15.54%) suggested a good fit for the above ground dry biomass and an excellent agreement (3.34%) between observed and model predicted grain yield. The model suggested to irrigate rice transplanted in puddled loamy sand soil one every 5th day to get higher IWP coupled with statistically similar grain yield as obtained with daily irrigation schedule.

Sethi *et al.* (2016) carried out study on paddy response to irrigation using AquaCrop model. Attempts were made to understand the response of paddy to irrigation by using the FAO AquaCrop model for crop yield data of 8-years. Weather parameters were analyzed for paddy crop growing period to validate the model; crop parameters were calibrated for paddy variety of 120 days duration in Ludhiana, India. Reference evapotranspiration (ET_o) and irrigation schedule (718-1048.1 mm) was decided by using ET_o calculator and CROPWAT model, respectively. The simulated yield (3.80-4.53 tha⁻¹) was validated with actual yield (3.53-4.63 tha⁻¹) with water use efficiency (3.1-3.7 kg ha⁻¹ mm⁻¹), obtained during the years of observation. The model was evaluated with the percentage error of 0.59, root mean square error of 0.064, mean absolute error of 0.06 indicating higher accuracy of the calibrated model. Thus, the model would be useful for predicting the paddy crop yield, irrigation water productivity under different irrigation scenarios.

Darko *et al.* (2016) evaluated AquaCrop model for tomato (*Lycopersicon esculentum*) grown under deficit and full irrigation. Two field experiments were carried out in the tropical humid coastal savanna zone in Mfantseman district of the Central Region of Ghana. Data from the first experiment were used to calibrate the model while data obtained from the second experiment were used to validate the model. Four treatments were investigated: T1 (no irrigation after plant establishment), T2 (50% ET_c restoration), T3 (100% ET_c restoration up to beginning of flowering, then 50% ET_c restoration) and T4 (100% ET_c restoration). The results revealed that AquaCrop was able to simulate the yield of tomato for T2-T4 with the exception of Treatment T1 which was simulated with the highest deviation of 45.1%. On

the other hand, the model was able to simulate the seasonal water requirements to an appreciable degree in both experiments.

Supekar *et al.* (2019) calibrated FAO-AquaCrop model for summer chilli (*Capsicum annuum* L.) in Marathwada region. In this study AquaCrop model was calibrated for the period 10th January 2018 to 10th May 2018 *i.e.* crop period, using field data for full irrigation treatment I4-Drip Irrigation at 100% of ETc. Results from this study provided a set of first estimates for the calibration of the AquaCrop model on chilli for Marathwada conditions and for further testing and validation of the model at other agro climatic conditions. AquaCrop model was calibrated by using field data of full irrigation treatment with harvest index of 75% and water productivity 30 g/m² as there was close match between observed and simulated canopy cover with high value statistical parameter of R²NS =0.97 and CRM=-0.051. It was also cleared that the canopy cover was overestimated by model particularly during 36 to 84 DAT *i.e.* during development stage. But the scatter plot clears that as the canopy cover lie on both sides of 1:1 line, there was no consistent over or under estimation.

2.2 Crop production under drip irrigation and mulches

Drip irrigation is an efficient method of water application for vegetables and horticultural crops. Drip irrigation method with its ability to apply small but frequent water application has been found superior in terms of water productivity and quality as well. Also, it is proved fact that crop productivity enhanced with use of mulches. A brief review of work done in the field of drip irrigation and mulch for crop production by several researchers is presented below.

Seyfi and Rashidi (2007) studied effect of drip Irrigation and plastic mulch on crop yield and yield components of cantaloupe. They observed that highest fruit weight and fruit thickness was obtained for drip with plastic mulch treatment and lowest for the conventional treatment. Results of study also indicated that irrigation method significantly affects cantaloupe yield in order of drip with plastic mulch > drip irrigation > conventional owing to differences in fruit weight and fruit thickness in the same order. The crop yield was

highest (27.07 tha^{-1}) for drip with plastic mulch treatment. Yield from drip irrigation treatment was intermediate but lowest (22.47 tha^{-1}) from conventional treatment. Highest WUE ($0.91 \text{ tha}^{-1}\text{cm}^{-1}$) was obtained from drip with plastic mulch treatment and lowest ($22.47 \text{ tha}^{-1}\text{cm}^{-1}$) from conventional treatment. Drip with plastic mulch treatment was found to be more effective irrigation method in improving WUE and increasing cantaloupe yield.

Diaz-Perez *et al.* (2010) studied effect of plastic film mulches on Bell pepper (*capsicum annum.*). The study emphasized on crop microenvironment, physiological attributes, and fruit yield. The study cleared that the plastic film mulches differed in their soil-warming ability with root zone temperatures (RZTs) in both spring and fall being highest in black mulches and lowest in silver mulches. Percentage of photo synthetically active radiation (PAR) reflected from mulches was highest in silver mulches and lowest in black mulches. Mean RZT under plastic mulch decreased with increasing percentages of reflected PAR. Number of thrips per flower and incidence of TSW in mature plants were not significantly different among plastic mulch treatments. Plastic mulch treatments had no significant effect on soil water status. Neither soil water content nor soil water potential had a relationship with RZT. In the fall season, during first 28 days after transplanting, plant growth attributes were among highest in silver mulches and lowest in black mulches. Gas exchange and accumulation of mineral nutrients in leaves and fruit were not significantly affected by plastic mulches. Both marketable and total yields were higher on silver mulches and lowest on black mulch in the fall, whereas they were in general higher on silver with a black strip mulch and lowest on white and silver mulches in the spring.

Ashrafuzzaman and Halim (2011) studied effect of plastic mulch on growth and yield of chilli (*Capsicum annum L.*). Plastic mulches used, were transparent, blue, and black; and bare soil was the control. Different mulches generated higher soil temperature and soil moisture under mulch over the control. Transparent and blue plastic mulches encouraged weed population which were suppressed under black plastic. Plant height, number of primary branches, stem base diameter, number of leaves and yield were better for

plants on plastic. Mulching produced fruits with highest chlorophyll-a, chlorophyll-b and total chlorophyll contents and also increased number of fruits per plant and yield. However, mulching did not affect length and diameter of the fruits and number of seeds per fruit. Plants on black plastic mulch had the maximum number of fruits and highest yield.

Devaranavadi *et al.* (2011) studied effect of different drip irrigation levels on growth and yield of bitter melon (*Momordica charantia* L.) in semi arid conditions of Karnataka. The important component which decides the superiority of a crop production system is yield. Among all the drip irrigation treatments at 100 per cent ET level, superior yield in kg per plant were obtained which was found to be at par with 80 per cent ET level. The higher yield per plant could be due to better soil moisture regimes created by the said treatments. The yield per hectare is the ultimate factor which decides the superiority of any treatment in terms of not only its biological returns but also its economic returns. In the present investigations highest bitter melon yield was produced by 100 per cent ET level followed by 80 per cent ET level which were at par. The yield levels achieved by 100 per cent ET level were higher by 65.40 per cent as compared to furrow irrigation and by 150 per cent compared to 60 per cent ET level. The trend clearly suggests the superiority of 100 per cent ET level when compared to all other drip and furrow irrigation treatments. This advantage is not only in terms of superior yields but also in terms of water saved.

Rajablariani *et al.* (2012) studied effect of colored plastic mulches on yield of tomato and weed biomass. Tomato (*Lycopersicon esculentum* L.) was grown on polyethylene mulch films and bare soil. Plastic mulches were blue, black, clear, red and silver on black. Black and silver/black plastic mulches suppressed weeds which were encouraged under clear, blue and red mulches. Results indicated that soil temperature increased under various colored plastic mulches about 3 to 6 °C more than in bare soil. Number of branches and leaves were better for the plants grown over plastic compared to bare soil. The highest early yield was obtained in clear plastic likely due to

light entrance and raising soil temperature. Mulching increased marketable yield relative to bare soil as plants grown on silver/black plastic mulch indicated 65% increase in marketable yield compared to control treatment. The plastic mulches resulted in an 84-98% reduction in weed biomass.

Paul *et al.* (2013) conducted field experiment on loamy sand soil at Bhubaneswar in eastern coastal of India for two years (2007-08 and 2008-09) to evaluate yield, water-use efficiency and economic feasibility of capsicum grown under drip and surface irrigation with non-mulch and black Linear Low Density Poly Ethylene (LLDPE) plastic mulch. Actual evapotranspiration for capsicum crop was estimated using modified pan evaporation method. Net irrigation volume (V) was determined after deducting effective rainfall. Effect of three irrigation levels viz. VD , $0.8 VD$ and $0.6 VD$ (VD = full irrigation volume with drip) in conjunction with LLDPE mulch and no mulch were studied on biometric and yield response of capsicum crop. Results of surface irrigation were compared with drip irrigation system under no mulch and in conjunction with LLDPE mulch. Study indicated better plant growth, more number of fruits per plant and enhancement in yield under drip irrigation system with LLDPE mulch. Highest yield (28.7 t/ha) was recorded under 100% net irrigation volume with drip irrigation (VD) and plastic mulching as compared to other treatments. This system increased yield and net seasonal income by 57% and 54% respectively as compared to conventional surface irrigation without mulch with a benefit cost ratio of 2.01. Benefit cost ratio was found to be the highest (2.44) for the treatment VD without mulch. Drip irrigation system could increase the yield by 28% over surface irrigation even in the absence of mulch. Similarly, LLDPE mulch alone could increase yield by 13% even in the absence of drip irrigation system.

Abdelrahman *et al.* (2016) conducted an experiment during rainy seasons (2014-15 and 2015/16) at two locations in North Kordofan of Sudan, consisted of two treatments (covered or uncovered with thin plastic sheet) laid out in a Randomized Complete Block Design (RCBD) with four replications. Plastic sheet mulching significantly increased plant height, fruit weight, fruit

number and seed yield of watermelon by 30%, 70%, 17%, and 65%, respectively. In cowpea plastic sheet mulching significantly increased number of pods per plant, grain yield and 100- seed weight by 17%, 30% and 10% respectively. It could be concluded that using plastic mulch as a soil cover increased the vegetative growth and yield of watermelon and cowpea crops under marginal sandy rain-fed conditions of North Kordofan State.

Bhatt *et al.* (2016) conducted a field experiment to find out the effect of different mulching materials *viz.*, black plastic, clear plastic, dry leaves, pine needles, green twigs of non-fodder plants, forest litter and F.Y.M. on vegetative characteristics, yield and production economics of summer squash, the field experiment were undertaken during spring-summer season of 2009 and 2010 under rainfed mid hill conditions of Uttarakhand. The maximum plant height (38.11 cm), plant spread (142.39 cm), number of leave per plant (41.85), root length (36.83 cm) and yield (62.72 tha^{-1}) were recorded in black plastic mulch compared with other treatments. The black plastic mulch not only advanced the harvesting time but also produced 74.17 per cent higher fruit yield than the control. Mulching with black plastic in summer squash was found also most economical with net return of 232628.70 ha^{-1} and benefit: cost ratio of 2.61.

Dimple *et al.* (2017) carried out study on the effect of deficit irrigation on yield and water use efficiency of drip irrigated capsicum under the naturally ventilated polyhouse. In this study, six different levels of drip irrigation equivalent to 100%, 90%, 80%, 70%, 60% and 100% (control without mulch) of crop evapotranspiration with four replications were considered for their effect on crop yield and water use efficiency inside the 10 naturally ventilated polyhouse. Capsicum (*Capsicum annuum* L. Indra Variety) plants were grown under the naturally ventilated polyhouse. The maximum crop yield was found in case of 80% irrigation level (42.64 t/ha) and the maximum water use efficiency was also recorded in the same treatment (1296.48 kg/ha-cm). Thus, the results revealed that all the vegetative parameters, quantity parameter and water use efficiency were found maximum at drip irrigation level equal to 80% of crop evapotranspiration under the naturally ventilated polyhouse.

Laulina *et al.* (2019) conducted an experiment at Centre for Protected Cultivation Technology, Indian Agricultural Research Institute, New Delhi. Water distribution in the root zone of capsicum (*Capsicum annum* L.) was simulated for three colored plastic mulches (silver, yellow and black) and unmulched condition (control) with three level of irrigation (100% ET_c, 80% ET_c and 60% ET_c). It was found that for two levels of irrigation (100% and 80% ET_c) highest yield was obtained, so for these two irrigation levels simulation of water dynamics was done by the Hydrus-2D model. The 12- irrigation cycle was 72 h (i.e. 3 days) and indicates that moisture was readily available in the vicinity of root zone. Simulation study showed that water content for sandy loam soil was more in the second layer of soil (15 to 30 cm) and was near the field capacity. The R²-value obtained for silver plastic mulchat 100% of ET_c was highest (0.91 to 0.94) and the second highest R²-value isfor yellow plastic mulch at 80% of ET_c (0.89 to 0.91). The results showed that at 100% of ET_c, silver color mulch has comparatively more water content thanother treatments. Simulation studies showed that silver plastic mulch optimized the water content in the vicinity of capsicum root zone for 1 lh-1 dripper discharge. So, silver plastic mulch was efficiently utilized, as the capsicum root zone was found within 20 to 30 cm depth. This indicates that the Hydrus-2D can be used effectively for predicting soil moisture distribution covered with plastic mulch.

CHAPTER III

MATERIAL AND METHODS

The research project entitled “Calibration and Validation of AquaCrop model for irrigated Chilli Crop” was carried out at Department of Irrigation and Drainage Engineering, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, during the period of 2020-21. This chapter deals with information regarding basic resources, material and methods employed during the course of study.

3.1 Basic Resource Information

3.1.1 Study area

The study was carried out at Department of Irrigation and Drainage Engineering, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (MS).

3.1.2 Data collection and input data preparation

AquaCrop model has a structure that overarches soil-plant-atmosphere continuum. For assessing yield and growth of irrigated chilli AquaCrop requires following data which were collected and processed as per requirement of model.

3.1.3 Weather data

Weather data for the period 20 July 2014 to 20 January 2015, 20 July 2015 to 20 January 2016 and 28 July 2016 to 23 January 2017 was obtained from Agro-meteorological Observatory, Department of Agronomy, Dr. P.D.K.V., Akola and presented in Annexure I. It comprised of maximum and minimum temperature ($^{\circ}\text{C}$), maximum and minimum relative humidity (%), daily sunshine hours (hr), wind speed (km/hr), rainfall (mm) and evaporation (mm/day).

The minimum temperature for the period of study 2014-2015 varied from 4.7 to 32.2 $^{\circ}\text{C}$ whereas maximum temperature varied from 20 to 39.4 $^{\circ}\text{C}$. The daily relative humidity, daily sunshine hours, wind speed and evaporation ranged between 6 to 100 %, 0.0 to 9.3 hr, 0 to 19.8 km/hr and 1.8 to 11.6 mm/day, respectively. The variation of minimum and maximum temperature as well as daily rainfall for year 2014-15 of study is depicted in Fig. 3.1 and 3.2.

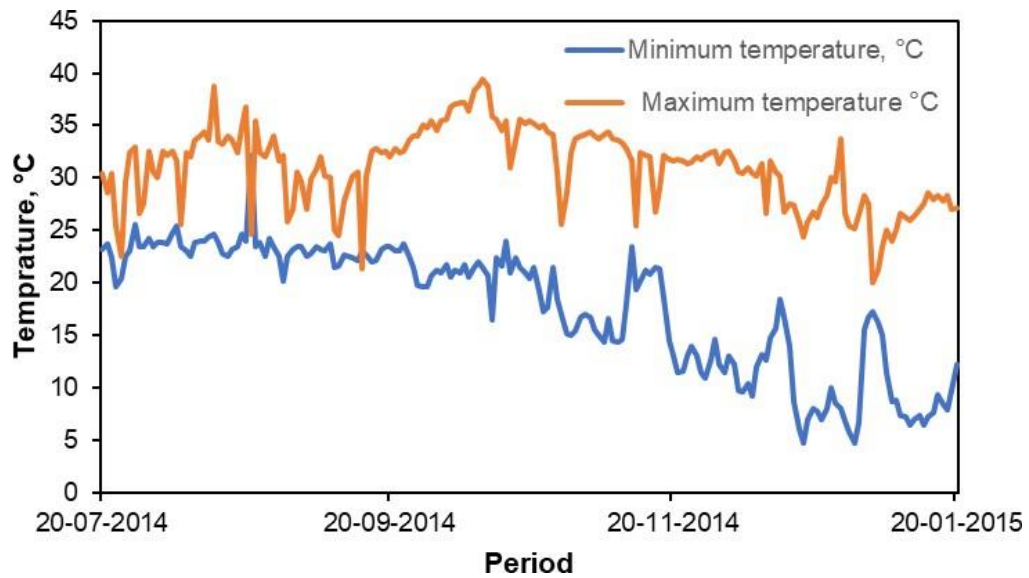


Fig. 3.1 Trend of maximum and minimum temperature (2014-15)

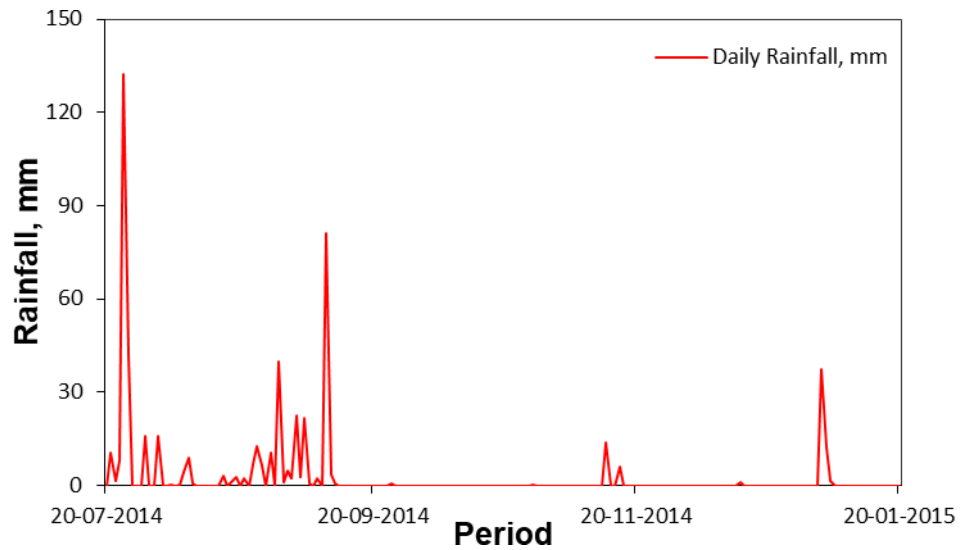


Fig.3.2 Trend of daily rainfall of year 2014-15

The minimum temperature for the period of study 2015-2016 varied from 4.6 to 24.4 °C whereas maximum temperature varied from 22.9 to 37.8 °C. The daily relative humidity, daily sunshine hours, wind speed and evaporation ranged between 13 to 98 %, 0.0 to 9.5 hr, 0.1 to 21.5 km/hr and 0 to 10.0 mm/day, respectively. The variation of minimum and maximum temperature as well as daily rainfall for year 2015-16 of study is depicted in Fig. 3.3 and 3.4.

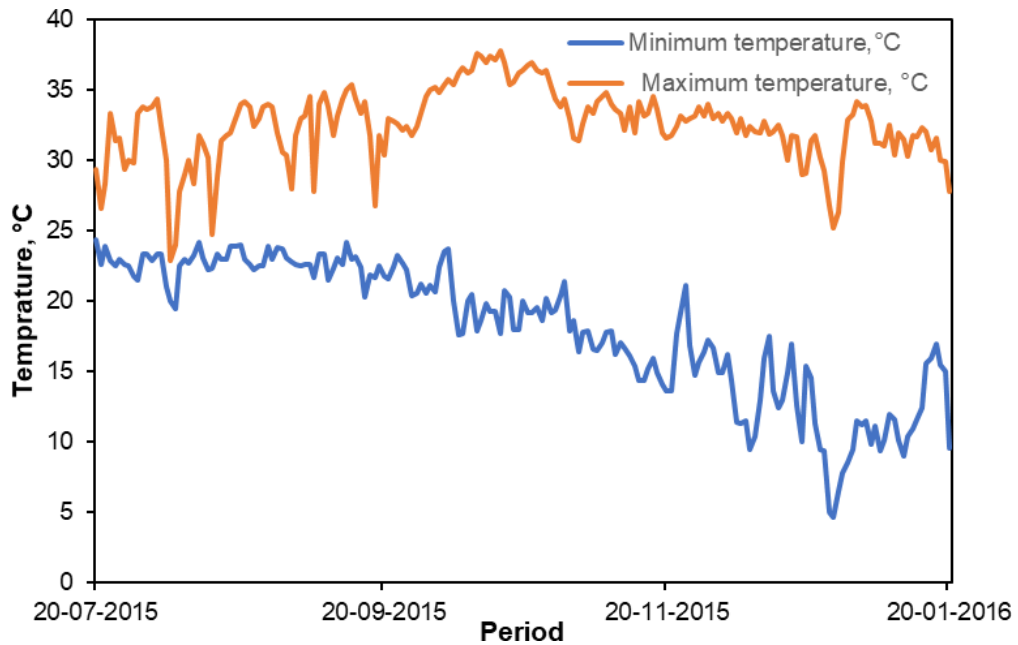


Fig. 3.3 Trend of maximum and minimum temperature (2015-16)

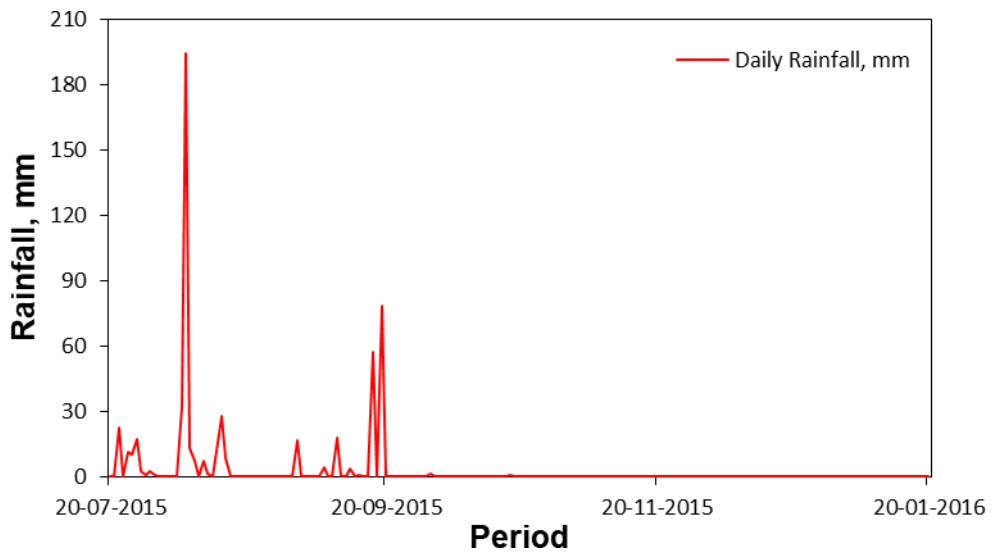


Fig. 3.4 Trend of daily rainfall of year 2015-16

The minimum temperature for the period of study 2016-2017 varied from 5 to 25.3 °C whereas maximum temperature varied from 24.2 to 34 °C. The daily relative humidity, daily sunshine hours, wind speed and evaporation ranged between 7 to 98 %, 0.0 to 10.1 hr, 0. to 10.1 km/hr and 1.5 to 6.8 mm/day, respectively. The variation of minimum and maximum temperature as well as daily rainfall for year 2016-17 of study is depicted in Fig. 3.5 and 3.6.

