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## Research Article

# CALIBRATE AND VALIDATE AQUACROP MODEL FOR BITTER GOURD PRODUCTION

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**Abstract:** A study entitled 'Calibrate and validate AquaCrop model for bitter gourd production' was undertaken with objective to improve water productivity *i.e.* 'more crop per drop'. The model provided excellent simulation of canopy and yield. The harvest index was observed as 85% for Bitter gourd. The formulated alternative delivery schedules were optimized based on water use efficiency. Simulations were carried out with calibrated model for the period 17th November 2014 to 9th March 2015. Schedule $S_4$ (mulch + Irrigation schedule at 85% $ET_c$) saved 16.18% water with only -30.18% reduction in the yield of bitter gourd. Therefore it should be used for bitter gourd production.

**Keywords:** Crop water productivity, Water use efficiency, Aqua Crop, Bitter gourd, crop evapotranspiration

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### Introduction

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. 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. Management practices for conservation of water have been increasingly emphasized because of scare natural precipitation, high evapotranspiration and excessive depletion of limited ground water resources. Estimation of water requirement of crop is essential for crop planning on farm 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 laborious and time consuming. Therefore use of available computer software with appropriate modifications to suit the site conditions may be a better option. 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 [1]. Bitter gourd (*Momord cacharantia* L.) is one of the most popular vegetable in South East Asia. It is a member of cucurbit family along with cucumber, squash, watermelon, and muskmelon. Bitter gourd is also known as bitter melon, karella, or balsam pear. The area and production of bitter gourd in India is 83.22 thousand hector and 940.15 thousand metric tons respectively and in Maharashtra is 45.32 thousand hector and 281 thousand metric tons respectively.

### Material and Method

#### 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, to determine the yield response to water of field, vegetable and tree crops, through the following equation:

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

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

#### The evolution of AquaCrop model is schematically described

AquaCrop evolves (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 ($T_r$) 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:

$$B = WP\sum Tr$$

Where,
B - Biomass
$T_r$ - crop transpiration, mm and
WP - water productivity parameter, $kgm^{-2}$

**Calibration and validation of model**

Part of the obtained field data *i.e.* data for full irrigation treatment (100% $ET_c$ under non-mulch – $T_7$) was used for calibration of the model, while the remaining data of remaining treatments was used to validate the model. AquaCrop version 4.0 was used in the study. The model was calibrated and validated by varying following parameters manually:

i) Canopy cover
- a) Initial canopy cover ($CC_o$)
- b) Mode of planting
- c) Canopy size of sowing seedling
- d) Maximum canopy cover
- e) Plant density
- f) Canopy decline
- g) Day 1 to recovery
- h) Day 1 to maximum canopy
- i) Senescence
- j) Harvest
- k) Root system
- l) Maximum effective depth

ii) Harvest index

iii) Water productivity ($WP_b$)

The bitter gourd yield (Y),biomass (B) and water productivity (WP) were simulated for different treatments using the calibrated model.

**Output extraction**

Simulation results were stored in a set of output files. The output files with daily data contain information on the crop development and production.

**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 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 dimensionless statistical measure *i.e.* coefficient of residual mass were used to judge the performance of the model [10].

**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)

$$R^2_{NS} = 1 - \frac{\sum (Q_O - Q_S)^2}{\sum (Q_O - Q_{av})^2}$$

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. $R^2_{NS}$ 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) Coefficient of Residual Mass**

Coefficient of Residual Mass (CRM) is a dimensionless statistical performance criteria as described below.

$$CRM = \frac{\left[\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} S_i\right]}{\sum_{i=1}^{n} O_i}$$

Where,

$O_i$ - Observed value at time i

$S_i$ - Simulated value at time i

This criterion indicates the overall under or over-estimation of the ordinates. For a perfect model, the value of CRM is zero. A positive value of CRM indicates the tendency of model to underestimate the observed ordinates, whereas the negative value indicates a tendency to overestimate the observed ordinates.

## Results and Discussion

**Calibration and validation of AquaCrop model**

AquaCrop model was set up as per procedure described and providing initial values for the following parameters

Table-1 *Observed and simulated canopy cover during calibration*

| Day after sowing | Canopy cover(%) | |
|---|---|---|
| | Observed | Simulated |
| 10 | 0 | 0.1 |
| 25 | 0.2 | 0.6 |
| 35 | 1 | 1.7 |
| 50 | 6.5 | 7.3 |
| 65 | 21.5 | 22.9 |
| 75 | 23.2 | 27.2 |
| 90 | 26.8 | 29.1 |
| 110 | 29.5 | 29.8 |
| $R^2_{NS}$ | 0.98 | |
| CRM | -0.092 | |

Temporal variation of observed and simulated canopy cover is presented in Fig. while [Fig-2] shows comparison of observed and simulated canopy cover.