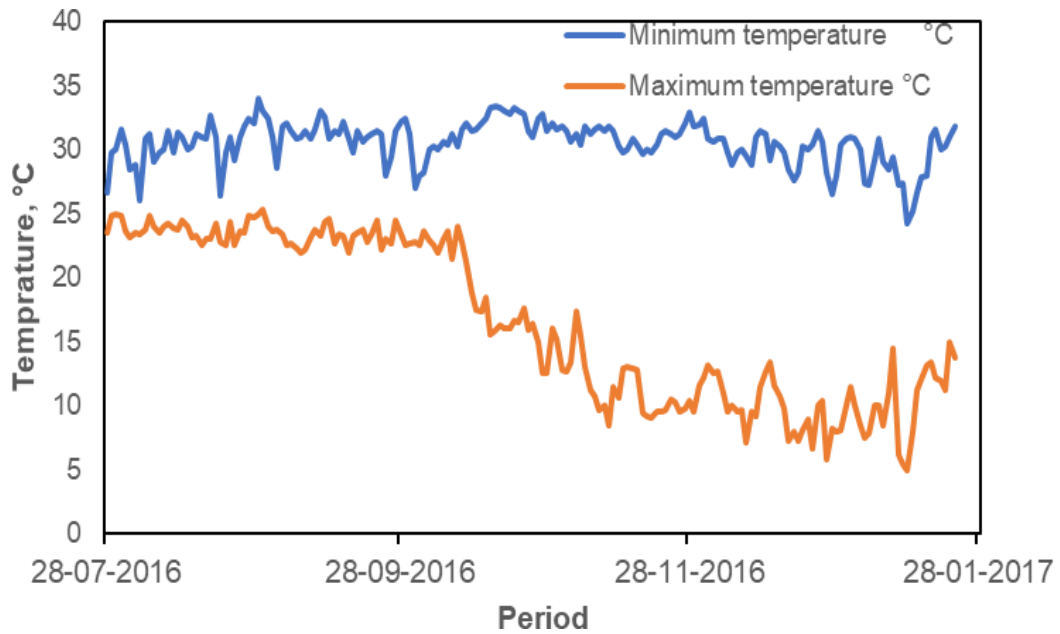


Fig. 3.5 Trend of maximum and minimum temperature (2016-17)

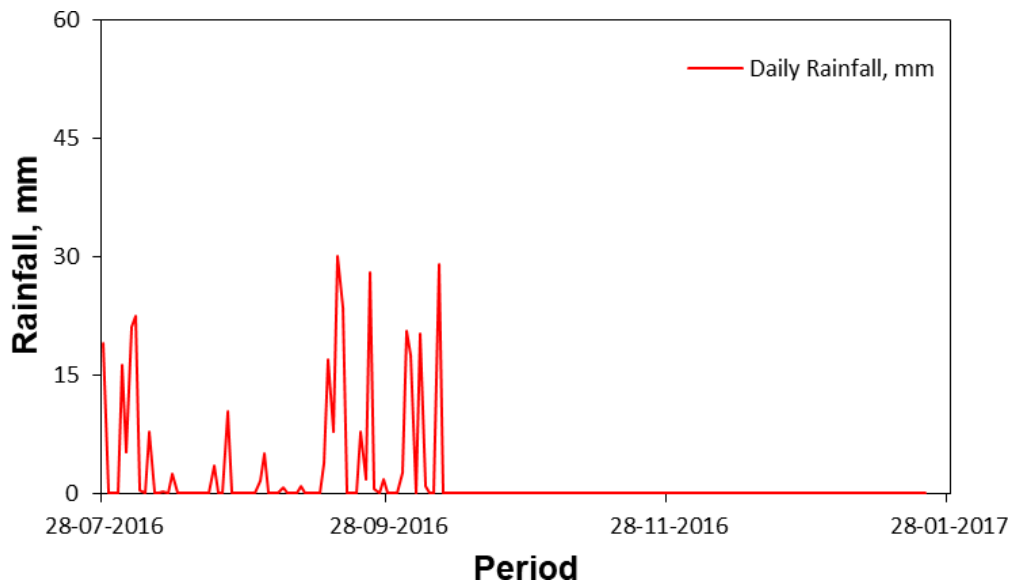


Fig. 3.6 Trend of daily rainfall of year 2016-17

3.1.4 Soil characterization

To characterize the soil at experimental plot, soil profile study was carried out. Soil samples were collected from respective soil horizons for physico-chemical analysis and results are presented in Table 3.1.

Table 3.1 Mechanical-chemical properties of experimental soil

Sr. No.	Particulars	Values
A.	Mechanical composition	
1	Sand (%)	45.74
2	Silt (%)	28.19
3	Clay (%)	26.07
4	Textured class	Sandy clay loam
B.	Chemical composition	
1	Soil organic carbon (%)	0.65
2	Available nitrogen (kg/ha)	234
3	Available phosphorus (kg/ha)	8.72
4	Available potassium (kg/ha)	324
5	pH	7.74
6	EC (dS/m)	4.43
C	Single value soil moisture constant	
1	Bulk density (g/cm ³)	1.51
2	Field Capacity (%)	28.24
3	Permanents wilting point (%)	17.20

3.1.5 Water source and its quality

The source of water on the experimental plot was bore well at Chilli and Vegetable Research Unit, Dr. PDKV, Akola. The water was conveyed to the field through pipe line. Before start of experiment, water was analyzed for its quality to evaluate different parameter. The result are presented in Table 3.2

Table 3.2 Chemical analysis of irrigation water

Sr. No.	Particulars	Observations
1	pH	7.24
2	EC (dS/m)	0.73
3	CO ₃ (meq/lit)	2
4	HCO ₃ (meq/lit)	8
5	Cl (meq/lit)	2.4
7	Ca + Mg (meq/lit)	2.4
8	Na (meq/lit)	3.2

3.1.6 Crop data

Crop-specific parameters required by AquaCrop model are plant density, yield, biomass, effective rooting depth, crop growth stages, while required user-specific parameters are crop cultivar, timing of crop cycle, water management and agronomic practices. The data was obtained from a field experiment (Fig 3.7) conducted earlier on the research farm of Chilli and Vegetable Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola., during the period July 2014 to January 2015, July 2015 to January 2016 and July 2016 to January 2017, of which details are given in Table 3.3 and 3.4.



Fig.3.7 Experimental plot of Chill

Table 3.3 Experimental details

Sr. No.	Particulars	Specification		
1.	Name of the crop	Chilli		
2.	Scientific name	<i>Capsicum annuum</i> L.		
3.	Variety	Jayanti		
4.	Planting time	Kharif season		
5.	Design	Randomized Block Design		
6.	Number of treatments	5		
7.	Number of replications	4		
8.	Number of plots	20		
9.	Plot size: Gross plot Net plot	4.2 m x 3.6 m 3.0 m x 2.4 m		
10.	Crop spacing	45 cm x 60 cm – 75 cm		
11.	Number of plants/plot	42		
12.	Duration of crop	2014-2015	2015-2016	2016-2017
		180	180 Days	173 Days
13.	Mulch	Silver/Black polyethylene mulch of 50 µm		
14.	Date of transplanting	2014-2015	2015-2016	2016-2017
		21 July 2014	21 July 2015	28 July 2016
14.	Date of harvesting	2014-2015	2015-2016	2016-2017
		5 Sept 2014 to 19 Jan 2015	7 Sept 2015 -19 Jan 2016	22 Sept 2016 -16 Jan 2017
16.	Dose of fertilizer	200:100:100 NPK kg/ha		

Table 3.4 Treatment details of field experiment

Treatments	Specification
T1	40 % ET with silver polyethylene mulch and drip fertigation
T2	60 % ET with silver polyethylene mulch and drip fertigation
T3	80 % ET with silver polyethylene mulch and drip fertigation
T4	100 % ET with silver polyethylene mulch and drip fertigation

The recommended fertilizer dose of 200:100:100 N:P:K Kg/ha was given through drip fertigation in 10 equal splits of N:P:K during the experimental work.

3.2 Water requirement of chilli at different level of ET under drip fertigation

The water requirement of chilli under drip irrigation at 100 % ET, 80 % ET, 60 % ET, and 40 % ET was worked out on the basis of pan evaporation.

The depth of water to be applied per plant was calculated by using Dick Krupp's formula given in equation 3.1

$$Q = A \times B \times C \times D \quad \text{.....(3.1)}$$

Where,

Q = Water requirement per plant (lit/plant)

A = $E_{To} = E_{pan} \times K_p$ (mm)

B = Crop coefficient (KC)

C = Canopy factor

D = Area allotted per plant (m^2)

E_{pan} = Cumulative evaporation for two days

K_p = Pan coefficient (0.8)

3.3 Irrigation scheduling during field experiment

Data of open pan evaporation and other climatic parameters were collected daily from the Agricultural Meteorological Observatory, Department of Agronomy, Dr. P.D.K.V., Akola and presented in Annexure-I.

Irrigation to chilli crop was scheduled on every alternate day considering the cumulative pan evaporation of previous two days. In case of precipitation, it was cumulated for the same previous two days and cumulative rainfall subtracted from cumulative evaporation. If cumulative evaporation was more than cumulative rainfall, then remaining evaporation was taken for calculating the water requirement. But if cumulative rainfall was more than cumulative evaporation, then irrigation was not applied on that scheduled day. Moreover, irrigation was not applied for next two days due to excess rainfall than evaporation and considering the two days (48 hrs) period for getting soil reach to its field capacity. The details of alternate day irrigation schedules are presented in Annexure-II.

3.4 Brief description of model

The complexity of crop responses to water deficits led to the use of empirical production functions as the most practical option to assess crop yield response to water. Among the empirical function approaches, *FAO Irrigation and Drainage Paper No. 33* (Doorenbos and Kassam, 1979) represented an important source to determine the yield response to water of field, vegetable and tree crops, through the following equation:

$$\left(1 - \frac{Y_a}{Y_x}\right) = k_y \left(1 - \frac{ET_a}{ET_x}\right) \quad \dots(3.2)$$

Where,

Y_x and Y_a - Maximum and actual yield,

ET_x and ET_a - Maximum and actual evapotranspiration, and

k_y -Crop yield factor

Continuous revision of above relationship by FAO experts resulted in AquaCrop model. It differs from the main existing models for its balance between accuracy, simplicity and robustness. The conceptual framework, underlying principles and distinctive component and features of AquaCrop are described by Steduto *et al.* (2009), while the structural details and algorithms are reported by Raes *et al.* (2009).

AquaCrop evolves from the previous Doorenbos and Kassam (1979) approach (Eq. 3.2) by separating (i) the ET into soil evaporation (E) and crop transpiration (Tr) and (ii) the final yield (Y) into biomass (B) and harvest index (HI). The separation of ET into soil evaporation (E) and crop transpiration (Tr) avoids the confounding effect of the non-productive consumptive use of water (E). This is important especially during incomplete ground cover. The separation of final yield (Y) into biomass (B) and harvest index (HI) allows the distinction of the basic functional relations between environment and biomass (B) from those between environment and HI. These relations are in fact

fundamentally different and their use avoids the confounding effects of water stress on biomass (B) and on harvest index (HI). The changes described led to the following equation at the core of AquaCrop growth engine:

$$B = WP \sum T_r \quad \dots(3.3)$$

Where,

B - Biomass

T_r - crop transpiration, mm and

WP - water productivity parameter, kg/m^2

The evolution of AquaCrop model is schematically described in Fig 3.8.

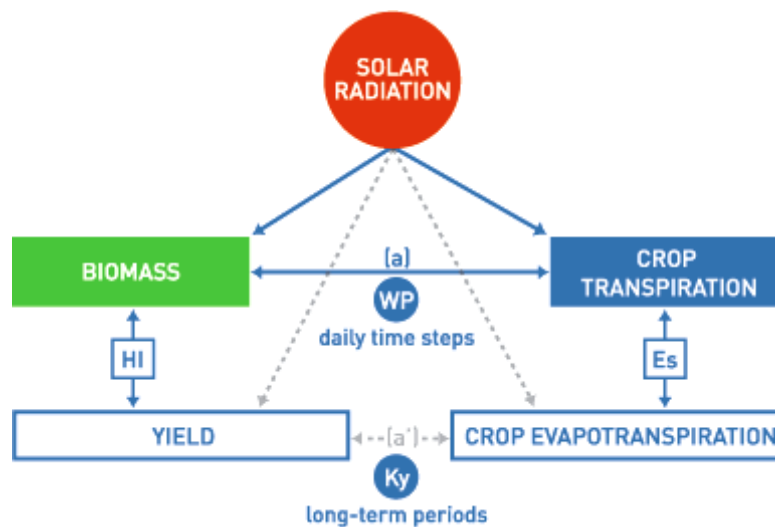


Fig 3.8 Schematic representation of evolution of AquaCrop

AquaCrop has a structure that includes the soil, with its water balance; the plant, with its development, growth and yield processes; and the atmosphere, with its thermal regime, rainfall, evaporative demand and carbon dioxide concentration. Additionally, some management aspects are explicitly considered (*e.g.*, irrigation, fertilization, *etc.*), as they will affect the soil water balance, crop development and therefore final yield. Pests, diseases, and

weeds are not considered. The functional relationships between the different model components are depicted in Fig. 3.9.

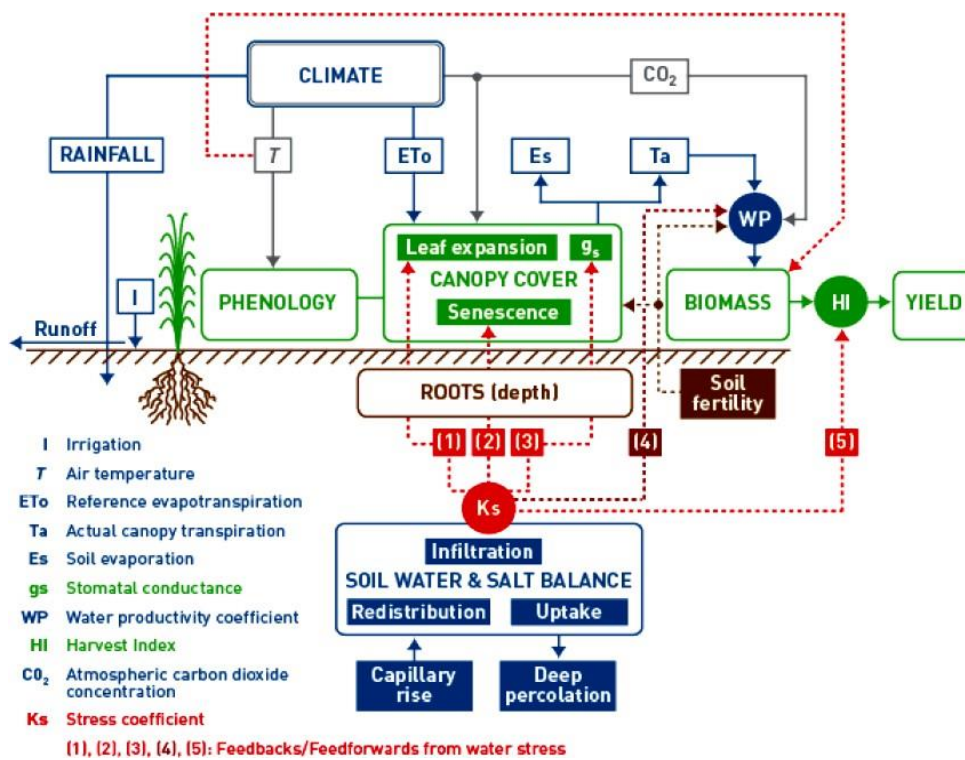


Fig 3.9 Main components of soil–plant–atmosphere continuum in AquaCrop model.

The canopy represents the source for actual transpiration that gets translated in a proportional amount of biomass produced through the water productivity parameter (WP) (Eq. 3.3). The harvestable portion of such biomass (yield) is then determined through harvest index (HI) as below.

$$Y = HI \times B \quad \dots(3.4)$$

Even though AquaCrop uses HI parameter, it does not calculate the partitioning of biomass into various organs (e.g. leaves, roots, etc.), i.e., biomass production is decoupled from canopy expansion and root deepening.

AquaCrop distinguishes four major crop types on the basis of their harvestable yields: fruit or grain producing crops, root and tuber producing crops, leafy vegetable producing crops and forage crops.

The normalization of WP for climate in AquaCrop is based on the atmospheric evaporative demand as defined by ET and the CO_2

concentration of the atmosphere. The goal is to make the WP value in the model specific for each crop applicable to diverse location and seasons, including future climate scenarios. The equation for calculating normalized water productivity (WP) is as given below:

$$WP = \frac{B}{\left[\sum \frac{T_r}{ET_o} \right]} \quad \dots(3.5)$$

Where,

WP - Water productivity

B - Biomass yield (B)

T_r - Transpiration

ET_o - Reference evapotranspiration

3.5 Model setup

The model was setup using create file menus. Using these menus input files for new climate, crop, irrigation management, soil profile, groundwater and field data were created.

3.5.1 Climate file

Climate file consists of creating a temperature file, ET0 file, rain file and CO2 file. While creating ET0, rain or temperature file, frequency or interval of data (daily, 10-days or monthly data) and time range was specified.

3.5.2 Crop file

While creating a crop file, type of crop (fruit/grain producing crops, leafy vegetable crops, roots and tubers, or forage crops) and parameters such as planting method, cropping period and length of growing cycle were specified. With the help of this information AquaCrop generates a complete set of required crop parameters. These included the planting dates, seedling emergence, duration of the various chilli physiological periods from sowing date and harvesting dates. Plant population was based on the recommended plant spacing for the site. The parameters are displayed and the values can be adjusted in the crop characteristics menu.

3.5.3 Soil profile file

To create a soil profile file, soil characteristics *viz.* soil type, number of horizons and their thickness were specified. With the help of this information AquaCrop generates a complete set of soil profile parameters. The parameters were displayed and the values can be adjusted in the soil profile characteristics menu.

3.5.4 Irrigation file

Type of irrigation file was specified first from the below, while creating an irrigation file:

- I. Net irrigation water requirement
- II. Irrigation schedule
- III. Generation of irrigation schedule

Subsequently in accordance to irrigation file specified, the following required information was also specified:

- a) The allowable depletion when determining the net irrigation requirement
- b) The time, application depth and the irrigation water quality of the successive irrigation events
- c) The irrigation water quality, time and depth criteria to generate irrigation events

3.5.5 Groundwater file

While creating groundwater file, type of file (from listed below) was specified first.

- I. Constant depth and water quality or
- II. Variable depth and water quality.

Subsequently, the depth and quality of the groundwater for various moments (if variable) in the season were specified in the groundwater characteristics menu.

3.5.6 Project file

In project file, type of file was specified first from the listed below.

- I. Single simulation run

- II. Successive years (multiple runs) or
- III. Crop rotation (multiple runs)

After creation of various files, sowing or planting date, simulation period and corresponding initial and off-season conditions were specified. The characteristics can be updated in the project characteristics menu.

3.5.7 Field data file

When creating a field data file, the assumed green canopy cover (CC) as obtained from field experiment data was specified in the Field Data menu.

3.6 Calibration and validation of model

Part of the obtained field data *i.e.*, data for irrigation treatment T1 to T4 for year 2014-2015 was used for calibration of the model, while the data of year 2015-2016 was used to validate the model for same treatments. The model was calibrated and validated by varying following parameters manually.

- i) Harvest index
- ii) Water productivity (WP)

AquaCrop version 6.1 was used in the study.

3.7 Model Performance

In addition to qualitative assessment with graphical displays using observed and simulated data set, the model simulation results were evaluated quantitatively using various statistical measures described below. Various performance measures were used in reference to the conclusion of Yapo *et al.* (1998) that any single performance measure may not adequately measure the ways in which model fails to match the important characteristics of target data. In accordance to the recommendation of ASCE (1993) task committee Nash Sutcliffe coefficient and a statistical measure *i.e.* Root mean square error were used to judge the performance of the model.

a) Nash-Sutcliffe coefficient of efficiency

Nash-Sutcliffe coefficient of efficiency (R^2_{NS}) is used to assess predictive power of hydrological models. R^2_{NS} is described by following formula (Nash and Sutcliffe, 1970)

$$R_{NS}^2 = 1 - \frac{\sum (Q_o - Q_s)^2}{\sum (Q_o - Q_{av})^2} \quad \dots(3.6)$$

where,

Q_o - observed values

Q_s - simulated values

Q_{av} - mean of observed values

Nash-Sutcliffe coefficient of efficiency can range from -∞ to 1. R_{NS}^2 value of 1 therefore indicate perfect fit. An efficiency of zero indicates that the model predictions are as accurate as the mean of observed data. Closer the model efficiency to 1, more accurate is the model. Model efficiency less than 0.7 correspond to a very poor fit (Coulibaly *et al.* 2000).

b) Root mean square error (RMSE)

The root mean square error or RMSE is one of the most widely used statistical indicators (Jacovides and Kontoyiannis, 1995) and measures the average magnitude of the difference between predictions and observations. It ranges from 0 to positive infinity, with the former indicating good and latter poor model performance. A big advantage of the RMSE is that it summarizes the mean difference in the unit of P and O. It does however not differentiate between over and underestimation.

$$RMSE = \sqrt{\frac{\sum_1^n (P_i - O)^2}{n}} \quad \dots(3.7)$$

where,

n - number of observations

P_i - Predicted value

O - Observed value

A disadvantage of RMSE is the fact that the residual errors are calculated as squared values, which has the result that the higher values in a time series

are given a larger weight compared to lower values (Legates and McCabe, 1999).

3.8 Testing of Formulated Irrigation Schedules (2016-17)

The objective of irrigation in the present era is not only to provide supplementary water for crop production but also to increase crop per drop of water. Mulching reduces the water requirement by restricting evaporation losses. The irrigation schedules commonly followed in traditional drip irrigation system apply more water when it is combined with mulches. Thus, an attempt is made here to verify different irrigation schedules developed based on different values of crop evapotranspiration during the year 2016-17.

Table 3.5. Formulation of irrigation schedules

Schedule	Particular
S0	Irrigation scheduling at 100 % ET _c
S1	Irrigation scheduling at 80 % ET _c
S2	Irrigation scheduling at 60 % ET _c
S3	Irrigation scheduling at 40 % ET _c

3.9 Simulation of AquaCrop model

The calibrated model was used to evaluate the impacts of different irrigation schedules on performance of chilli production. Water use efficiency (WUE) is a useful indicator for quantifying the impact of irrigation schedule in regard to water management. WUE refers to the ratio between the total yield of irrigated chilli and total irrigation water applied (Michael, 1978).

$$WUE = \frac{\text{Total chilli yield, kg}}{\text{Total water applied, m}^3} \dots\dots(3.8)$$

3.10 Comparison of AquaCrop results with field observations

AquaCrop model was calibrated for the year 2014-15 and without any further adjustment model was validated for the period 2015-16. After obtaining both calibration and validation results satisfactory model was tested for

different irrigation schedules (Table 3.5) for the year 2016-17 and obtained results by model were compared with experimental outputs of year 2016-17.

CHAPTER IV

RESULTS AND DISCUSSION

The research project entitled “Calibration and Validation of AquaCrop model for irrigated Chilli Crop” was carried out at Department of Irrigation and Drainage Engineering, Dr. PDKV, Akola. This study was conducted to calibrate and validate the AquaCrop model for irrigated chilli crop for the period of 2014-15 and 2015-16 respectively. This study also comprises the testing of different irrigation schedules for the year 2016-17. The observations recorded and results obtained are discussed in this chapter.

4.1 Calibration and validation of AquaCrop model

AquaCrop model was set up as per procedure described in Article 3.3 and by providing initial values for the following parameters;

Table 4.1 Conservative and cultivar specific parameters

Description	Value		
Base temperature, °C	10		
Upper temperature,	30		
Crop type	Fruit/Grain producing crop		
Date of transplanting	2014-2015	2015-2016	2016-2017
	21 July 2014	21 July 2015	28 July 2016
Date of harvesting	2014-2015	2015-2016	2016-2017
	5 Sept 2014 - 19 Jan 2015	7 Sept 2015 - 19 Jan 2016	22 Sept 2016 -16 Jan 2017
Growing cycle, days	2014-2015	2015-2016	2016-2017
	180	180	173
Mode of planting	Transplanting		
Harvest, days	2014-2015	2015-2016	2016-2017
	136	134	116
Root system	Shallow rooted crop		
Maximum effective root zone depth, m	0.80		

4.1.1 Calibration of AquaCrop model for the year 2014-15

AquaCrop model was calibrated for the period from 22nd July 2014 to 20th Jan 2015 *i.e.*, crop period, using field data for irrigation treatment T1 to T4. AquaCrop was calibrated manually by varying model parameters (Art. 3.4). To judge the performance of model, observed values of experimental outputs *i.e.*, yield of Chilli and canopy cover were compared with simulated outputs. The performance of model is discussed in the following sections.

4.1.1.1 Yield of chilli

The variation of observed and simulated yield is presented in Table 4.2.

Table 4.2 Cumulative Observed and Simulated yield during 2014-15

Irrigation level	Observed yield (q/ha)	Simulated yield (q/ha)
T1 (40 % ET with PM)	117.81	124.61
T2 (60 %ET with PM)	147.09	133.90
T3 (80 % ET with PM)	198.27	183.73
T4 (100 % ET with PM)	187.39	175.62
R ² NS	0.87	
RMSE (q/ha)	11.93	

The observed yield of chilli varied between 117.81 q/ha to 198.27 q/ha. Whereas simulated yield of chilli varied from 124.61 q/ha to 183.73 q/ha.

Nash Sutcliffe coefficient (R²NS) value found as 0.87 for chilli yield which shows close match between observed and simulated yield. Whereas Root mean square error (RMSE) is found as 11.93 q/ha between observed and simulated yield.

Variation of observed and simulated yield is presented in Fig. 4.1, while Fig. 4.2 shows comparison of observed and simulated yield.

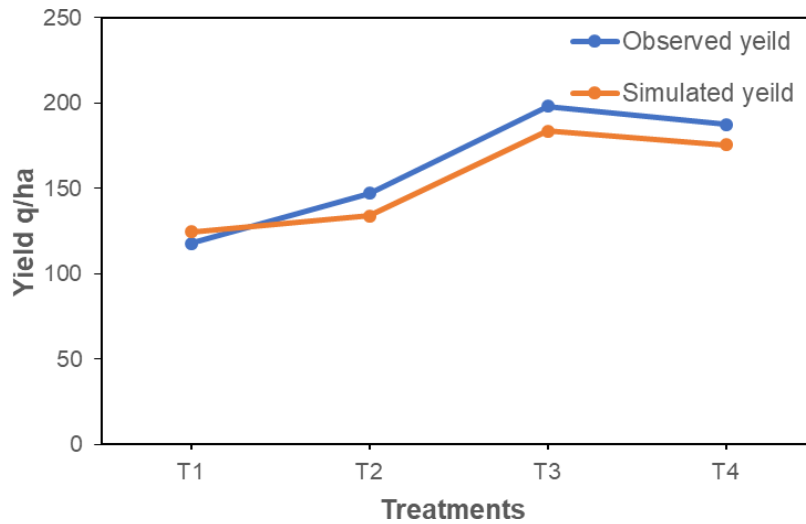


Fig 4.1 Observed and simulated yield for calibration period (2014-15)

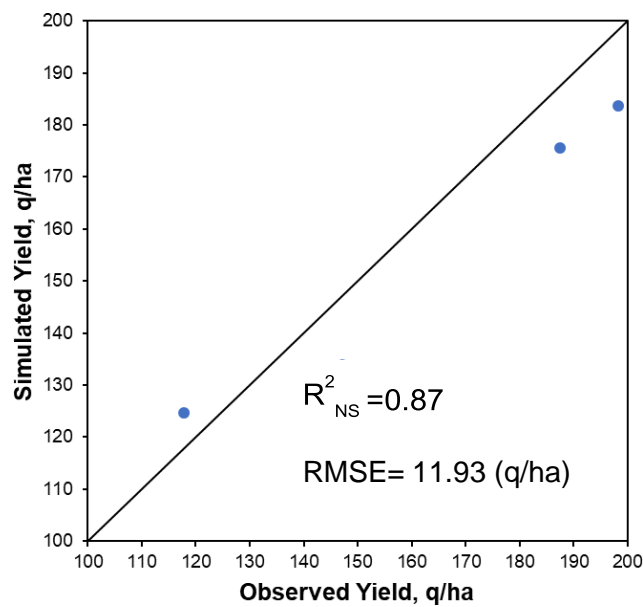


Fig. 4.2 Comparison between observed and simulated yield for calibration period (2014-15)

Fig. 4.1 shows that there was a close match between observed and simulated values. It was supported by high value of R^2_{NS} (0.87). As simulated values of yield lie on both side of 1:1 line, it was cleared from the scatter plot that model does not overestimate or underestimate the parameters consistently (Fig.4.2).



4.1.1.2 Canopy of chilli

The variation of observed and simulated canopy during calibration period is presented in Table 4.3. Table 4.3 also shows the statistical results obtained for each irrigation level.

Table 4.3 Statistical analysis of observed and simulated canopy cover for calibration period 2014-15

Irrigation level	DAT	Observed Canopy (%)	Simulated Canopy (%)	R ² _N _S	RMSE (%)
T1 (40 % ET with PM)	30	19	8.1	0.77	8.2
	60	39.9	30.3		
	90	55.9	62		
	120	62.9	67.1		
T2 (60 % ET with PM)	30	22.6	9.1	0.82	8.5
	60	46.5	43		
	90	64.9	74.2		
	120	74.9	77.9		
T3 (80 % ET with PM)	30	26.9	11.8	0.88	7.7
	60	58.7	60		
	90	78.7	80.3		
	120	84.7	82.5		
T4 (100 % ET with PM)	30	25.7	10.2	0.86	8.1
	60	54.1	50.4		
	90	75.3	76.8		
	120	82.4	79.7		

The graphical display of canopy cover obtained for each irrigation level during calibration of AquaCrop model is presented in Fig. 4.3.

 Simulated canopy
 Observed canopy

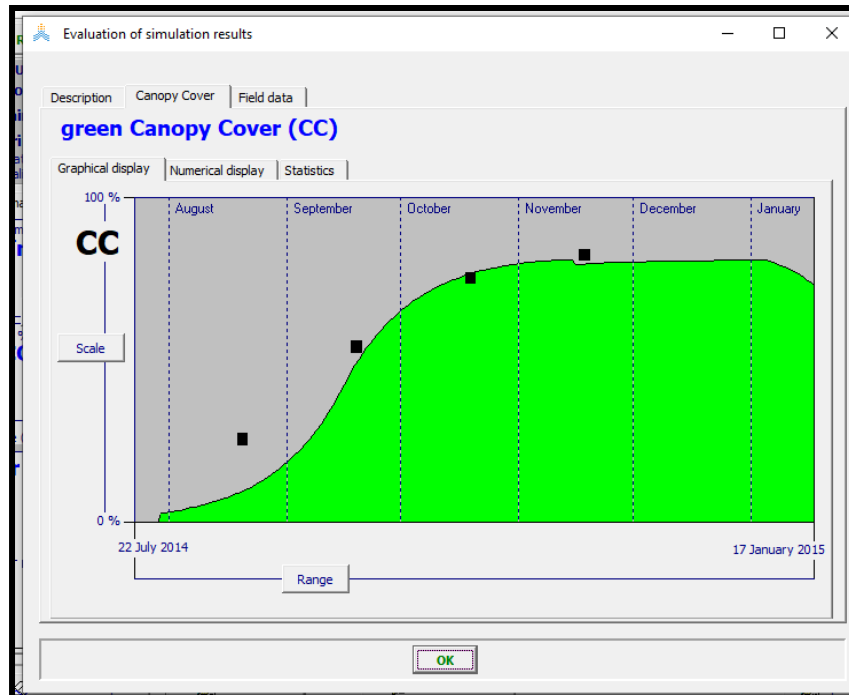


Fig. 4.3(a) Graphical display of canopy for T₄ (100 % ET with PM) during calibration period (2014-15)

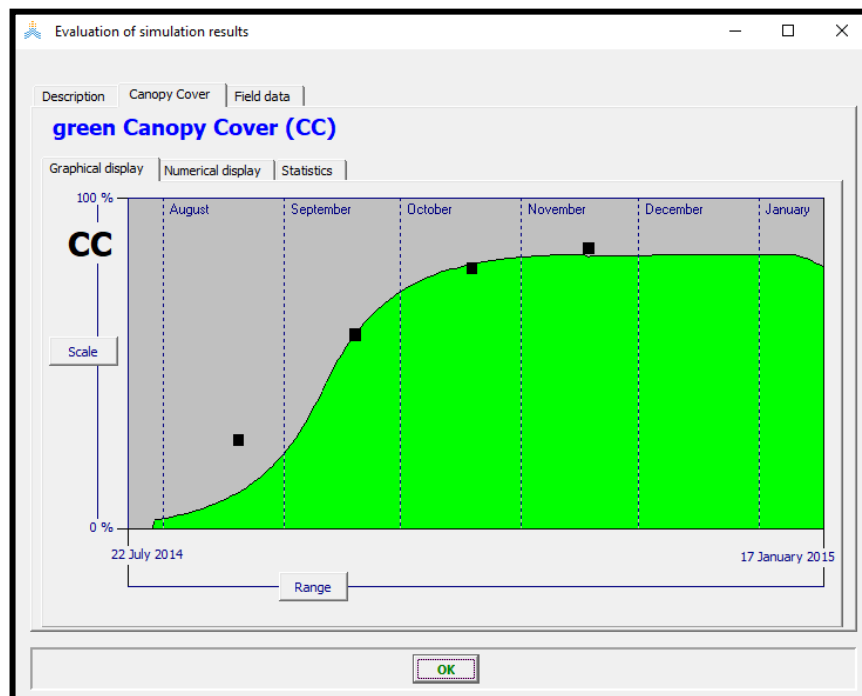


Fig. 4.3(b) Graphical display of canopy for T₃ (80 % ET with PM) during calibration period (2014-15)

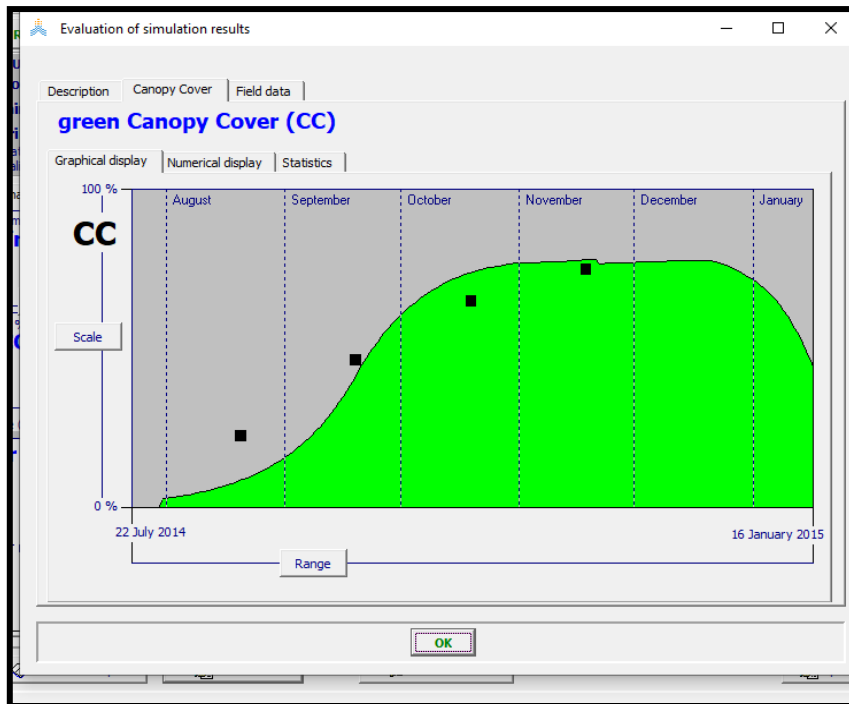
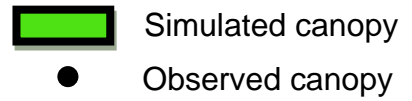


Fig. 4.3(c) Graphical display of canopy for T₂ (60 % ET with PM) during calibration period (2014-15)

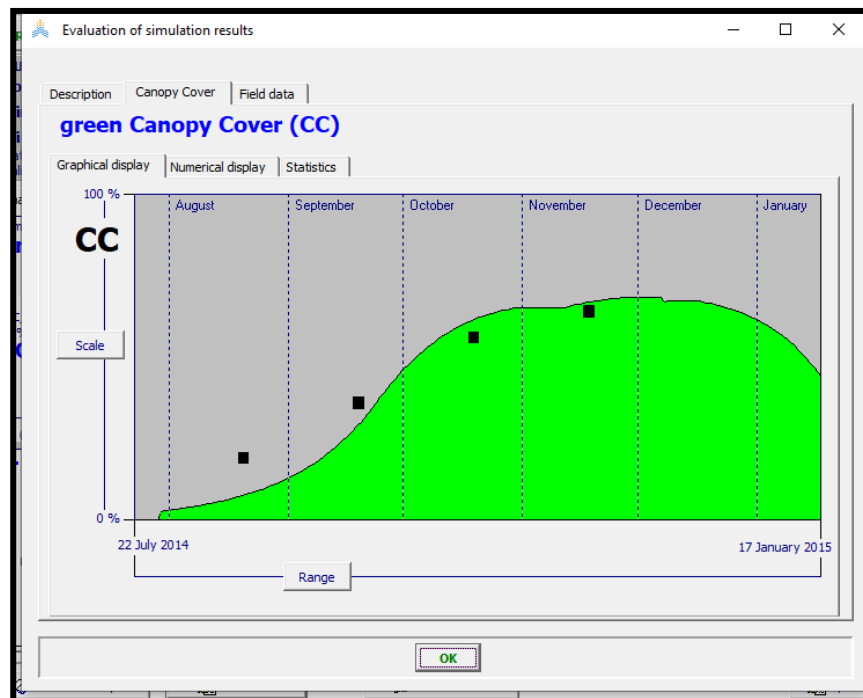


Fig. 4.3(d) Graphical display of canopy for T₁ (40 % ET with PM) during calibration period (2014-15)

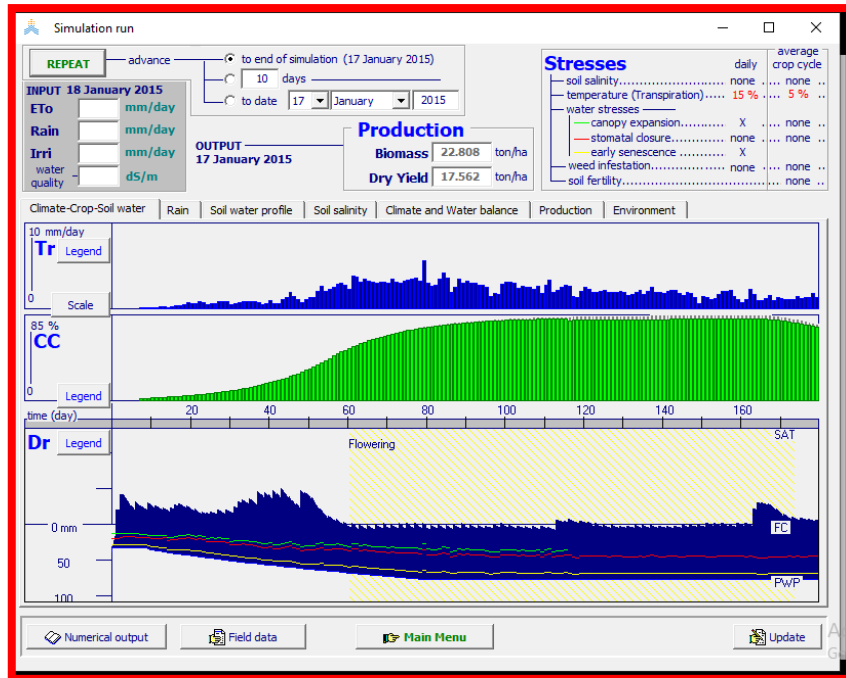


Fig. 4.4 Model generated transpiration, canopy cover and soil moisture in the root zone for drip irrigation at T₄ (100% ET with PM) for Calibration period (2014-15).

AquaCrop model was calibrated by varying harvesting index and water productivity manually for matching yield. Model generated transpiration, canopy cover and soil moisture in the root zone for drip irrigation at 100% ET with PM (T₄ for 2014-15) for calibration period was depicted in Fig. 4.4. It indicates that soil moisture in the root zone was almost at field capacity throughout the crop period except for rainy days during crop period. The canopy cover was found to be well matched. Similar calibration process was followed for other three irrigation levels of the calibration period i.e., T₁, T₂ and T₃. For harvesting index of 77 % and water productivity 18 g/m², model predicted yield was 175.62 q/ha for T₄ for the calibration period.

Above results showed that the model calibration was satisfactory as the observed and simulated values of canopy cover and chilli yield matched well, and also statistical parameters R²_{NS} and RMSE were in acceptable limit. Hence, the AquaCrop model setup was considered as calibrated. Calibrated model parameters are presented in Table 4.4.

Table 4.4 Calibrated model parameters

Description	Measure
Harvesting index, %	77
Water productivity (WP), g/m ²	18

4.2 Model validation for year 2015-16

Model validation is in fact the extension of calibration process. Thus, validation was carried out without any further adjustments to the calibrated model parameters. The model was validated during the period 20th July 2015 to 20th Jan 2016 for irrigation levels T₁ to T₄. The cumulative yield for validation period for each treatment were simulated with model and presented in Table 4.5. Table 4.5 also presents the results of statistical tests for validation period.

Table 4.5 Statistical analysis of validated results for yield (2015-2016)

Irrigation level	Observed yield(q/ha)	Simulated yield(q/ha)
T ₁ (40 % ET with PM)	115.08	121.17
T ₂ (60 %ET with PM)	141.4	140.32
T ₃ (80 % ET with PM)	184.88	192.72
T ₄ (100 % ET with PM)	176.69	184.4
R ² _{NS}	0.95	
RMSE (q/ha)	6.30	

The observed yield varied between 115.08 to 184.88 q/ha for year 2015-2016, whereas simulated yield of chilli varied between 121.17 to 192.72 q/ha for validation period.

Nash Sutcliffe coefficient (R²_{NS}) value was found as 0.95 for validation period which shows close match between observed and simulated yield. Root mean square error value was observed as 6.30 q/ha. Both statistical parameters were found in acceptable limit for the validation period.

Temporal variation of observed and simulated yield is presented in Fig. 4.5, while Fig. 4.6 shows comparison of observed and simulated yield for validation period (2015-16).

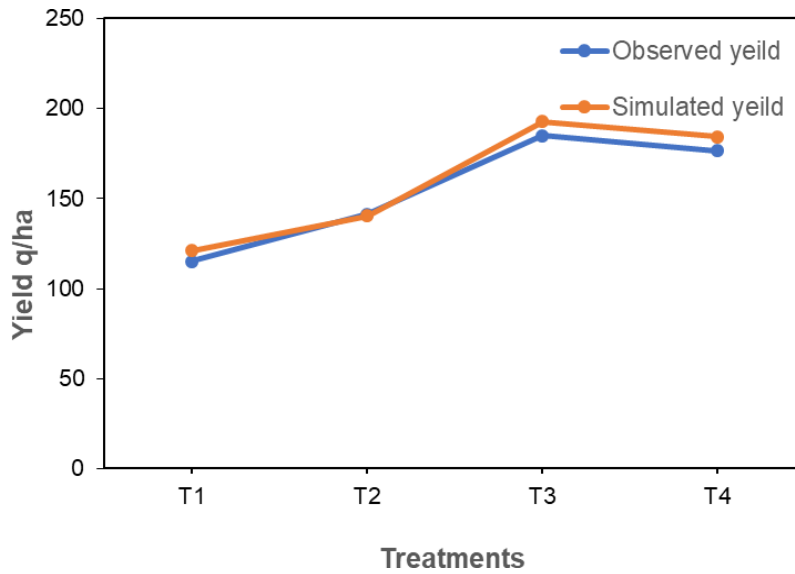


Fig. 4.5 Observed and simulated yield for validation period (2015-16)

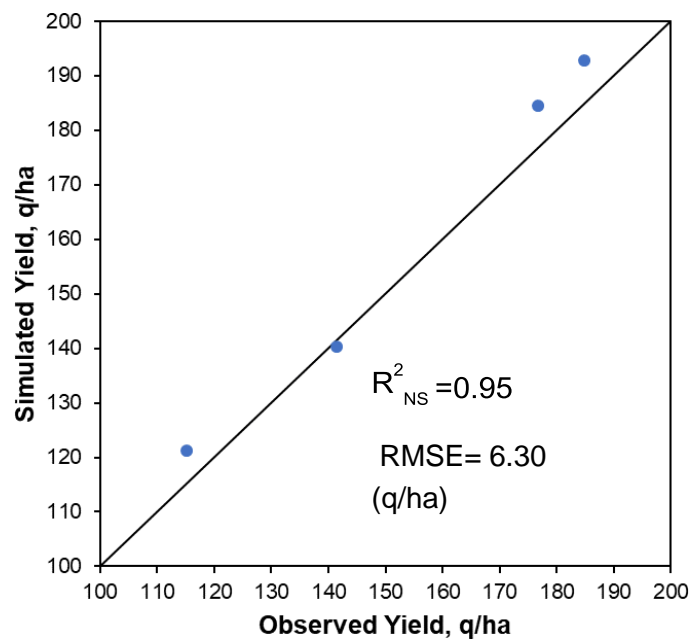


Fig. 4.6 Comparison between observed and simulated yield for validation (2015-16)

Fig. 4.5 shows that there is a close match between observed and simulated yield, whereas from Fig.4.6. It is seen that the model does not overestimate or underestimate the parameters consistently.

The variation of observed and simulated canopy during validation period is presented in Table 4.6. Table 4.6 also shows the statistical results obtained for each irrigation level.

Table 4.6 Statistical analysis of validated results for canopy (2015-16)

Irrigation level	DAT	Observed Canopy (%)	Simulated Canopy (%)	R ² _{NS}	RMSE(%)
T ₁ (40 % ET with PM)	30	18.5	7.4	0.71	9.7
	60	43.5	27.7		
	90	59.4	60.9		
	120	65.2	63.1		
T ₂ (60 % ET with PM)	30	25	8.2	0.80	9.2
	60	45	38.8		
	90	70	73.7		
	120	77	79.8		
T ₃ (80 % ET with PM)	30	30	10.5	0.77	11.4
	60	64	56.9		
	90	86	79.8		
	120	90	83.1		
T ₄ (100 % ET with PM)	30	28	9.2	0.74	11.7
	60	58	46.6		
	90	79	76.1		
	120	87	79.5		

The graphical display of canopy cover obtained for each irrigation level during validation of AquaCrop model is presented in Fig. 4.7

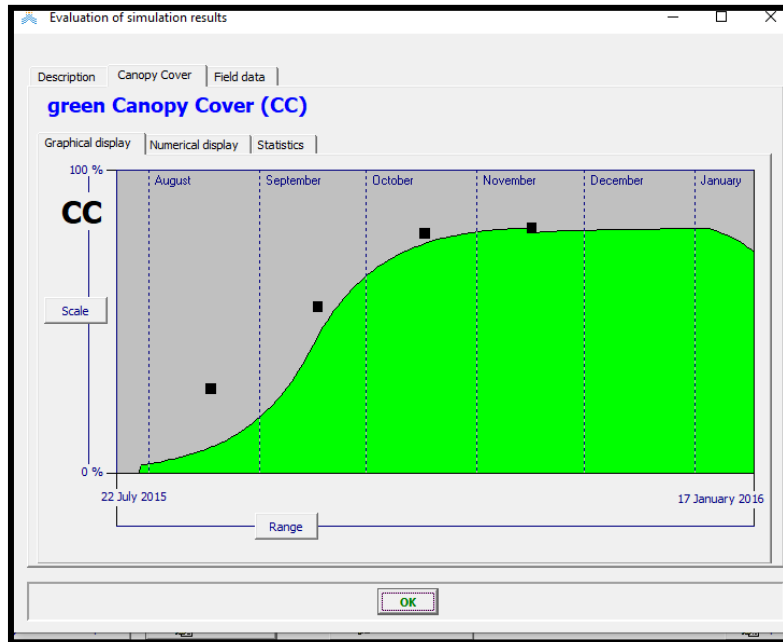
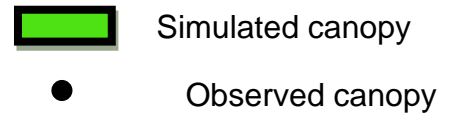


Fig. 4.7(a) Graphical display of canopy for T₄ (100 % ET with PM) during validation period (2015-16)

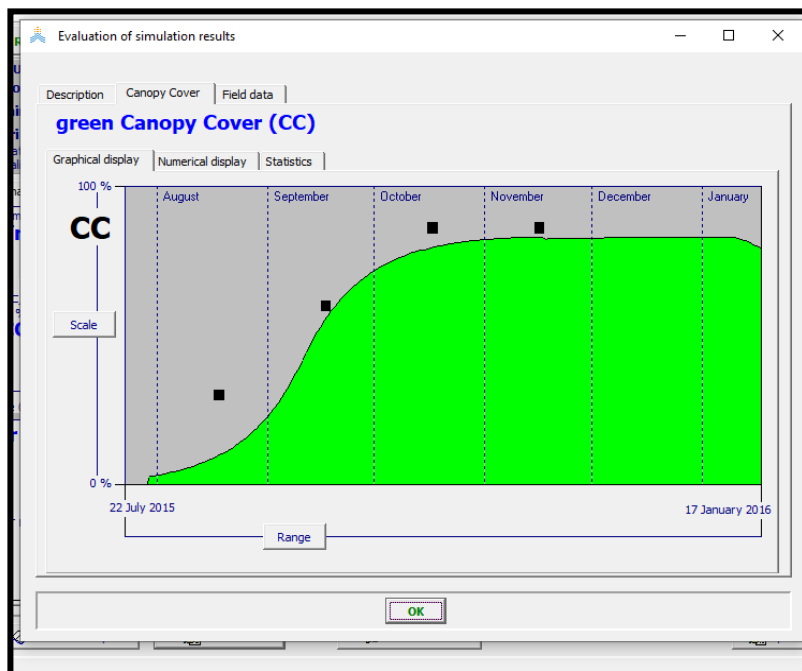


Fig. 4.7(b) Graphical display of canopy for T₃ (80 % ET with PM) during validation period (2015-16)

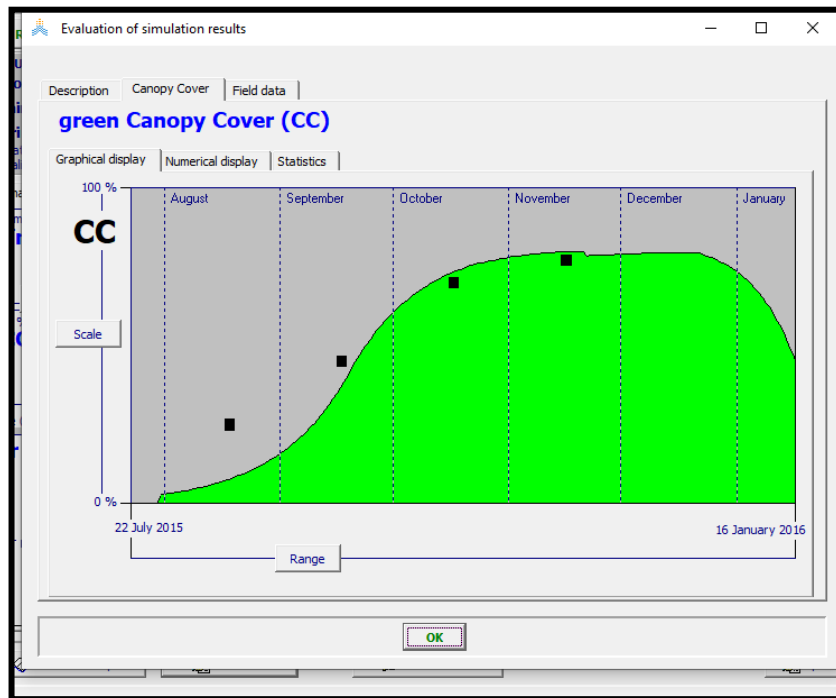
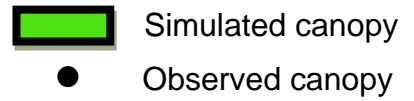


Fig. 4.7(c) Graphical display of canopy for T₂ (60 % ET with PM) during validation period (2015-16)

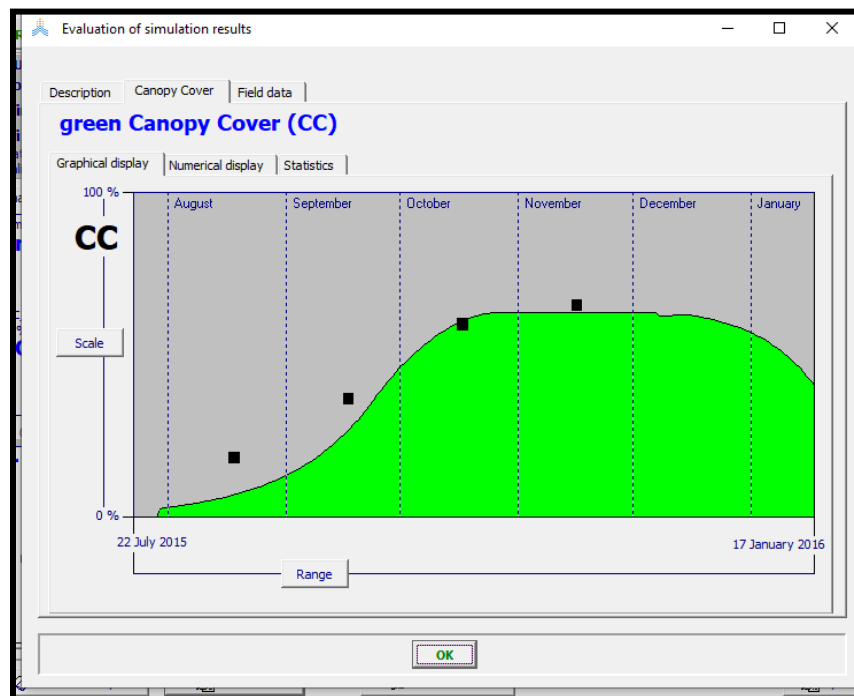


Fig. 4.7(d) Graphical display of canopy for T₁ (40 % ET with PM) during validation period (2015-16)

4.7 Testing of AquaCrop model for different irrigation schedules formulated during 2016-17

The calibrated model was tested for the period of 28th July 2016 to 23rd Jan 2017 for four different irrigation schedules viz. irrigation scheduling with polyethylene mulch at 100% ET (S₀), irrigation scheduling with polyethylene mulch at 80% ET (S₁), irrigation scheduling with polyethylene mulch at 60% ET (S₂) and irrigation scheduling with polyethylene mulch at 40 % ET (S₃).

During testing of AquaCrop model, model estimated water use efficiency (WUE) for different developed irrigation schedules as well as model also simulated the yield according to the irrigation schedules. Respective outputs of simulated yield and WUE are presented in Table 4.7.

Table 4.7 Water use efficiency and simulated yield for different irrigation schedules

Irrigation Schedule	Water applied, mm		Yield, q/ha		Water use efficiency, kg/m ³	
	During field experiment	By model	Obs.	Simulated	Obs.	Simulated
S ₀ (100 % ET with PM)	388.03	333	169.69	182.60	4.37	5.22
S ₁ (80 % ET with PM)	327.05	267	188.40	188.86	5.76	5.13
S ₂ (60 % ET with PM)	266.06	215	144.23	139.77	5.42	5.21
S ₃ (40 % ET with PM)	205.08	172	113.11	124.71	5.51	5.32

For irrigation schedules from S0 to S3, WUE varied between 5.13 to 5.32 kg/m³. Whereas simulated yield for irrigation schedules from S0 to S3 varied from 124.71 q/ha to 188.86 q/ha. Maximum simulated yield obtained for schedule S1 (80 % ET with PM). The model generated transpiration, canopy cover and soil moisture in the root zone for schedule S0 , S1 , S2 and S3 are depicted in Fig. 4.8, Fig. 4.9 , Fig. 4.10 and Fig. 4.11, respectively.

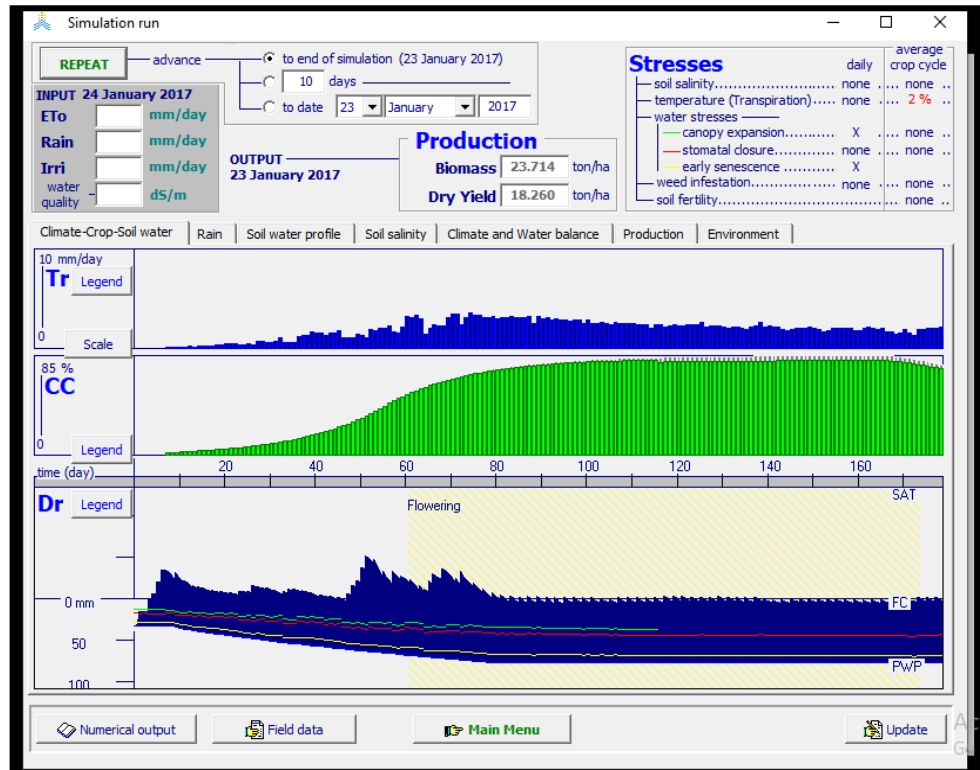


Fig. 4.8 Model generated transpiration, canopy cover and soil moisture in the root zone for schedule S0

Fig. 4.8 clears that soil moisture in the root zone is at field capacity throughout the crop period except during rainy days where soil moisture level shows greater moisture content than that of field capacity. Soil moisture content during vegetative stage was found more than that of field capacity, which may have slight adverse effect on growth & yield of chilli crop. Simulated yield obtained for schedule S0 were 182.60 q/ha.

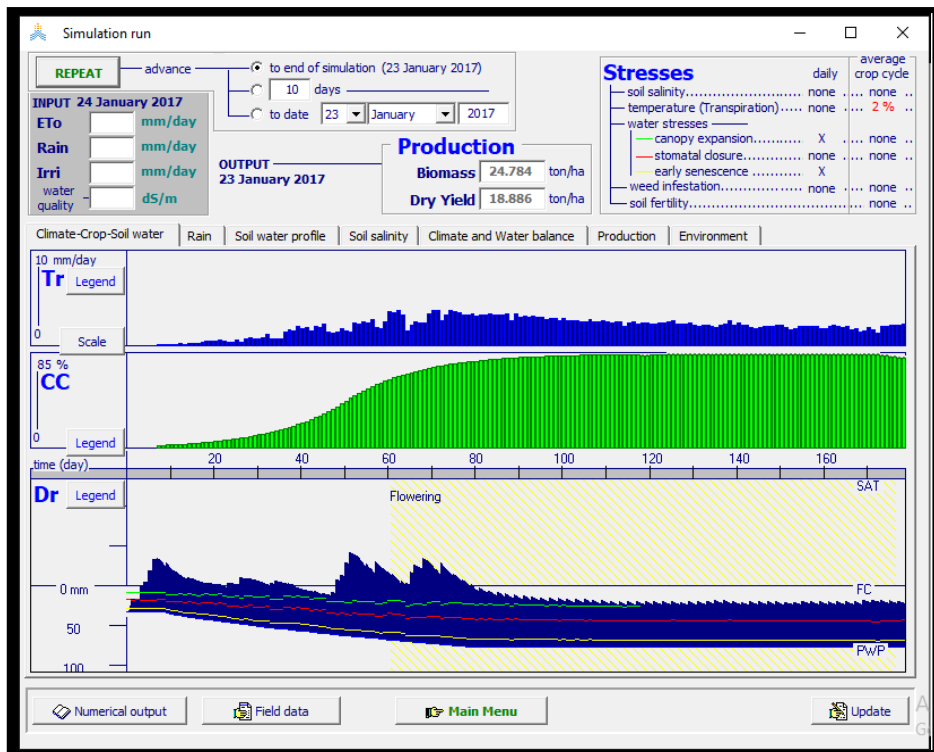


Fig. 4.9 Model generated transpiration, canopy cover and soil moisture in the root zone for schedule S1

Fig. 4.9 clears that constant water is applied in the root zone near the field capacity of soil for schedule S1. Though 20 % less water is applied, chilli production is maximum i.e. 188.86 q/ha. It is also seen that for schedule S1, canopy cover and transpiration is better as compared to that for schedule S0 with added advantage of saving of 20% water.

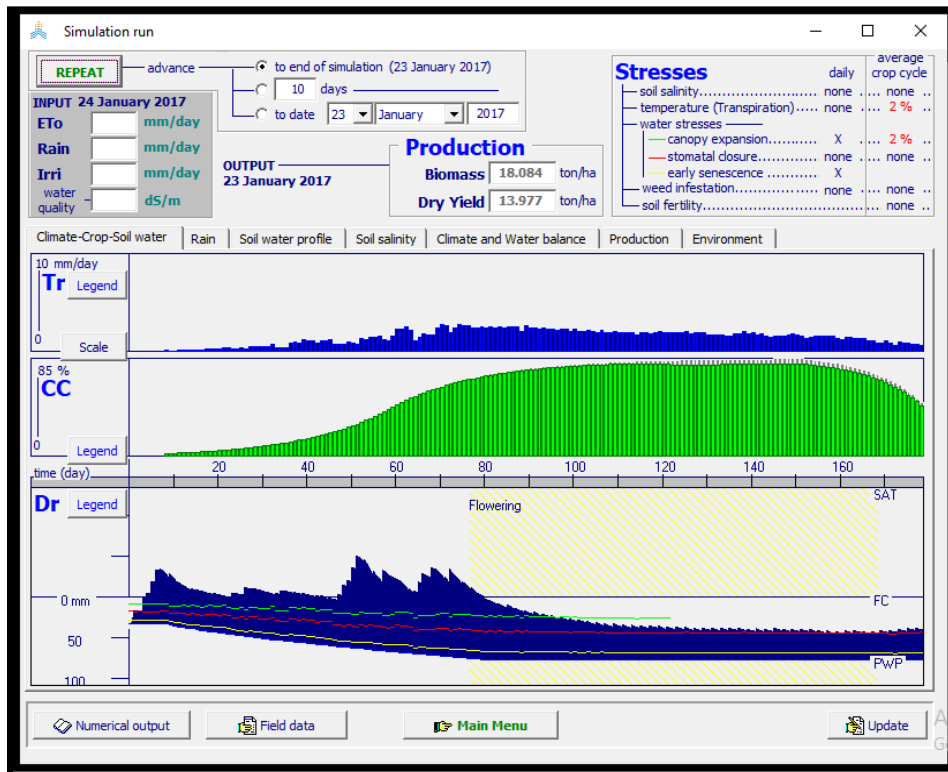


Fig. 4.10 Model generated transpiration, canopy cover and soil moisture in the root zone for schedule S2

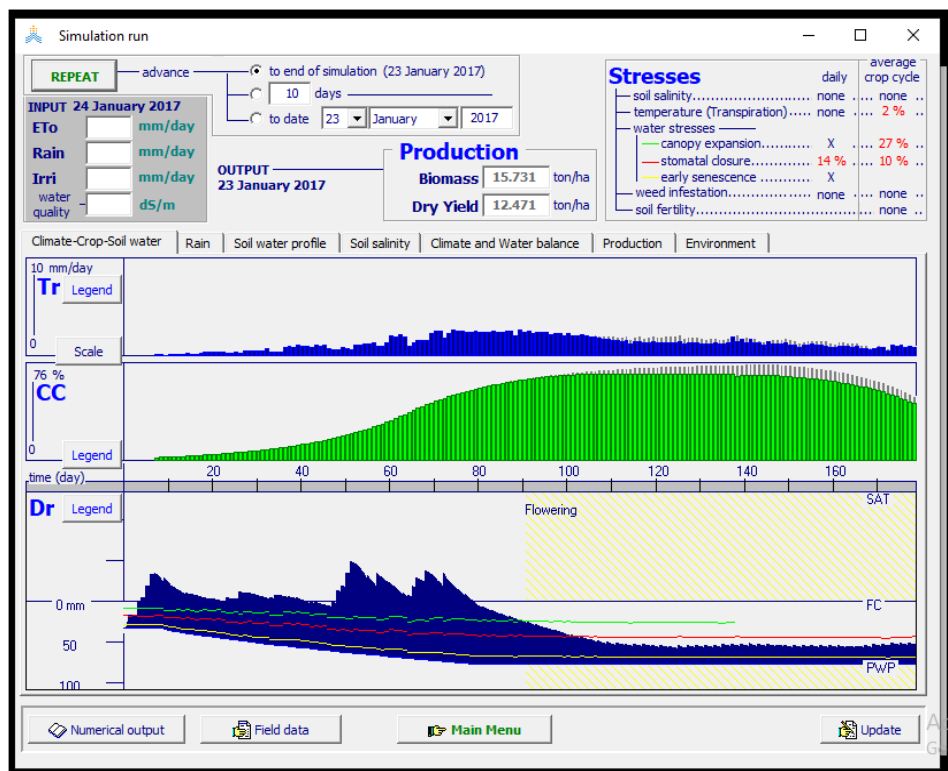


Fig. 4.11 Model generated transpiration, canopy cover and soil moisture in the root zone for schedule S3

Fig. 4.9 shows that for schedule S1 simulated yield was found as 188.86 q/ha and it also shows that there was less water applied as compared to the schedule S0 in the root zone and it is near to that of field capacity for most of the growth period. Similarly, from Fig. 4.10 and Fig. 4.11 the variation between yield obtained, water applied, model generated canopy cover and transpiration can be clearly seen for schedule S2 and S3, which shows water stress during most of growth period, particularly in flowering & fruiting stages. That is why these two schedules yielded less compared to S0 & S1.

4.8 Comparing model output with field result

The simulated yield, yield obtained from field experiment *i.e.*, observed yield and variation in water applied for different irrigation schedules were presented in Table 4.8

Table 4.8 Observed and simulated crop yield during model testing

Irrigation Schedule	Observed yield (q/ha)	Simulated yield (q/ha)	Variation in water applied, %
S0 (100 % ET with PM)	169.69	182.6
S1 (80 % ET with PM)	188.4	188.86	20
S2 (60 % ET with PM)	144.23	139.77	40
S3 (40 % ET with PM)	113.11	124.71	60

From Table 4.8 it clears that observed yield varied from 113.11 to 188.4 q/ha during year 2016-17 whereas model simulated yield varied between 124.71 to 188.86 q/ha for irrigation schedule S0 to S3. The variation

between water applied ranged from 20 to 60 % over that were applied in control irrigation schedule.

It was seen from Table 4.8 that irrigation schedule S1(80 % ET with PM) recorded maximum yield for observed output as well as for AquaCrop model simulation run when compared to other three irrigation schedules. Irrigation schedule S1 (80 % ET with PM) used 20 % less water as compared to controlled treatment and also gave 3.3 % more yield from controlled treatment (S0).

Temporal variation of observed and simulated yield is presented in Fig. 4.12, while Fig.4.13 shows comparison of observed and simulated yield for period 2016-17.

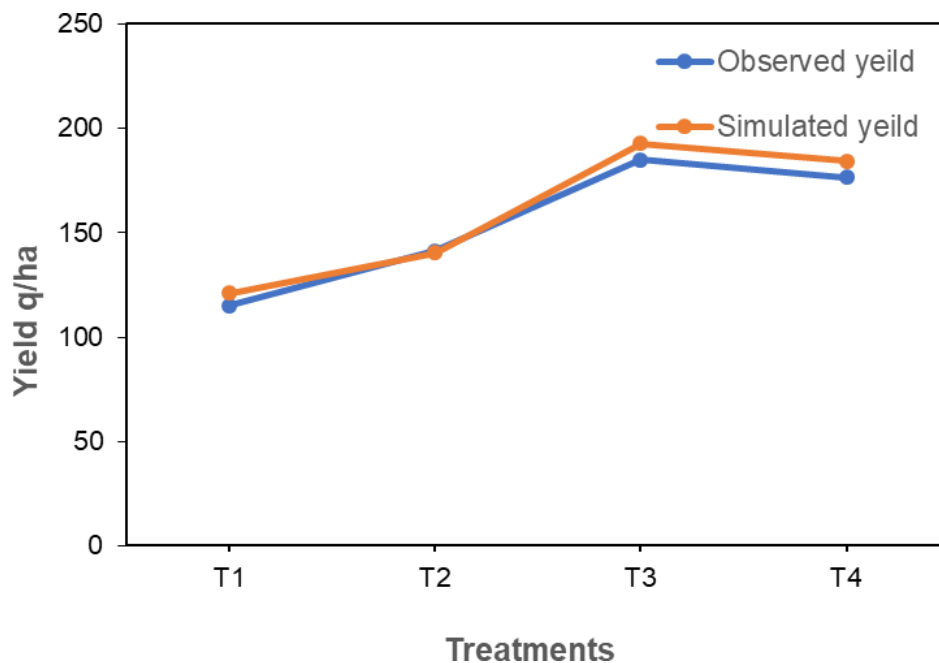


Fig. 4.12 Observed and simulated yield for period (2016-17)

Above Fig. 4.12 shows that there is a close match between observed and simulated yield, whereas from Fig.4.13 it is seen that the model does not overestimate or underestimate the parameters consistently for the period 2016-17 as shown as follow.

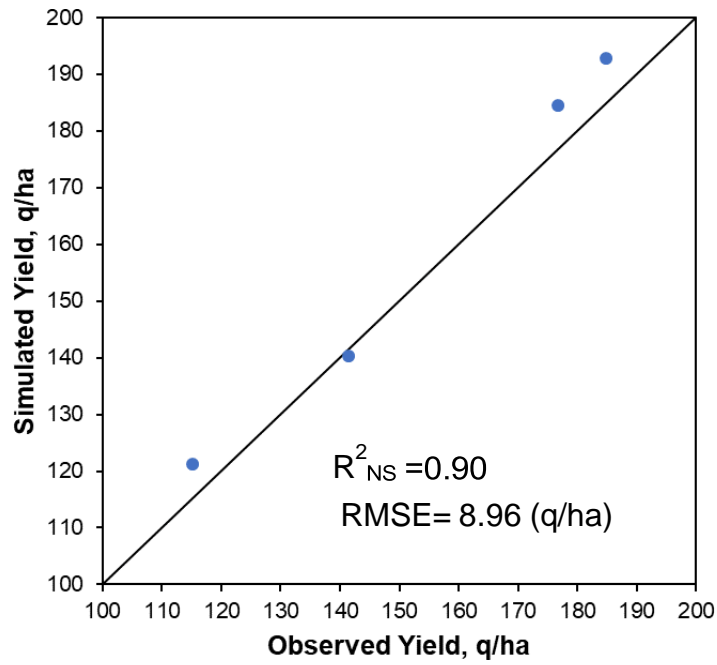


Fig. 4.13 Comparison between observed and simulated yield for period (2016-17)

CHAPTER V

SUMMARY AND CONCLUSIONS

Irrigated agriculture is the largest water-consuming sector and it faces competing demands from other sectors, like industrial and domestic. Increasing demand and scarcity of water makes it important to use available water in most economic ways. Since land is a shrinking resource for agriculture, the pathway for achieving this goal has to be higher productivity per unit of available land and water. Thus, the objective of irrigation in the present era is not only to provide supplementary water for crop production but also to increase crop per drop of water. As such, the question of improving the present level of water use efficiency in general and for irrigation in particular assumes a great significance in perspective water resource planning. Keeping these points in view, the research project entitled “Calibration and Validation of AquaCrop model for irrigated Chilli Crop” was carried out at Department of Irrigation and Drainage Engineering, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, during 2020-21. Investigation was undertaken with the following objectives:

- I. To calibrate and validate AquaCrop model for Irrigated Chilli.
- II. To verify the field result with that of validated model.

The experiment was conducted in such a way that AquaCrop model was calibrated for the year 2014-15 and then it was validated for the year 2015-16. Testing of AquaCrop model for different irrigation schedules were done for the year 2016-17.

The data required for conducting research *i.e.*, daily climatological data, crop data, soil data, water quality data, data of daily irrigation applied for different treatments, field condition data, groundwater data etc., was collected from previous field experiments on chilli carried out during years 2014-15, 2015-16 and 2016-17 at Chilli and Vegetable Research Unit, C.R.S., Dr. PDKV, Akola.

The specific results obtained are summarized below

- I. AquaCrop model proved its capability in simulating canopy cover, biomass and yield. The AquaCrop model was calibrated for year 2014-15 for drip irrigation at 40% ET, 60% ET, 80% ET and 100% ET with polyethylene mulch. The calibrated model parameters *i.e.* harvesting index and water productivity were observed as 77% and 18 g/m².
- II. Nash Sutcliffe coefficient (R^2_{NS}) value was found as 0.87 whereas, Root mean square error (RMSE) was found as 11.93 q/ha during the calibration period of 2014-15.
- III. The model validation was carried out without any further adjustments to the calibrated model parameters. The model was validated for the period 20th July 2015 to 20th Jan 2016 for the same treatments *i.e.*, T1 to T4. Nash Sutcliffe coefficient (R^2_{NS}) value was found as 0.95 for year 2015-16. Whereas, Root mean square error value was found as 6.30 q/ha for the validation period.
- IV. Nash Sutcliffe coefficient (R^2_{NS}) value was found as 0.90 whereas, Root mean square error (RMSE) was found as 8.96 q/ha for the year 2016-17.
- V. AquaCrop model was tested for different irrigation schedules formulated during 2016-17 and it was observed that irrigation schedule S1 (80 % ET with PM) was best fitted in terms of water saving and yield obtained as compared to other irrigation schedules.
- VI. The obtained statistical parameters values were well in acceptable limits that shows close match between observed and simulated yield as well as canopy for the calibration and validation period.

Conclusions

- I. Considering overall acceptability of validation results in terms of statistical parameters, it was concluded that model performs well with relatively high validity and field experiment results verified results of AquaCrop model.
- II. As potential of AquaCrop model in predicting yield of chilli in response to water for western Vidarbha region is verified, it confirmed the capability of AquaCrop model. It is therefore recommended to use this model to improve yield of chilli in response to water.

- III. Overall, the observed and simulated results for chilli were good with R^2 NS and RMSE. Respecting the simplicity and small number of parameters in AquaCrop compared to other different models, we can recommend that, the calibrated model (V 6.1) could be used as a decision support tool for predicting chilli yield under different water management strategies.
- IV. It is recommended to implement irrigation schedule S1(80 % ET with PM) as it saves 20% water and increase the yield of chilli crop by by 3.3% as compared to irrigation schedule S0(100 % ET with PM). Hence, irrigation schedules S2(60 % ET with PM) and S3(40 % ET with PM) resulted in lower yields.

CHAPTER VI

BIBLIOGRAPHY

- Abdelrahman NA, Elgailani AA, Elshiekh AI and Ahmed MEN (2016). The Effect of Plastic Mulch on Growth and Yield of Rain-fed Cowpea and Watermelon in North Kordofan State of Sudan. *World Journal of Agricultural Research*, 4(5): 139-142.
- Abedinpour M, Sarangi A, Rajput TBS, Singh, Man, Pathak H, Ahmad T (2012). Performance evaluation of AquaCrop model for maize crop in a semi-arid environment. *Agricultural Water Management*, 110: 55– 66.
- Abrha B, Delbecque N, Raes D, Tsegay A, Todorovic M, Heng L, Vanutrecht E, Geerts S, Garcia-Vila M and Deckers S (2012). Sowing strategies for barley (*Hordeum vulgare* L.) based on modelled yield response to water with Aquacrop. *Expl Agric.*, 48 (2): 252–271.
- Ahmadi SH, Mosallaeepour E, Kamgar-Haghighi AA, and Sepaskhah AR (2015). Modeling maize yield and soil water content with AquaCrop under full and deficit irrigation managements. *Water Resource Management*, 29:2837–2853.
- Andarzian A, Bannayan M, Steduto P, Mazraeh H, Barati ME, Barati MA and Rahnama A (2011). Validation and testing of the AquaCrop model under full and deficit irrigated wheat production in Iran. *Agricultural Water Management*, 100: 1– 8.
- Araya A, Habtu S, Hadgu KM, Kebede A and Dejene T (2010a). Test of AquaCrop model in simulating biomass and yield of water deficient and irrigated barley (*Hordeum vulgare*). *Agricultural Water Management*, 97: 1838–1846.
- Araya A., Keesstra SD and Stroosnijder L (2010b). Simulating yield response to water of Teff (*Eragrostis tef*) with FAO's AquaCrop model. *Field Crops Research*, 116:196–204.
- ASCE Task Committee on Definition of Criteria for Evaluation of Watershed Models of Watershed Management Committee, Irrigation and Drainage Division (1993). Criteria for evaluation of watershed models. *J. Irrig. and Drain. Engg*, 119(3): 429-442.
- Ashrafuzzaman M and Halim MA (2011). Effect of plastic mulch on growth and yield of chilli (*Capsicum annuum* L.). *An International JBiological and Applied Sciences*, 54(2): 321-330.
- Bhatt L, Rana R, Uniyal SP and Singh VP (2016). Effect of mulch materials on vegetative characters, yield and economics of summer squash (*Cucurbitapepo*) under rainfed mid-hill condition of Uttarakhand. *Vegetable Science*, 38(2):165-168.

- Casa A, Ovando G, Bressanini L and Martinez J. 2013. AquaCrop Model Calibration in Potato and Its Use to Estimate Yield Variability under Field Conditions Atmospheric and Climate Sciences 3: 397-407.
- Coulibaly P, Anctil F, and Bobee B (2000). Daily reservoir inflow forecasting using artificial neural networks with stopped training approach. *J. Hydrol.*, 230: 244-257.
- Darko RO, Shouqi Y, Haofang Y, Junping L and Abbey A (2016). Calibration and validation of AquaCrop for deficit and full irrigation of tomato. *Int J Agric & Biol Eng*, 9(3): 104-110.
- Devaranavadi, Vivek S., Shirahatti, S.S. and Patil, M.G. (2011). Effect of different drip irrigation levels on growth and yield of bitter melon (*Momordica charantia*. L) in semi-arid conditions of Karnataka. *Internat. J. Agric. Engg.*, 4(2): 179-182.
- Diaz-Perez JC (2010). Bell Pepper (*Capsicum annum L.*) grown on plastic film mulches: Effects on crop microenvironment, physiological attributes, and fruit yield. *Hortscience* 45(8):1196–1204.
- Dimple, Bhakar S.R., Lakhawat S.S. and Kothari M. (2017). Effect of deficit irrigation and plastic mulch on yield and water use efficiency of drip irrigated capsicum under naturally ventilated polyhouse. *Int. J. Curr. Microbial. App. Sci.* 6(12): 2878-2889.
- Doorenbos J and Pruitt WJ (1977). Guidelines for predicting crop water requirements. *Irrigation and Drainage Paper No. 24*, FAO, Rome:30-35.
- Doorenbos J, Kassam AH, and Bentvelsen CIM (1979). Yield response to water, Rome. Food and Agriculture Organization of the United Nations.
- Droogers P, Hunink J (2012). Assessment of Impact of Climate Change on Wheat in Armenia, Azerbaijan and Georgia. Regional Analytical and Advisory Activities Program on Developing Adaptation and Mitigation Strategies in the Agricultural Sector for Armenia, Azerbaijan and Georgia. *Future Water*, 1-42.
- Garcia-Vila M and Fereres E (2012). Combining the simulation crop model AquaCrop with an economic model for the optimization of irrigation management at farm level. *Europ. J. Agron.*, 36: 21– 31.
- Garcia-Vila M, Fereres E, Mateos L, Orgaz F and Steduto P (2009). Deficit irrigation Optimization of Cotton with AquaCrop. *Agron. J.* 101: 477–487.
- Geerts S, Raes D and Garcia M (2010). Using AquaCrop to derive deficit irrigation schedules. *Agricultural Water Management*, 98: 213–216.

- Heidariniya M, Naseri AA, Boroumandnasab S, Moshkabadi BS and Nasrolahi AH (2012). Evaluation of AquaCrop model application in irrigation management of Cotton. *World Rural Observations* 4(2): 55-59.
- Heng LK, Hsiao T, Evett S, Howell T, and Steduto P (2009). Validating the FAO AquaCrop Model for Irrigated and Water Deficient Field Maize. *Agron. J.*, 101: 488-498.
- Hsiao TC, Heng L, Steduto P, Rojas-Lara B, Raes D and Fereres E (2009). AquaCrop—The FAO Crop Model to Simulate Yield Response to Water: III. Parameterization and Testing for Maize. *Agron. J.*, 101: 448–459.
- Kiptum CK, Kipkorir EC, Munyao TM and Ndambuki JM (2013). Application of AquaCrop model in deficit irrigation management of cabbages in Keiyo Highlands, *International J. of Water Resources and Environmental Engg.* 5(7): 360-369.
- Kumar P, Sarangi A, Singh DK and Parihar SS (2014). Evaluation of AquaCrop model in predicting wheat yield and water productivity under irrigated saline regimes. *Irrigation and Drainage*, 63(4): 474- 487.
- Laulina K; Hasan M; Singh D K; (2019). Response of different colour plastic mulches on water dynamics under drip fertigated greenhouse capsicum (*Capsicum annuum*). The Indian Journal of Agricultural Sciences, Vol 89, No 3 (2019).
- Michael AM., (1978) Irrigation Engineering: Theory and Practice. Vikas Publishing House, New Delhi: 457.
- Mkhabela MS and Bullock PR (2012). Performance of the FAO AquaCrop model for wheat grain yield and soil moisture simulation in Western Canada. *Agricultural Water Management*, 110: 16– 24.
- Nash JE, and Sutcliffe JV (1970). River flow forecasting through conceptual models part 1 - a discussion of principles. *J. Hydrol.*, 10: 282–290.
- Nazeer Muhammad and Hussain Ali (2012) Modeling the response of onion crop to deficit irrigation. *Journal of Agricultural Technology* 8(1): 393-402.
- Paul JC, Mishra JN, Pradhan PL, and Panigrahi B (2013). Effect of drip and surface irrigation on yield, water use efficiency and economics of capsicum (*Capsicum annum* L.) grown under mulch and non mulch conditions in eastern coastal India. *European Journal of Sustainable Development*, 2(1): 99-108.
- Raes D, Steduto P, Hsiao TC and Fereres E (2009). AquaCrop The FAO Crop Model to Simulate Yield Response to Water: II. Main Algorithms and Software Description. *Agronomy J.*, 101 (3): 438.

- Raes D, Steduto P, Hsiao TC and Fereres E (2012). Reference manual AquaCrop 4.0, FAO, <<http://www.fao.org/nr/water/AquaCrop.html>
- Rajablariani HR, Hassankhan F and Rafezi R (2012). Effect of Colored Plastic Mulches on Yield of Tomato and Weed Biomass. *International J of Environmental Science and Development*, 3(6): 590-593.
- Reference Manual, Chapter 1 – AquaCrop, Version 6.0 – 6.1 (FAO) Rome, May 2018.
- Reference Manual, Chapter 2 – AquaCrop, Version 6.0 – 6.1 (FAO) Rome May 2018.
- Saadati Z, Pirmoradian N and Rezaei M (2011). Calibration and Evaluation of AquaCrop Model in Rice Growth Simulation under Different Irrigation Managements. *ICID 21st International Congress on Irrigation and Drainage, Tehran, Iran* IC R.56.5/Poster/14.
- Sam-Amoah LK, Darko RO and Owusu-Sekyere JD (2013). Calibration and validation of AquaCrop for full and Deficit Irrigation of hot Pepper. *ARPJ*, 8(2): 175-178.
- Sandhu SS, Mahal SS and Kaur P (2015). Calibration, validation and application of AquaCrop model in irrigation scheduling for rice under northwest India. *Journal of Applied and Natural Science*, 7 (2): 691–699.
- Sethi RR, Mandal KG, Sarangi A, Behera A, Aggarwal R, Brar AS Sahu AS, Bandyopadhyay KK and Ambast SK (2016). Simulating paddy crop response to irrigation using FAO AquaCrop model: A case study. *Journal of Food, Agriculture & Environment*, 14 (2): 99 – 103.
- Seyfi K and Rashidi M (2007). Effect of drip irrigation and plastic mulch on crop yield and yield components of cantaloupe: *International J. of Agriculture & Biology*, 1560–8530: 247–249.
- Singh A, Saha S and Mondal S (2013). Modelling irrigated wheat production using the FAO AquaCrop model in West Bengal, India, for sustainable agriculture. *Irrig. and Drain*. 62: 50–56.
- Steduto P, Hsiao TC, Raes D, and Fereres E (2009). AquaCrop—The FAO crop model to simulate yield response to water: I. Concepts and Underlying Principles. *Agron. J.*, 101(3): 426-437.
- Stricevic R, Cosic M, Djurovic N, Pejic B and Maksimovic L (2011). Assessment of the FAO AquaCrop model in the simulation of rainfed and supplementally irrigated maize, sugar beet and sunflower. *Agricultural Water Management*, 98: 1615– 162.
- Supekar SJ, Kadale AS and Bhagyawant RG.2019. Calibration of FAO-aquacrop model for summer chilli (*Capsicum annuum* L.) in

- Marathwada region. *International Journal of Chemical Studies* 2020; 8(1):2574-2578.
- Thokal RT, Jadhav PB, Mane MS, Bhangre HN and Kale SR (2014). Strategies of Deficit Irrigation in Canal Command. *International Journal of Engineering Innovation & Research*, 3(6): 921-929.
- Todorovic M, Albrizio R, Zivotic L, Abi-Saab MT, Stockle C and Steduto P (2009). Assessment of AquaCrop, CropSyst, and WOFOST models in the simulation of sunflower growth under different water regimes. *Agron. J.*, 101: 509–521.
- Wellens J, Raes D, Traore F, Denis A, Djaby B, Tychon B (2013). Performance assessment of the FAO AquaCrop model for irrigated cabbage on farmer plots in a semi-arid environment. *Agricultural Water Management*, 127: 40– 47.
- Whisler FD, Acock B, Baker DN, Fye RE, Hodges HF, Lambert JR, Lemmon HE, Mc Kinion JM and Reddy VR (1986). Crop simulation models in agronomic systems. *Adv. Agron.* 40, 141–208.
- Yapo PO, Gupta HV, and Sorooshian S (1998). Multi-objective global optimization for hydrologic models, *J. Hydrol.*,204: 83–97.

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Place: Akola
Date: / /2021

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ANNEXURE-I

Daily Meteorological Data

a) Daily meteorological data from 20th July 2014 to 20th January 2015

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) , %	Relative humidity (Evening) , %	Open Pan Evaporation , mm	Daily Rainfall, mm
20-07-2014	23.2	30.5	0.6	12.7	93	77	2.5	10.5
21-07-2014	23.7	28.6	0	13.4	95	64	2.1	1.5
22-07-2014	22.4	30.4	0	14	96	96	3.4	8
23-07-2014	19.7	25.4	0	19.8	100	98	4.2	132.4
24-07-2014	20.4	22.6	0	14	86	57	6	42
25-07-2014	22.6	29.6	1.1	8.3	82	47	3.2	0
26-07-2014	23.1	32.4	1.1	8.1	81	46	5.8	0
27-07-2014	25.6	33	6.4	10.4	92	95	7.6	0
28-07-2014	23.4	26.6	0	9.2	95	86	4.2	15.8
29-07-2014	23.4	27.6	0	9.9	92	51	3.6	0
30-07-2014	24.2	32.6	3.1	8.2	90	68	5.4	0
31-07-2014	23.5	30.6	2.4	3.1	96	69	4.2	16
01-08-2014	23.8	30	2.3	5	87	56	4.0	0
02-08-2014	23.9	32.6	4	5	82	62	6.0	0
03-08-2014	23.7	32.1	5.2	5.2	90	54	7.6	0.2
04-08-2014	24.8	32.6	4.4	13.3	85	56	8.2	0
05-08-2014	25.4	31.6	0.7	13.4	95	96	6.4	0.2

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) , %	Relative humidity (Evening) , %	Open Pan Evaporation , mm	Daily Rainfall, mm
06-08-2014	23.5	25.6	0	11.7	96	51	4.2	4.2
07-08-2014	23	32.4	4	12	92	54	8.0	9
08-08-2014	22.6	32	6.4	9.3	90	45	8.1	0.5
09-08-2014	23.9	33.6	7.4	9.9	79	41	8.6	0
10-08-2014	24	34	8.4	16.6	81	43	11.6	0
11-08-2014	24	34.4	8.1	14.7	86	49	9.6	0
12-08-2014	24.4	33.6	6.8	12.8	87	51	8.4	0
13-08-2014	24.6	38.8	8.3	13.8	84	52	10.4	0
14-08-2014	23.8	33.5	7.5	14.9	90	54	11.2	0
15-08-2014	22.8	33.2	3.6	7	93	42	5.0	3
16-08-2014	22.5	34	5.6	6.9	85	41	6.0	0
17-08-2014	23.2	33.6	6.3	6.3	91	51	5.0	1.2
18-08-2014	23.5	32.4	5.5	12.7	97	42	6.7	2.7
19-08-2014	24.6	34.8	8.5	3.7	81	40	5.2	0
20-08-2014	24	36.8	8.1	2.8	97	56	3.7	2.5
21-08-2014	32.2	24.6	3.2	0.5	84	50	3.0	0
22-08-2014	23.5	35.4	4.8	1	95	59	5.8	7
23-08-2014	2.8	32.4	4.6	2.7	98	64	6.0	12.6
24-08-2014	22.5	32	7.3	2.1	98	62	4.3	6.3
25-08-2014	24.3	33	6.5	0.2	84	58	3.6	0
26-08-2014	23.5	34	5.1	2.3	85	60	4.5	10.5
27-08-2014	22.5	31.6	2.5	5.4	82	48	2.9	0

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) , %	Relative humidity (Evening) , %	Open Pan Evaporation , mm	Daily Rainfall, mm
28-08-2014	20.2	32.2	3.1	3.7	98	90	6.0	40
29-08-2014	22.6	25.8	0.4	2	93	95	3.6	1
30-08-2014	23.2	27	1.4	2.1	97	74	4.3	4.7
31-08-2014	23.5	30.6	4.5	1.8	98	82	4.5	2.5
01-09-2014	23.4	29.6	0	4.2	98	89	5.0	22.4
02-09-2014	22.6	27	0	7.5	88	92	5.7	2.7
03-09-2014	22.8	29.9	2.5	3	88	60	3.8	21.8
04-09-2014	23.5	30.8	4.4	4.3	90	56	6.5	0.5
05-09-2014	23.2	32	9	6.9	85	70	10.0	0
06-09-2014	23	30.2	4.5	7	98	67	7.7	2.2
07-09-2014	23.7	30	3	12.8	96	96	9.9	0
08-09-2014	21.5	25	0	14.8	98	93	7.0	81
09-09-2014	21.6	24.5	0	12.1	95	75	4.3	3.7
10-09-2014	22.7	27.8	0.5	8.5	95	69	3.0	0.7
11-09-2014	22.5	29	0.3	6.2	96	66	6.0	0
12-09-2014	22.4	30.2	4.7	7	90	61	7.0	0
13-09-2014	22.2	30.6	8.5	9.7	90	66	7.5	0
14-09-2014	23	21.4	5	8.8	73	77	6.4	0
15-09-2014	22.7	30.2	4.9	6	90	62	5.2	0
16-09-2014	22	32.6	5.3	4.6	88	56	4.2	0
17-09-2014	22.2	32.8	6.8	6.4	93	60	6.4	0
18-09-2014	23.2	32.4	6.6	6.8	92	62	6.6	0

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) , %	Relative humidity (Evening) , %	Open Pan Evaporation , mm	Daily Rainfall, mm
19-09-2014	23.4	32.6	4.8	6.4	91	64	4.0	0
20-09-2014	23.4	32	2.4	4.2	93	52	3.8	0
21-09-2014	23	32.8	7.8	9.2	92	51	6.0	0
22-09-2014	23	32.4	7.7	7.5	88	52	5.2	0
23-09-2014	23.7	32.6	5.7	4.2	84	53	4.3	0.5
24-09-2014	22.5	33.6	8.3	3	85	46	3.4	0
25-09-2014	21.5	34	8.4	1.6	82	34	4.4	0
26-09-2014	19.8	34	9	0.8	80	35	4.8	0
27-09-2014	19.7	35	9	0.3	78	30	4.2	0
28-09-2014	19.6	34.8	8.8	0.3	82	40	4.0	0
29-09-2014	20.7	35.4	8.2	0.5	81	38	4.4	0
30-09-2014	21.2	34.6	7.9	0.3	82	36	4.0	0
01-10-2014	21	35.4	8.7	1.3	79	35	3.0	0
02-10-2014	21.8	35.6	7.7	0.6	85	28	5.0	0
03-10-2014	20.6	36.8	5.8	1.2	77	32	5.0	0
04-10-2014	21.2	37	8.2	1	54	26	5.4	0
05-10-2014	21	37.2	6.2	1.9	63	19	5.8	0
06-10-2014	21.7	37.2	7.7	1.5	60	33	5.6	0
07-10-2014	20.5	36.4	7.5	2.3	64	32	6.8	0
08-10-2014	21.5	38.4	7.3	1	78	28	4.0	0
09-10-2014	22	38.8	2.8	11	79	29	4.8	0
10-10-2014	21.5	39.4	5.6	1	74	32	4.2	0

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) , %	Relative humidity (Evening) , %	Open Pan Evaporation , mm	Daily Rainfall, mm
11-10-2014	20.7	4.8	3.8	1	80	24	4.4	0
12-10-2014	16.5	35.8	7.7	1	54	9	4.2	0
13-10-2014	22.4	35.6	6.3	2.4	41	33	7.8	0
14-10-2014	21.6	34.6	6.7	4.4	51	29	8.4	0
15-10-2014	24	35.4	8	1.2	81	54	7.0	0
16-10-2014	21	31	0	1.9	85	46	7.6	0
17-10-2014	22.4	33.6	3.8	0.9	79	36	4.8	0
18-10-2014	21.5	35.6	6.2	2.5	74	32	7.0	0
19-10-2014	21	35.2	6.1	1.3	72	30	5.2	0
20-10-2014	20.4	35.4	8.3	1.3	66	29	3.6	0
21-10-2014	21.5	35.2	7.1	0.9	73	33	4.2	0
22-10-2014	19.2	34.8	7.5	1	75	25	7.0	0
23-10-2014	17.2	35	8.1	0.4	73	21	7.4	0
24-10-2014	17.6	34.4	7.5	0.8	57	22	4.0	0
25-10-2014	21.5	34.2	4.6	0.4	89	62	3.0	0
26-10-2014	18.5	30.6	0	0.2	77	60	2.0	0.2
27-10-2014	17	25.6	0	1.6	85	37	3.0	0
28-10-2014	15.2	28.6	2.1	0.3	86	29	1.8	0
29-10-2014	15	32.4	8.5	1	77	25	4.4	0
30-10-2014	15.4	33.8	8.3	1.8	72	26	5.4	0
31-10-2014	16.77	34	8.2	1.8	66	27	5.8	0
01-11-2014	17	34.2	8.1	1.6	65	23	5.6	0

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) , %	Relative humidity (Evening) , %	Open Pan Evaporation , mm	Daily Rainfall, mm
02-11-2014	16.7	34.4	7.4	0.7	65	15	3.8	0
03-11-2014	15.5	34	7.8	1	66	14	4.2	0
04-11-2014	15	33.8	6.8	1	67	15	4.0	0
05-11-2014	14.4	34.2	6.7	1	68	16	4.2	0
06-11-2014	16.6	34.4	6.6	0.5	57	17	3.4	0
07-11-2014	14.5	33.8	7.6	1.1	74	16	5.6	0
08-11-2014	14.4	33.6	0.8	0.8	78	12	3.6	0
09-11-2014	14.6	33.4	2.7	2.7	74	14	7.0	0
10-11-2014	18	32.8	6.6	3.4	58	34	8.4	0
11-11-2014	23.4	31.6	2.7	0.4	77	87	4.2	0
12-11-2014	19.4	25.4	2.8	2.3	79	38	6.0	14
13-11-2014	20.2	32.4	7.3	0.6	86	39	3.0	0
14-11-2014	21.2	32.2	5.4	2.2	81	50	5.2	0
15-11-2014	20.8	32	0.8	9.6	94	66	2.1	6.1
16-11-2014	21.5	26.8	0.7	0.4	93	59	2.6	0
17-11-2014	21.4	29	0.5	0.03	84	39	1.8	0
18-11-2014	18.6	32.2	5.7	0.3	83	31	3.6	0
19-11-2014	14.5	31.8	6.5	1.7	71	14	5.0	0
20-11-2014	13	31.6	8.6	1.1	69	15	4.6	0
21-11-2014	11.5	31.77	7.9	0.8	76	8	4.0	0
22-11-2014	11.6	31.6	8	0.6	81	11	3.8	0
23-11-2014	13	31.4	7.7	0.6	68	17	3.6	0

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) , %	Relative humidity (Evening) , %	Open Pan Evaporation , mm	Daily Rainfall, mm
24-11-2014	14	31.5	6.5	0.9	71	25	4.8	0
25-11-2014	13	32	6.4	0.7	68	20	3.4	0
26-11-2014	11.5	31.8	7.5	0.7	82	12	4.0	0
27-11-2014	11	32.2	8.2	0.6	80	14	3.6	0
28-11-2014	12.7	32.4	8.3	0.6	76	16	3.4	0
29-11-2014	14.6	32.6	6.7	0.5	72	17	3.2	0
30-11-2014	12.2	31.4	4	0.4	78	11	3.0	0
01-12-2014	11.5	32.4	5	0.7	70	12	3.8	0
02-12-2014	13	32.6	7.2	0.5	68	21	4.0	0
03-12-2014	12.2	31.6	7.8	0.9	76	19	4.8	0
04-12-2014	9.8	30.6	7.6	0.6	79	12	4.2	0
05-12-2014	9.6	30.4	8.3	1.2	78	15	5.0	0
06-12-2014	10.4	31	8.7	2.1	71	21	6.4	0
07-12-2014	9.2	30.4	8	1	76	17	3.6	0
08-12-2014	12	30.2	8.5	0.5	68	20	3.0	0
09-12-2014	13.2	31.4	8.6	0.3	61	21	4.0	0
10-12-2014	12.6	2.2	8.7	0.5	69	26	5.2	0
11-12-2014	14.7	31.6	7.9	0.7	72	40	6.4	0
12-12-2014	15.7	30.6	4.4	1.9	71	43	7.0	0
13-12-2014	18.5	30.2	1.7	2.8	87	59	3.7	0.9
14-12-2014	16.8	26.8	0.32.5	1.8	88	41	1.8	0
15-12-2014	14	27.6	7.2	1.4	54	13	3.0	0

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) , %	Relative humidity (Evening) , %	Open Pan Evaporation , mm	Daily Rainfall, mm
16-12-2014	8.7	27.4	8.5	1.6	80	12	5.4	0
17-12-2014	6	25.8	7	3	78	8	5.8	0
18-12-2014	4.7	24.4	8.9	1.8	6	21	3.2	0
19-12-2014	7	25.8	9	3.6	70	11	6.0	0
20-12-2014	8	26.8	6.8	0.8	68	18	3.4	0
21-12-2014	7.8	26.2	8.6	0.3	74	20	4.0	0
22-12-2014	7	27.4	8.8	0.6	74	19	6.0	0
23-12-2014	8	28.4	8.5	1.1	65	17	6.0	0
24-12-2014	10	30	8.3	1.2	71	19	5.4	0
25-12-2014	8.6	29.6	8.4	1.6	64	12	5.8	0
26-12-2014	8	33.8	8.5	1.6	80	20	5.6	0
27-12-2014	6.8	26.6	8.6	1.5	73	15	5.0	0
28-12-2014	5.8	25.4	9.1	2.2	68	12	5.6	0
29-12-2014	4.8	25.2	9	1.8	64	13	5.0	0
30-12-2014	6.7	26.5	8.5	0.5	66	18	4.0	0
31-12-2014	15.6	28.4	8	1.4	68	48	5.2	0
01-01-2015	16.7	27.6	2.8	3.1	87	86	3.5	37.5
02-01-2015	17.2	20	0	1	82	78	3.6	12.4
03-01-2015	16.2	21.2	0	1	88	60	2.9	1.5
04-01-2015	15	23.44	1.7	0.6	89	56	2.6	0
05-01-2015	11.4	25	7.1	1.1	88	28	4.0	0
06-01-2015	8.7	24	8.8	0	90	18	3.2	0

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) , %	Relative humidity (Evening) , %	Open Pan Evaporation , mm	Daily Rainfall, mm
07-01-2015	8.8	25	9	0.7	90	19	3.6	0
08-01-2015	7.4	26.6	8.9	0.6	80	13	3.2	0
09-01-2015	7.2	26.2	9.1	0.6	74	12	3.0	0
10-01-2015	6.5	26	9.2	1.2	76	11	5.0	0
11-01-2015	7	26.4	9.3	0.4	84	13	2.0	0
12-01-2015	7.4	27	9.1	1.2	90	20	5.2	0
13-01-2015	6.5	27.5	8.7	0.6	86	17	3.2	0
14-01-2015	7.3	28.6	9.3	0.5	75	15	3.6	0
15-01-2015	7.6	28	8.8	0.8	77	18	4.0	0
16-01-2015	9.4	28.4	8.7	1.5	74	31	5.6	0
17-01-2015	8.4	27.8	8.6	0.4	82	30	3.0	0
18-01-2015	7.9	28.3	8.5	0.4	84	29	3.2	0
19-01-2015	9.7	27	8.6	0.5	79	27	4.8	0
20-01-2015	12.3	27.2	8.4	1.7	73	31	6.8	0

b) Daily meteorological data from 20th July 2015 to 20th January 2016

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning), %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
20/07/2015	24.4	29.4	0.8	19.9	74	87	6.6	0.0
21/07/2015	22.6	26.6	0.0	14.6	90	76	3.5	22.5
22/07/2015	23.9	28.4	0.2	7.8	88	56	2.2	0.30
23/07/2015	22.9	33.4	4.9	8.0	87	68	6.7	11.3
24/07/2015	22.5	31.4	0.9	6.4	90	61	6.0	10.0
25/07/2015	23.0	31.6	2.0	5.7	81	66	5.5	17.5
26/07/2015	22.6	29.4	0.0	7.9	82	73	4.5	2.7
27/07/2015	22.5	30.0	1.3	5.0	84	62	2.9	0.9
28/07/2015	21.8	29.8	0.0	4.8	82	48	3.5	2.5
29/07/2015	21.5	33.4	5.8	7.5	80	48	4.5	1.0
30/07/2015	23.4	33.8	5.7	12.4	87	47	6.4	0.0
31/07/2015	23.4	33.6	8.1	9.3	79	43	6.4	0.0
01/08/2015	22.9	33.8	8.0	10.3	84	42	8.4	0.0
02/08/2015	23.4	34.4	7.2	10.6	76	49	8.6	0.0
03/08/2015	23.4	32.4	4.8	15.2	75	61	10.0	0.0
04/08/2015	21.0	30.0	0.6	13.6	98	96	6.5	32.5
05/08/2015	20.0	22.9	0.0	21.5	98	95	0.0	194.0
06/08/2015	19.5	24.0	0.0	15.3	96	75	2.2	13.0
07/08/2015	22.5	27.8	0.0	9.3	90	73	2.6	7.0
08/08/2015	23.0	29.0	0.3	9.3	90	73	3.6	0.0
09/08/2015	22.7	30.0	0.5	7.0	88	77	4.4	7.4

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning), %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
10/08/2015	23.3	28.4	0.0	6.6	90	65	2.6	1.4
11/08/2015	24.2	31.8	0.9	6.0	87	68	3.8	0.0
12/08/2015	23.1	31.2	1.3	7.5	91	67	5.1	11.9
13/08/2015	22.2	30.2	2.3	9.6	88	96	5.0	28.0
14/08/2015	22.3	24.7	0.0	10.1	90	79	2.0	8.5
15/08/2015	23.4	28.8	0.2	6.5	90	63	2.8	0.0
16/08/2015	23.0	31.4	7.8	8.0	85	59	4.2	0.0
17/08/2015	23.0	31.8	8.2	9.1	84	58	4.6	0.0
18/08/2015	23.9	32.0	5.9	7.4	84	55	4.0	0.0
19/08/2015	23.9	33.0	4.5	4.3	84	53	4.0	0.0
20/08/2015	24.0	34.0	5.6	5.9	76	43	4.8	0.0
21/08/2015	23.0	34.2	8.4	7.1	82	48	4.4	0.0
22/08/2015	22.6	33.8	9.0	8.8	80	50	5.6	0.0
23/08/2015	22.2	32.4	3.5	8.4	82	53	5.0	0.0
24/08/2015	22.5	33.0	7.0	8.6	82	49	5.8	0.0
25/08/2015	22.5	33.8	9.1	9.7	80	48	6.2	0.0
26/08/2015	23.9	34.0	8.5	7.3	79	46	4.8	0.0
27/08/2015	23.0	33.8	6.1	7.8	82	59	6.0	0.0
28/08/2015	23.8	32.0	1.2	6.3	79	68	4.2	0.0
29/08/2015	23.7	30.6	0.8	9.5	81	70	6.4	0.0
30/08/2015	23.1	30.4	0.0	7.6	90	85	5.4	16.4
31/08/2015	22.8	28.0	0.0	8.0	90	62	2.0	0.0
01/09/2015	22.6	31.8	2.6	6.7	82	51	4.4	0.0
02/09/2015	22.5	33.0	9.5	7.5	76	42	6.4	0.0

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning), %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
03/09/2015	22.6	33.2	8.6	4.7	83	39	3.8	0.0
04/09/2015	22.6	34.6	8.7	2.3	90	83	2.8	0.0
05/09/2015	21.7	27.8	3.1	1.0	95	49	0.8	4.4
06/09/2015	23.4	34.0	9.1	1.2	81	51	1.8	0.0
07/09/2015	23.4	34.8	8.2	4.2	76	53	4.9	0.0
08/09/2015	21.5	33.8	7.8	4.5	93	65	7.0	18.0
09/09/2015	22.3	31.8	6.3	0.4	90	56	2.0	0.0
10/09/2015	23.1	33.2	5.9	0.8	87	41	4.0	0.0
11/09/2015	22.6	34.4	7.7	0.8	84	47	4.8	3.6
12/09/2015	24.2	35.0	8.7	3.2	82	52	5.0	0.0
13/09/2015	23.0	35.4	6.1	5.6	85	55	5.2	1.0
14/09/2015	23.2	34.4	8.8	7.7	88	58	6.0	0.0
15/09/2015	22.4	33.4	3.6	5.8	96	54	4.4	0.0
16/09/2015	20.3	34.2	5.3	5.1	93	72	6.0	57.0
17/09/2015	21.9	31.8	7.1	10.1	90	92	8.0	0.0
18/09/2015	21.7	26.8	0.0	9.3	98	66	4.5	78.5
19/09/2015	22.5	31.8	3.5	5.5	85	69	2.8	0.4
20/09/2015	21.8	30.4	6.1	1.9	85	48	2.0	0.0
21/09/2015	21.6	33.0	8.9	2.4	82	53	2.6	0.0
22/09/2015	22.4	32.8	9.1	1.9	82	54	2.4	0.0
23/09/2015	23.3	32.6	8.0	3.5	87	61	3.8	0.0
24/09/2015	22.7	32.2	7.5	3.5	88	56	3.6	0.0
25/09/2015	22.2	32.4	8.8	4.6	88	56	4.4	0.0
26/09/2015	20.4	31.8	9.0	4.0	84	44	3.8	0.0

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning), %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
27/09/2015	20.6	32.4	9.2	2.1	83	46	3.0	0.0
28/09/2015	21.2	33.4	8.0	1.1	80	40	2.8	0.0
29/09/2015	20.6	34.6	7.8	0.8	88	38	3.4	1.4
30/09/2015	21.1	35.0	9.0	0.4	90	39	4.8	0.0
01/10/2015	20.7	35.2	9.0	0.9	83	47	6.0	0.0
02/10/2015	22.4	34.8	8.0	0.9	88	44	5.0	0.0
03/10/2015	23.5	35.4	7.8	1.1	82	40	5.2	0.0
04/10/2015	23.7	35.8	7.4	2.8	87	52	6.6	0.0
05/10/2015	20.0	35.4	6.6	1.8	85	34	4.0	0.0
06/10/2015	17.6	36.2	9.0	0.5	82	26	3.8	0.0
07/10/2015	17.7	36.6	8.6	1.0	79	27	4.0	0.0
08/10/2015	20.0	36.2	9.0	0.4	78	25	3.6	0.0
09/10/2015	20.5	36.4	6.7	0.8	71	21	4.4	0.0
10/10/2015	17.9	37.6	6.2	1.2	67	23	5.2	0.0
11/10/2015	18.6	37.4	5.3	1.2	67	28	6.1	0.0
12/10/2015	19.8	37.0	8.8	0.6	69	27	4.6	0.0
13/10/2015	19.3	37.4	8.2	0.4	78	24	4.0	0.0
14/10/2015	19.3	37.2	8.9	0.6	65	19	4.2	0.0
15/10/2015	17.7	37.8	7.3	1.2	67	25	5.8	0.0
16/10/2015	20.8	37.0	7.7	1.1	74	41	5.8	0.0
17/10/2015	20.3	35.4	7.8	2.0	80	35	6.9	0.5
18/10/2015	18.0	35.6	8.9	1.9	70	29	6.4	0.0
19/10/2015	18.0	36.2	9.0	0.9	77	77	4.6	0.0
20/10/2015	20.0	36.4	8.6	0.6	62	25	4.2	0.0

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning), %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
21/10/2015	19.2	36.8	9.0	1.9	67	29	6.4	0.0
22/10/2015	19.2	37.0	8.9	0.5	70	29	4.0	0.0
23/10/2015	19.6	36.4	7.9	1.8	68	31	6.4	0.0
24/10/2015	18.6	36.2	8.0	0.7	72	33	4.0	0.0
25/10/2015	20.2	36.4	8.4	0.8	73	34	4.2	0.0
26/10/2015	19.2	35.2	4.5	1.7	75	36	6.2	0.0
27/10/2015	19.4	34.4	6.8	0.6	73	40	4.0	0.0
28/10/2015	20.4	33.8	7.0	1.0	76	36	5.6	0.0
29/10/2015	21.4	34.4	7.0	1.1	74	35	5.8	0.0
30/10/2015	17.9	33.0	6.7	1.4	83	35	6.2	0.0
31/10/2015	18.6	31.6	7.8	1.4	77	44	6.4	0.0
01/11/2015	16.4	31.4	5.7	0.7	85	37	4.0	0.0
02/11/2015	17.8	32.6	8.4	2.7	73	33	7.0	0.0
03/11/2015	17.9	33.8	8.6	1.5	72	31	6.0	0.0
04/11/2015	16.6	33.4	8.0	1.7	76	34	6.4	0.0
05/11/2015	16.5	34.2	7.8	0.2	75	25	3.4	0.0
06/11/2015	17.1	34.6	8.5	0.3	60	26	3.8	0.0
07/11/2015	17.8	34.8	9.0	0.4	66	22	4.4	0.0
08/11/2015	17.9	34.0	8.4	1.2	72	33	5.2	0.0
09/11/2015	16.2	33.6	8.2	2.0	79	25	5.4	0.0
10/11/2015	17.1	33.4	4.1	1.1	71	34	4.0	0.0
11/11/2015	16.7	32.2	3.6	1.1	79	31	3.8	0.0
12/11/2015	16.1	33.8	7.4	1.7	73	25	5.0	0.0
13/11/2015	15.4	32.0	8.4	2.3	71	27	6.0	0.0

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning), %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
14/11/2015	14.4	34.2	8.5	0.8	78	28	3.8	0.0
15/11/2015	14.4	33.2	5.5	0.9	70	28	3.6	0.0
16/11/2015	15.2	33.4	7.4	1.0	74	22	4.2	0.0
17/11/2015	15.9	34.6	8.6	2.2	66	26	6.2	0.0
18/11/2015	14.9	33.6	8.5	2.4	76	27	6.4	0.0
19/11/2015	14.1	32.0	8.1	2.5	74	26	6.0	0.0
20/11/2015	13.6	31.6	8.4	4.3	75	25	7.2	0.0
21/11/2015	13.6	31.8	9.0	3.3	70	35	6.8	0.0
22/11/2015	17.7	32.4	8.9	2.1	62	50	5.0	0.0
23/11/2015	19.2	33.2	7.4	2.2	61	37	5.2	0.0
24/11/2015	21.1	32.8	0.0	1.4	60	35	4.8	0.0
25/11/2015	16.9	33.0	0.5	1.5	69	33	5.0	0.0
26/11/2015	14.7	33.2	6.5	1.9	72	30	5.4	0.0
27/11/2015	15.7	33.8	1.1	1.0	70	31	4.4	0.0
28/11/2015	16.4	33.2	7.8	0.9	71	34	3.6	0.0
29/11/2015	17.2	34.0	7.0	1.0	74	40	4.0	0.0
30/11/2015	16.7	33.0	7.5	1.6	81	34	4.6	0.0
01/12/2015	14.9	33.4	7.9	1.2	77	34	4.2	0.0
02/12/2015	14.9	32.8	9.0	0.5	64	33	4.0	0.0
03/12/2015	16.2	33.4	8.0	0.3	72	32	3.8	0.0
04/12/2015	14.4	33.0	7.8	0.3	80	29	3.6	0.0
05/12/2015	11.4	32.0	8.3	0.6	72	27	4.4	0.0
06/12/2015	11.3	33.0	8.5	0.5	78	29	4.2	0.0
07/12/2015	11.5	31.8	8.5	0.8	52	17	5.8	0.0

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning), %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
08/12/2015	9.5	32.4	8.9	0.5	76	18	3.8	0.0
09/12/2015	10.4	32.1	8.5	0.7	73	27	5.0	0.0
10/12/2015	13.0	32.0	8.2	0.03	68	31	5.0	0.0
11/12/2015	15.9	32.8	6.7	0.6	64	36	4.0	0.0
12/12/2015	17.5	31.9	4.6	0.5	54	28	4.8	0.0
13/12/2015	13.6	32.1	8.9	0.5	75	28	5.0	0.0
14/12/2015	12.4	32.5	8.6	0.4	56	41	4.8	0.0
15/12/2015	13.0	31.8	8.2	0.5	68	30	5.6	0.0
16/12/2015	14.9	30.0	8.4	1.0	57	31	6.0	0.0
17/12/2015	17.0	31.8	8.1	0.7	74	35	4.0	0.0
18/12/2015	12.6	31.7	8.0	1.2	62	21	6.0	0.0
19/12/2015	10.0	29.0	8.0	0.6	66	31	3.8	0.0
20/12/2015	15.4	29.1	7.7	2.5	63	36	6.6	0.0
21/12/2015	14.6	31.4	6.7	1.0	71	25	5.0	0.0
22/12/2015	11.3	31.8	8.4	1.2	67	30	5.2	0.0
23/12/2015	9.5	30.2	8.8	0.8	66	24	4.0	0.0
24/12/2015	9.4	29.3	8.7	1.3	76	22	4.4	0.0
25/12/2015	5.0	26.8	8.7	0.6	57	20	3.6	0.0
26/12/2015	4.6	25.2	8.5	1.6	59	18	4.5	0.0
27/12/2015	6.5	26.3	9.0	1.1	59	17	4.0	0.0
28/12/2015	7.8	29.9	9.0	0.3	63	13	3.0	0.0
29/12/2015	8.5	32.9	9.2	0.6	64	15	4.8	0.0
30/12/2015	9.5	33.3	9.4	0.1	64	18	4.7	0.0
31/12/2015	11.5	34.2	7.2	0.6	64	18	5.0	0.0

Date	Minimum temperature, °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning), %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
01/01/2016	11.2	33.8	9.5	0.5	62	22	5.4	0.0
02/01/2016	11.5	33.9	8.8	0.9	65	13	5.8	0.0
03/01/2016	9.8	32.8	9.3	0.8	72	18	4.8	0.0
04/01/2016	11.1	31.2	8.9	0.9	70	21	4.8	0.0
05/01/2016	9.4	31.2	9.3	0.5	65	19	4.4	0.0
06/01/2016	10.1	31.0	9.3	0.4	67	24	4.4	0.0
07/01/2016	12.0	32.5	9.0	0.6	58	27	4.8	0.0
08/01/2016	11.6	30.4	5.0	0.5	58	26	3.2	0.0
09/01/2016	10.1	32.0	8.1	1.0	66	22	4.7	0.0
10/01/2016	9.0	31.5	8.8	0.7	64	23	4.8	0.0
11/01/2016	10.4	30.3	9.1	1.3	59	20	4.0	0.0
12/01/2016	10.9	31.8	8.7	0.9	63	19	4.4	0.0
13/01/2016	11.6	31.7	8.5	1.9	52	26	5.6	0.0
14/01/2016	12.4	32.3	8.3	0.8	61	23	5.2	0.0
15/01/2016	15.6	32.1	7.0	1.8	61	31	5.8	0.0
16/01/2016	15.9	30.8	7.5	2.8	71	28	6.8	0.0
17/01/2016	17.0	31.6	6.9	3.4	84	36	7.0	0.0
18/01/2016	15.5	30.0	6.9	1.5	73	35	3.8	0.0
19/01/2016	15.0	29.9	7.4	2.4	62	31	4.6	0.0
20/01/2016	9.6	27.8	8.5	5.2	74	22	6.2	0.0

c) Daily meteorological data from 28th July 2016 to 23rd January 2017

Date	Minimum temperature °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
28/07/2016	26.6	23.5	0.4	2.2	93	70	3.0	19.0
29/07/2016	29.8	24.8	4.4	4.4	88	67	3.6	0.0
30/07/2016	30.0	25.0	2.2	5.7	78	60	4.4	0.0
31/07/2016	31.6	24.8	7.8	3.5	82	68	4.4	0.0
01/08/2016	30.4	23.6	0.4	6.7	91	77	3.7	16.3
02/08/2016	28.4	23.2	0.3	8.5	91	76	3.7	5.2
03/08/2016	28.8	23.5	0.3	10.7	93	90	5.3	21.0
04/08/2016	26.0	23.4	0.0	9.1	88	63	3.1	22.5
05/08/2016	30.8	23.8	5.2	8.5	79	64	3.7	0.3
06/08/2016	31.2	24.8	6.9	7.4	78	76	5.2	0.0
07/08/2016	29.0	24.0	0.0	9.3	85	66	2.8	7.8
08/08/2016	29.8	23.5	1.4	6.6	88	67	4.0	0.0
09/08/2016	30.0	24.0	2.2	5.0	85	61	3.6	0.0
10/08/2016	31.4	24.2	5.7	7.9	84	70	4.0	0.2
11/08/2016	29.8	23.9	1.7	5.8	82	59	3.9	0.0
12/08/2016	31.3	23.8	7.2	4.1	88	62	4.5	2.5
13/08/2016	31.0	24.5	4.6	6.2	85	63	4.5	0.0
14/08/2016	30.0	24.0	0.4	12.8	84	66	5.6	0.0
15/08/2016	30.2	23.2	4.0	11.2	86	59	5.4	0.0
16/08/2016	31.2	23.3	5.8	13.7	82	53	6.8	0.0
17/08/2016	31.0	22.5	6.8	12.8	83	58	6.0	0.0
18/08/2016	30.8	23.0	5.8	11.7	87	51	5.4	0.0
19/08/2016	32.6	23.0	9.4	11.9	88	56	5.4	0.0

Date	Minimum temperature °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
20/08/2016	31.0	24.2	6.2	10.9	79	76	6.4	0.0
21/08/2016	26.4	22.8	4.9	0.0	83	62	3.0	3.4
22/08/2016	29.8	22.6	2.4	4.0	85	61	2.2	0.0
23/08/2016	31.0	24.4	6.6	3.9	81	72	3.4	0.0
24/08/2016	29.2	22.5	2.3	2.3	85	63	3.5	10.3
25/08/2016	31.0	23.6	8.4	4.0	81	55	4.4	0.0
26/08/2016	31.8	23.5	9.9	3.6	87	58	5.0	0.0
27/08/2016	32.4	24.8	5.2	3.8	82	62	4.0	0.0
28/08/2016	32.0	24.7	5.4	2.7	85	56	3.8	0.0
29/08/2016	34.0	25.0	6.9	1.5	84	60	4.4	0.0
30/08/2016	33.0	25.3	10.1	5.8	81	61	5.2	0.0
31/08/2016	32.4	24.0	1.8	6.4	90	62	4.3	1.5
01/09/2016	31.0	23.6	1.2	5.4	87	75	2.5	5.0
02/09/2016	28.6	23.8	0.8	6.2	88	60	3.2	0.0
03/09/2016	31.8	23.4	8.6	9.5	85	56	5.8	0.0
04/09/2016	32.0	22.6	9.8	8.8	83	51	6.4	0.0
05/09/2016	31.4	22.7	9.2	8.6	90	63	6.7	0.7
06/09/2016	30.8	22.3	9.1	9.4	85	7	6.8	0.0
07/09/2016	31.0	22.0	9.0	7.1	78	49	6.0	0.0
08/09/2016	31.4	22.2	8.7	8.4	88	51	6.8	0.0
09/09/2016	30.8	23.2	4.8	7.0	83	55	4.8	0.8
10/09/2016	31.6	23.8	3.9	14.0	82	51	6.4	0.0
11/09/2016	33.0	23.3	5.0	8.9	85	50	6.0	0.0
12/09/2016	32.5	24.4	7.1	6.2	77	58	4.0	0.0
13/09/2016	30.8	24.6	1.0	4.4	82	60	3.8	0.0

Date	Minimum temperature °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
14/09/2016	31.4	22.7	1.5	2.3	88	57	3.8	3.8
15/09/2016	31.2	23.4	1.8	1.9	90	66	1.7	16.9
16/09/2016	32.2	23.3	3.8	1.1	95	70	3.4	7.8
17/09/2016	30.8	22.0	2.8	0.4	98	78	3.0	30.0
18/09/2016	29.8	23.3	1.2	0.5	97	72	3.5	23.5
19/09/2016	31.4	23.5	5.9	1.4	93	73	3.8	0.0
20/09/2016	30.6	23.8	3.8	6.7	92	70	4.0	0.0
21/09/2016	31.0	22.8	5.4	7.1	93	67	4.8	0.0
22/09/2016	31.2	23.4	4.9	2.5	96	62	2.3	7.7
23/09/2016	31.4	24.5	6.4	1.3	92	67	2.3	1.7
24/09/2016	31.2	22.2	2.6	3.4	98	87	3.0	28.0
25/09/2016	28.0	23.0	1.0	3.6	90	74	3.5	0.5
26/09/2016	29.4	22.7	4.2	4.4	88	63	3.9	0.0
27/09/2016	31.5	24.5	8.8	4.9	91	60	3.8	1.8
28/09/2016	32.2	23.4	8.3	5.7	90	65	5.6	0.0
29/09/2016	32.4	22.6	9.0	6.4	91	59	5.8	0.0
30/09/2016	31.2	22.7	8.1	6.1	95	86	5.5	0.0
01/10/2016	27.0	22.8	0.0	3.7	96	80	3.6	2.6
02/10/2016	28.0	22.6	3.0	0.5	93	80	1.5	20.5
03/10/2016	28.2	23.6	4.9	0.8	95	70	3.4	17.4
04/10/2016	30.0	22.9	3.6	0.9	95	75	3.0	0.0
05/10/2016	30.2	22.5	3.9	0.9	88	74	3.4	20.2
06/10/2016	30.0	22.0	7.8	3.2	91	67	4.0	0.8
07/10/2016	30.6	23.0	9.3	2.6	87	68	3.2	0.0
08/10/2016	30.4	23.6	8.7	3.2	87	69	4.4	0.0

Date	Minimum temperature °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
09/10/2016	31.2	21.5	3.9	4.2	95	67	4.0	29.0
10/10/2016	30.2	24.0	6.6	6.0	96	68	5.0	0.0
11/10/2016	31.6	22.8	8.7	3.1	90	53	4.4	0.0
12/10/2016	32.0	21.2	8.4	2.5	91	55	4.0	0.0
13/10/2016	31.4	18.8	8.7	1.9	86	47	4.2	0.0
14/10/2016	31.6	17.5	8.4	0.2	84	56	3.0	0.0
15/10/2016	32.0	17.4	8.8	0.2	82	33	4.2	0.0
16/10/2016	32.4	18.4	9.1	0.5	75	32	4.8	0.0
17/10/2016	33.2	15.5	8.7	0.2	79	27	4.3	0.0
18/10/2016	33.4	15.9	8.5	0.3	88	25	4.4	0.0
19/10/2016	33.2	16.3	8.6	0.2	87	30	4.2	0.0
20/10/2016	33.0	16.1	9.2	0.6	73	25	4.6	0.0
21/10/2016	32.8	16.0	9.1	0.5	79	30	4.3	0.0
22/10/2016	33.2	16.6	9.0	0.4	78	33	4.2	0.0
23/10/2016	33.0	16.5	8.8	0.6	74	44	4.4	0.0
24/10/2016	32.8	17.6	9.0	0.8	80	34	5.0	0.0
25/10/2016	31.4	15.9	5.7	1.3	90	30	5.4	0.0
26/10/2016	31.0	16.4	8.8	2.2	77	40	6.0	0.0
27/10/2016	32.4	15.0	8.7	0.3	86	22	3.2	0.0
28/10/2016	32.8	12.6	8.9	1.0	78	33	5.0	0.0
29/10/2016	31.4	12.5	8.8	0.6	80	30	3.5	0.0
30/10/2016	32.0	16.0	9.0	0.3	77	44	5.2	0.0
31/10/2016	31.6	15.2	8.8	0.5	72	26	5.8	0.0
01/11/2016	31.8	12.8	8.6	0.4	91	23	4.2	0.0
02/11/2016	31.4	12.7	8.7	0.3	76	35	4.0	0.0

Date	Minimum temperature °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
03/11/2016	30.6	13.4	9.0	0.4	84	43	4.2	0.0
04/11/2016	31.2	17.4	7.9	0.4	86	38	4.0	0.0
05/11/2016	30.4	15.4	7.2	0.3	77	36	3.8	0.0
06/11/2016	31.8	13.0	8.8	0.3	81	33	4.0	0.0
07/11/2016	31.2	11.2	8.7	0.3	78	23	3.8	0.0
08/11/2016	31.6	10.8	8.9	0.5	71	30	4.5	0.0
09/11/2016	31.8	9.7	9.1	0.3	81	21	3.8	0.0
10/11/2016	31.4	10.0	8.8	0.4	74	22	4.0	0.0
11/11/2016	31.8	8.4	9.0	0.0	79	23	2.6	0.0
12/11/2016	31.4	11.5	9.0	0.2	88	26	4.0	0.0
13/11/2016	30.2	10.6	8.5	0.1	88	31	3.6	0.0
14/11/2016	29.8	12.9	8.0	0.3	82	38	3.8	0.0
15/11/2016	30.0	13.0	8.4	0.2	85	41	4.0	0.0
16/11/2016	30.8	12.9	7.4	0.3	91	35	3.2	0.0
17/11/2016	30.4	12.8	8.1	0.1	73	32	2.8	0.0
18/11/2016	29.6	9.4	9.0	1.3	82	29	4.8	0.0
19/11/2016	30.0	9.2	8.7	0.5	92	36	4.0	0.0
20/11/2016	29.8	9.0	7.3	0.1	83	37	3.8	0.0
21/11/2016	30.4	9.6	8.7	0.4	83	26	4.0	0.0
22/11/2016	31.2	9.5	8.8	0.2	86	32	2.8	0.0
23/11/2016	31.4	9.7	7.9	0.1	83	38	3.6	0.0
24/11/2016	31.2	10.5	8.8	0.2	86	28	3.0	0.0
25/11/2016	31.0	10.3	8.6	0.9	84	27	4.0	0.0
26/11/2016	31.2	9.5	9.0	0.5	83	22	4.2	0.0
27/11/2016	32.0	9.8	9.1	0.1	82	30	3.3	0.0

Date	Minimum temperature °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
28/11/2016	32.9	10.4	9.0	0.1	86	29	4.2	0.0
29/11/2016	31.8	9.5	9.1	0.3	88	29	4.2	0.0
30/11/2016	31.9	11.6	9.2	0.1	88	31	3.2	0.0
01/12/2016	32.4	12.2	9.1	0.1	88	41	5.0	0.0
02/12/2016	30.8	13.1	7.6	0.2	82	37	2.8	0.0
03/12/2016	30.6	12.5	8.0	0.7	89	35	3.0	0.0
04/12/2016	30.8	12.7	7.5	1.3	89	52	3.8	0.0
05/12/2016	30.8	11.0	8.2	1.1	88	38	3.6	0.0
06/12/2016	29.8	9.5	7.7	0.7	88	38	3.6	0.0
07/12/2016	28.8	10.0	8.3	1.1	86	28	4.0	0.0
08/12/2016	29.8	9.5	7.8	0.7	88	30	2.8	0.0
09/12/2016	30.0	9.7	8.4	0.2	87	25	3.4	0.0
10/12/2016	29.5	7.1	8.2	0.3	87	41	3.8	0.0
11/12/2016	28.8	9.6	8.5	0.3	83	28	4.0	0.0
12/12/2016	31.0	9.2	8.8	0.5	81	29	4.4	0.0
13/12/2016	31.4	11.5	8.6	0.8	78	28	4.8	0.0
14/12/2016	31.2	12.7	8.7	2.0	70	32	4.2	0.0
15/12/2016	29.2	13.4	4.9	2.8	75	30	4.0	0.0
16/12/2016	30.6	11.6	8.5	1.6	82	38	4.0	0.0
17/12/2016	30.2	10.7	8.4	0.8	81	33	3.8	0.0
18/12/2016	29.8	9.8	8.6	1.0	87	34	4.4	0.0
19/12/2016	28.4	7.2	8.6	0.6	84	33	3.2	0.0
20/12/2016	27.6	8.0	8.3	0.3	87	41	3.0	0.0
21/12/2016	28.2	7.2	8.7	0.3	89	30	3.4	0.0
22/12/2016	30.2	8.1	8.3	0.2	87	39	3.4	0.0

Date	Minimum temperature °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
23/12/2016	30.0	8.9	8.6	0.1	77	36	3.6	0.0
24/12/2016	30.4	6.7	8.9	0.5	86	24	3.4	0.0
25/12/2016	31.4	10.0	8.9	0.2	83	35	3.2	0.0
26/12/2016	30.6	10.4	8.7	0.3	81	30	3.2	0.0
27/12/2016	28.2	5.8	8.7	0.6	85	31	4.4	0.0
28/12/2016	26.5	8.2	8.3	1.0	84	29	3.2	0.0
29/12/2016	28.0	8.0	7.9	0.9	76	24	3.8	0.0
30/12/2016	30.4	8.1	8.0	0.5	89	30	3.0	0.0
31/12/2016	30.8	10.0	8.3	0.1	83	31	3.2	0.0
01/01/2017	31.0	11.5	8.0	0.3	73	35	3.6	0.0
02/01/2017	30.8	10.0	7.7	0.6	81	27	3.8	0.0
03/01/2017	30.0	8.4	8.3	0.8	84	31	3.6	0.0
04/01/2017	27.4	7.5	8.0	0.4	89	34	3.0	0.0
05/01/2017	27.2	7.8	8.3	0.3	87	36	3.0	0.0
06/01/2017	29.2	10.0	8.4	0.3	83	25	3.6	0.0
07/01/2017	30.8	10.0	8.2	0.6	75	42	3.6	0.0
08/01/2017	29.0	8.4	8.0	0.5	89	38	2.6	0.0
09/01/2017	28.4	11.0	8.0	0.2	83	42	2.8	0.0
10/01/2017	29.4	14.5	6.0	0.6	89	46	3.0	0.0
11/01/2017	27.2	6.2	7.2	0.9	88	30	4.2	0.0
12/01/2017	27.4	5.4	7.8	0.4	74	36	3.8	0.0
13/01/2017	24.2	5.0	8.4	0.8	79	46	3.6	0.0
14/01/2017	25.2	8.0	7.8	0.8	86	41	2.8	0.0
15/01/2017	26.6	11.2	7.3	1.4	84	39	4.0	0.0
16/01/2017	27.8	12.1	4.7	0.8	84	43	2.6	0.0

Date	Minimum temperature °C	Maximum temperature °C	Bright Sunshine Hours, hrs	Wind Speed, kmph	Relative humidity (Morning) %	Relative humidity (Evening), %	Open Pan Evaporation, mm	Daily Rainfall, mm
17/01/2017	28.0	13.2	1.9	0.1	73	34	3.0	0.0
18/01/2017	31.0	13.4	5.8	0.3	84	33	3.0	0.0
19/01/2017	31.6	12.2	6.4	0.7	76	38	3.8	0.0
20/01/2017	30.0	12.0	7.9	1.1	80	30	4.8	0.0
21/01/2017	30.2	11.2	6.8	1.5	75	37	5.2	0.0
22/01/2017	31.0	15.0	7.5	0.4	71	42	3.8	0.0
23/01/2017	31.8	13.8	8.1	0.6	80	34	5.0	0.0

Annexure – II

Details of irrigation water applied in different treatments

a) For the year 2014-2015

Date	Cumulative Evaporation (mm)	Cumulative Rainfall (mm)	Amount of water applied, mm			
			100% ET	80% ET	60%ET	40%ET
Before transplanting			87.46	87.46	87.46	87.46
21-07-2014	4.6	12	Water not applied due to rainfall			
23-07-2014	7.6	140.4	Water not applied due to rainfall			
25-07-2014	9.2	42	Water not applied due to rainfall			
27-07-2014	13.4	0	1.59	1.2692	0.9519	0.6346
29-07-2014	7.8	15.8	Water not applied due to rainfall			
31-07-2014	9.6	16	Water not applied due to rainfall			
02-08-2014	10	0	1.41	1.1264	0.8448	0.5632
04-08-2014	15.8	0.2	2.20	1.7572	1.3179	0.8786
06-08-2014	10.6	4.4	0.87	0.6984	0.5238	0.3492
08-08-2014	16.1	9.5	0.93	0.7434	0.5576	0.3717
10-08-2014	20.2	0	2.84	2.2753	1.7065	1.1377
12-08-2014	18	0	2.53	2.0275	1.5206	1.0138
14-08-2014	21.6	0	3.04	2.433	1.8248	1.2165
16-08-2014	11	3	1.43	1.1469	0.8602	0.5734
18-08-2014	11.7	3.9	1.40	1.1182	0.8387	0.5591
20-08-2014	8.9	2.5	1.15	0.9175	0.6881	0.4588
22-08-2014	8.8	7	0.32	0.258	0.1935	0.129
24-08-2014	10.3	18.9	Water not applied due to rainfall			
26-08-2014	8.1	10.5	Water not applied due to rainfall			
28-08-2014	8.9	40	Water not applied due to rainfall			
30-08-2014	7.9	5.7	0.39	0.3154	0.2365	0.1577
01-09-2014	9.5	24.9	Water not applied due to rainfall			
03-09-2014	9.5	24.5	Water not applied due to rainfall			
05-09-2014	16.5	0.5	4.38	3.5021	2.6266	1.751
07-09-2014	17.6	2.2	4.21	3.3708	2.5281	1.6854
09-09-2014	11.3	84.7	Water not applied due to rainfall			
11-09-2014	9	0.7	2.27	1.8167	1.3625	0.9084
13-09-2014	14.5	0	3.97	3.1738	2.3803	1.5869
15-09-2014	11.6	0	3.17	2.539	1.9043	1.2695
17-09-2014	10.6	0	3.59	2.8696	2.1522	1.4348
19-09-2014	10.6	0	3.59	2.8696	2.1522	1.4348
21-09-2014	9.8	0	3.68	2.9478	2.2109	1.4739
23-09-2014	9.5	0.5	3.38	2.7072	2.0304	1.3536
25-09-2014	7.8	0	2.93	2.3462	1.7597	1.1731

Date	Cumulative Evaporation (mm)	Cumulative Rainfall (mm)	Amount of water applied, mm			
			100 % ET	80 % ET	60 % ET	40 % ET
27-09-2014	9	0	3.38	2.7072	2.0304	1.3536
29-09-2014	8.4	0	3.16	2.5267	1.895	1.2634
01-10-2014	7	0	2.88	2.3072	1.7304	1.1536
03-10-2014	10	0	4.12	3.296	2.472	1.648
05-10-2014	11.2	0	6.09	4.8728	3.6546	2.4364
07-10-2014	12.4	0	6.74	5.3949	4.0462	2.6974
09-10-2014	8.8	0	4.79	3.8286	2.8715	1.9143
11-10-2014	8.6	0	4.68	3.7416	2.8062	1.8708
13-10-2014	12	0	6.53	5.2209	3.9156	2.6104
15-10-2014	15.4	0	8.38	6.7001	5.0251	3.3501
17-10-2014	12.4	0	7.07	5.6568	4.2426	2.8284
19-10-2014	12.2	0	6.96	5.5655	4.1742	2.7828
21-10-2014	7.8	0	4.78	3.8279	2.8709	1.9139
23-10-2014	14.4	0	8.83	7.0668	5.3001	3.5334
25-10-2014	7	0	4.29	3.4353	2.5764	1.7176
27-10-2014	5	0.2	2.94	2.3556	1.7667	1.1778
29-10-2014	6.2	0	3.80	3.0427	2.282	1.5213
31-10-2014	11.2	0	6.87	5.4964	4.1223	2.7482
02-11-2014	9.4	0	5.82	4.6558	3.4918	2.3279
04-11-2014	8.2	0	5.08	4.0614	3.0461	2.0307
06-11-2014	7.6	0	4.71	3.7642	2.8232	1.8821
08-11-2014	9.2	0	5.70	4.5567	3.4175	2.2784
10-11-2014	15.4	0	9.53	7.6276	5.7207	3.8138
12-11-2014	10.2	14	Water not applied due to rainfall			
14-11-2014	8.2	0	5.08	4.0614	3.0461	2.0307
16-11-2014	4.7	6.1	Water not applied due to rainfall			
18-11-2014	5.4	0	3.22	2.5764	1.9323	1.2882
20-11-2014	9.6	0	6.45	5.161	3.8707	2.5805
22-11-2014	7.8	0	5.24	4.1933	3.145	2.0966
24-11-2014	8.4	0	5.64	4.5158	3.3869	2.2579
26-11-2014	7.4	0	4.97	3.9782	2.9837	1.9891
28-11-2014	7	0	4.70	3.7632	2.8224	1.8816
30-11-2014	6.2	0	4.17	3.3331	2.4998	1.6666
02-12-2014	7.8	0	4.99	3.9936	2.9952	1.9968
04-12-2014	9	0	5.76	4.608	3.456	2.304
06-12-2014	11.4	0	7.30	5.8368	4.3776	2.9184
08-12-2014	6.6	0	4.22	3.3792	2.5344	1.6896
10-12-2014	9.2	0	5.89	4.7104	3.5328	2.3552
12-12-2014	13.4	0	8.58	6.8608	5.1456	3.4304
14-12-2014	5.5	0.9	2.94	2.3552	1.7664	1.1776
16-12-2014	8.4	0	5.00	3.9997	2.9998	1.9999
18-12-2014	9	0	5.36	4.2854	3.2141	2.1427

Date	Cumulative Evaporation (mm)	Cumulative Rainfall (mm)	Amount of water applied, mm			
			100 % ET	80 % ET	60 % ET	40 % ET
20-12-2014	9.4	0	5.59	4.4759	3.3569	2.238
22-12-2014	10	0	5.95	4.7616	3.5712	2.3808
24-12-2014	11.4	0	6.79	5.4282	4.0712	2.7141
26-12-2014	11.4	0	6.79	5.4282	4.0712	2.7141
28-12-2014	10.6	0	6.31	5.0473	3.7855	2.5236
30-12-2014	9	37.5	5.36	4.2854	3.2141	2.1427
01-01-2015	8.7	13.9	Water not applied due to rainfall			
03-01-2015	6.5	0	Water not applied due to rainfall			
05-01-2015	6.6	0	3.93	3.1427	2.357	1.5713
07-01-2015	6.8	0	4.05	3.2379	2.4284	1.6189
09-01-2015	6.2	0	3.69	2.9522	2.2141	1.4761
11-01-2015	7	0	4.17	3.3331	2.4998	1.6666
13-01-2015	8.4	0	5.00	3.9997	2.9998	1.9999
15-01-2015	7.6	0	4.52	3.6188	2.7141	1.8094
17-01-2015	8.6	0	5.12	4.095	3.0712	2.0475
19-01-2015	8	0	4.76	3.8093	2.857	1.9046
Total(mm)	908.1	542.4	431.42	362.63	293.83	225.04
lit/plant			155.31	130.54	105.78	81.02
ha-cm			43.14	36.26	29.38	22.5

b) For the year 2015-2016

Date	Cumulative Evaporation (mm)	Cumulative Rainfall (mm)	Amount of water applied, mm			
			100% ET	80% ET	60%ET	40%ET
Before transplanting			92.77	92.77	92.77	92.77
22/07/2015	5.7	22.8	Water not applied due to rainfall			
24/07/2015	12.7	21.3	Water not applied due to rainfall			
26/07/2015	10	20.2	Water not applied due to rainfall			
28/07/2015	6.4	3.4	0.36	0.28	0.21	0.14
30/07/2015	10.9	1	1.17	0.94	0.70	0.47
01/08/2015	14.8	0	1.75	1.40	1.05	0.70
03/08/2015	18.6	0	2.20	1.76	1.32	0.88
05/08/2015	6.5	226.5	Water not applied due to rainfall			
07/08/2015	4.8	20	Water not applied due to rainfall			
09/08/2015	8	7.4	0.08	0.07	0.05	0.03
11/08/2015	6.4	1.4	0.70	0.56	0.42	0.28
13/08/2015	10.1	39.9	Water not applied due to rainfall			
15/08/2015	4.8	8.5	Water not applied due to rainfall			
17/08/2015	8.8	0	1.24	0.99	0.74	0.50
19/08/2015	8	0	1.13	0.90	0.68	0.45
21/08/2015	9.2	0	1.65	1.32	0.99	0.66
23/08/2015	10.6	0	1.90	1.52	1.14	0.76
25/08/2015	12	0	2.15	1.72	1.29	0.86
27/08/2015	10.8	0	1.94	1.55	1.16	0.77
29/08/2015	10.6	0	1.90	1.52	1.14	0.76
31/08/2015	7.4	16.4	Water not applied due to rainfall			
02/09/2015	10.8	0	1.94	1.55	1.16	0.77
04/09/2015	6.6	0	1.18	0.95	0.71	0.47
06/09/2015	2.6	4.4	Water not applied due to rainfall			
08/09/2015	11.9	18	Water not applied due to rainfall			
10/09/2015	6	0	1.82	1.46	1.09	0.73
12/09/2015	9.8	3.6	1.88	1.51	1.13	0.75
14/09/2015	11.2	1	3.10	2.48	1.86	1.24
16/09/2015	10.4	57	Water not applied due to rainfall			
18/09/2015	12.5	78.5	Water not applied due to rainfall			
20/09/2015	4.8	0.4	1.65	1.32	0.99	0.66
22/09/2015	5	0	2.18	1.74	1.31	0.87
24/09/2015	7.4	0	3.23	2.58	1.94	1.29
26/09/2015	8.2	0	3.58	2.86	2.15	1.43

Date	Cumulative Evaporation (mm)	Cumulative Rainfall (mm)	Amount of water applied, mm			
			100% ET	80% ET	60% ET	40% ET
28/09/2015	5.8	0	2.53	2.02	1.52	1.01
30/09/2015	8.2	1.4	2.97	2.37	1.78	1.19
02/10/2015	11	0	4.80	3.84	2.88	1.92
04/10/2015	11.8	0	5.15	4.12	3.09	2.06
06/10/2015	7.8	0	4.56	3.65	2.74	1.83
08/10/2015	7.6	0	4.45	3.56	2.67	1.78
10/10/2015	9.6	0	5.62	4.49	3.37	2.25
12/10/2015	10.7	0	6.26	5.01	3.76	2.50
14/10/2015	8.2	0	4.80	3.84	2.88	1.92
16/10/2015	11.6	0	6.79	5.43	4.07	2.71
18/10/2015	13.3	0.5	7.49	5.99	4.49	3.00
20/10/2015	8.8	0	5.40	4.32	3.24	2.16
22/10/2015	10.4	0	7.19	5.75	4.31	2.88
24/10/2015	10.4	0	7.19	5.75	4.31	2.88
26/10/2015	10.4	0	7.19	5.75	4.31	2.88
28/10/2015	9.6	0	6.64	5.31	3.98	2.65
30/10/2015	12	0	8.29	6.64	4.98	3.32
01/11/2015	10.4	0	7.19	5.75	4.31	2.88
03/11/2015	13	0	8.99	7.19	5.39	3.59
05/11/2015	9.8	0	6.84	5.47	4.10	2.73
07/11/2015	8.2	0	6.01	4.81	3.60	2.40
09/11/2015	10.6	0	7.76	6.21	4.66	3.11
11/11/2015	7.8	0	5.71	4.57	3.43	2.29
13/11/2015	11	0	8.06	6.45	4.83	3.22
15/11/2015	7.4	0	5.42	4.34	3.25	2.17
17/11/2015	10.4	0	7.62	6.09	4.57	3.05
19/11/2015	12.4	0	9.08	7.27	5.45	3.63
21/11/2015	14	0	10.35	8.28	6.21	4.14
23/11/2015	10.2	0	7.54	6.03	4.52	3.02
25/11/2015	9.8	0	7.24	5.80	4.35	2.90
27/11/2015	9.8	0	7.24	5.80	4.35	2.90
29/11/2015	7.6	0	5.62	4.49	3.37	2.25
01/12/2015	8.8	0	6.50	5.20	3.90	2.60
03/12/2015	7.8	0	5.77	4.61	3.46	2.31
05/12/2015	8	0	5.63	4.51	3.38	2.25
07/12/2015	10	0	7.04	5.63	4.22	2.82
09/12/2015	8.8	0	6.20	4.96	3.72	2.48
11/12/2015	9	0	6.34	5.07	3.80	2.53
13/12/2015	9.8	0	6.90	5.52	4.14	2.76
15/12/2015	10.4	0	7.32	5.86	4.39	2.93

Date	Cumulative Evaporation (mm)	Cumulative Rainfall (mm)	Amount of water applied, mm			
			100 % ET	80% ET	60% ET	40% ET
17/12/2015	10	0	7.04	5.63	4.22	2.82
19/12/2015	9.8	0	6.90	5.52	4.14	2.76
21/12/2015	11.6	0	7.59	6.08	4.56	3.04
23/12/2015	9.2	0	6.02	4.82	3.61	2.41
25/12/2015	8	0	5.24	4.19	3.14	2.10
27/12/2015	8.5	0	5.57	4.45	3.34	2.23
29/12/2015	7.8	0	5.11	4.09	3.06	2.04
31/12/2015	9.7	0	6.35	5.08	3.81	2.54
02/01/2016	11.2	0	7.33	5.87	4.40	2.93
04/01/2016	9.6	0	6.29	5.03	3.77	2.51
06/01/2016	8.8	0	5.76	4.61	3.46	2.30
08/01/2016	8	0	5.24	4.19	3.14	2.10
10/01/2016	9.5	0	6.22	4.98	3.73	2.49
12/01/2016	8.4	0	5.50	4.40	3.30	2.20
14/01/2016	10.8	0	7.07	5.66	4.24	2.83
16/01/2016	12.6	0	8.25	6.60	4.95	3.30
18/01/2016	10.8	0	7.07	5.66	4.24	2.83
20/01/2016	10.8	0	7.07	5.66	4.24	2.83
Total(mm)	871.6	553.6	506.78	423.98	341.18	258.38
lit/plant			182.44	152.49	121.53	92.38
ha-cm			50.68	42.36	33.76	25.66

c) For the year 2016-2017

Date	Cumulative Evaporation (mm)	Cumulative Rainfall (mm)	Amount of water applied, mm			
			100% ET	80 % ET	60% ET	40% ET
Before Transplanting			83.11	83.11	83.11	83.11
30-07-2016	8	0	0.95	0.76	0.57	0.38
01-08-2016	8.1	16.3	Water not applied due to rainfall			
03-08-2016	9	26.2	Water not applied due to rainfall			
05-08-2016	6.8	22.8	Water not applied due to rainfall			
07-08-2016	8	7.8	0.02	0.02	0.01	0.01
09-08-2016	7.6	0	0.90	0.72	0.54	0.36
11-08-2016	7.9	0.2	0.91	0.73	0.55	0.36
13-08-2016	9	2.5	0.92	0.73	0.55	0.37
15-08-2016	11	0	1.55	1.24	0.93	0.62
17-08-2016	12.8	0	1.80	1.44	1.08	0.72
19-08-2016	10.8	0	1.52	1.22	0.91	0.61
21-08-2016	9.4	3.4	0.84	0.68	0.51	0.34
23-08-2016	5.6	0	0.79	0.63	0.47	0.32
25-08-2016	7.9	10.3	Water not applied due to rainfall			
27-08-2016	9	0	1.61	1.29	0.97	0.65
29-08-2016	8.2	0	1.47	1.18	0.88	0.59
31-08-2016	9.5	1.5	1.43	1.15	0.86	0.57
02-09-2016	5.7	5	0.13	0.10	0.08	0.05
04-09-2016	12.2	0	2.19	1.75	1.31	0.87
06-09-2016	13.5	0.7	2.29	1.84	1.38	0.92
08-09-2016	12.8	0	2.29	1.84	1.38	0.92
10-09-2016	11.2	0.8	2.19	1.75	1.31	0.88
12-09-2016	10	0	2.86	2.29	1.71	1.14
14-09-2016	7.6	3.8	1.09	0.87	0.65	0.43
16-09-2016	5.1	24.7	Water not applied due to rainfall			
18-09-2016	6.5	53.5	Water not applied due to rainfall			
20-09-2016	7.8	0	2.23	1.78	1.34	0.89
22-09-2016	7.1	7.7	Water not applied due to rainfall			
24-09-2016	5.3	29.7	Water not applied due to rainfall			
26-09-2016	7.4	0.5	2.91	2.32	1.74	1.16
28-09-2016	9.4	1.8	3.20	2.56	1.92	1.28
30-09-2016	11.3	0	4.76	3.81	2.86	1.90
02-10-2016	5.1	23.1	Water not applied due to rainfall			
04-10-2016	6.4	17.4	Water not applied due to rainfall			
06-10-2016	7.4	21	Water not applied due to rainfall			
08-10-2016	7.6	0	3.20	2.56	1.92	1.28
10-10-2016	9	29	Water not applied due to rainfall			
12-10-2016	8.4	0	4.78	3.82	2.87	1.91
14-10-2016	7.2	0	4.09	3.27	2.46	1.64
16-10-2016	9	0	5.12	4.09	3.07	2.05

Date	Cumulative Evaporation (mm)	Cumulative Rainfall (mm)	Amount of water applied, mm			
			100% ET	80 % ET	60% ET	40% ET
18-10-2016	8.7	0	4.95	3.96	2.97	1.98
20-10-2016	8.8	0	5.00	4.00	3.00	2.00
22-10-2016	8.5	0	4.83	3.87	2.90	1.93
24-10-2016	9.4	0	5.34	4.28	3.21	2.14
26-10-2016	11.4	0	7.58	6.07	4.55	3.03
28-10-2016	8.2	0	5.46	4.36	3.27	2.18
30-10-2016	8.7	0	5.79	4.63	3.47	2.32
01-11-2016	10	0	6.65	5.32	3.99	2.66
03-11-2016	8.2	0	5.46	4.36	3.27	2.18
05-11-2016	7.8	0	5.19	4.15	3.11	2.08
07-11-2016	7.8	0	5.19	4.15	3.11	2.08
09-11-2016	8.3	0	5.52	4.42	3.31	2.21
11-11-2016	6.6	0	4.49	3.59	2.69	1.80
13-11-2016	7.6	0	5.17	4.14	3.10	2.07
15-11-2016	7.8	0	5.31	4.24	3.18	2.12
17-11-2016	6	0	4.08	3.26	2.45	1.63
19-11-2016	8.8	0	5.99	4.79	3.59	2.39
21-11-2016	7.8	0	5.31	4.24	3.18	2.12
23-11-2016	6.4	0	4.35	3.48	2.61	1.74
25-11-2016	7	0	4.82	3.86	2.89	1.93
27-11-2016	7.5	0	5.17	4.13	3.10	2.07
29-11-2016	8.4	0	5.79	4.63	3.47	2.31
01-12-2016	8.2	0	5.65	4.52	3.39	2.26
03-12-2016	5.8	0	4.00	3.20	2.40	1.60
05-12-2016	7.4	0	5.10	4.08	3.06	2.04
07-12-2016	7.6	0	5.23	4.19	3.14	2.09
09-12-2016	6.2	0	4.27	3.42	2.56	1.71
11-12-2016	7.8	0	5.12	4.09	3.07	2.05
13-12-2016	9.2	0	6.04	4.83	3.62	2.41
15-12-2016	8.2	0	5.38	4.30	3.23	2.15
17-12-2016	7.8	0	5.12	4.09	3.07	2.05
19-12-2016	7.6	0	4.99	3.99	2.99	1.99
21-12-2016	6.4	0	4.20	3.36	2.52	1.68
23-12-2016	7	0	4.59	3.67	2.76	1.84
25-12-2016	6.6	0	4.03	3.22	2.42	1.61
27-12-2016	7.6	0	4.64	3.71	2.78	1.85
29-12-2016	7	0	4.27	3.42	2.56	1.71
31-12-2016	6.2	0	3.78	3.03	2.27	1.51
02-01-2017	7.4	0	4.51	3.61	2.71	1.81
04-01-2017	6.6	0	4.03	3.22	2.42	1.61
06-01-2017	6.6	0	4.03	3.22	2.42	1.61
08-01-2017	6.2	0	3.78	3.03	2.27	1.51
10-01-2017	5.8	0	3.54	2.83	2.12	1.42
12-01-2017	8	0	4.88	3.90	2.93	1.95
14-01-2017	6.4	0	3.90	3.12	2.34	1.56

Date	Cumulative Evaporation (mm)	Cumulative Rainfall (mm)	Amount of water applied, mm			
			100% ET	80 % ET	60% ET	40% ET
16-01-2017	6.6	0	4.03	3.22	2.42	1.61
18-01-2017	6	0	3.66	2.93	2.20	1.46
20-01-2017	8.6	0	5.25	4.20	3.15	2.10
22-01-2017	9	0	5.49	4.39	3.29	2.20
24-01-2017	9.8	0	5.98	4.78	3.59	2.39
Total(mm)	724.9	309.7	388.03	327.05	266.06	205.08
lit/plant			139.69	117.74	95.78	73.83
ha-cm			38.80	32.70	26.61	20.51

Annexure – III

Model Parameter	Description		
Climatic parameters	Maximum and Minimum temperature °C, Bright Sunshine Hours (hrs), Maximum and Minimum Relative humidity (%), Open pan evaporation (mm), Daily Rainfall (mm).		
Base temprature	10 °C		
Upper temprature	30 °C		
Mode of planting	Transplanting		
Crop water productivity	18 g/m ²		
Harvest index	77 %		
Crop period	2014-15	2015-16	2016-17
	22 nd July 2014 to 20 th Jan 2015	20 th July 2015 to 20 th Jan 2016	28 th July 2016 to 23 rd Jan 2017
Irrigation method	Drip irrigation		
Type of mulch	Synthetic plastic mulch		
Weed management	Perfect		
Field surface practices	Do not affect surface runoff		
Soil type	Sandy clay loam		
Soil pH	7.74		
Soil EC (dS/m)	4.43		
Bulk density (g/cm ³)	1.51		
Field Capacity (%)	28.24		
Permanent Wilting point (%)	17.20		
Maximum effective root zone depth, m	0.80		
Depth of groundwater table	5 meter below soil surface		
pH of irrigation water	7.24		
EC (dS/m)	0.73		
Field data	Canopy data		

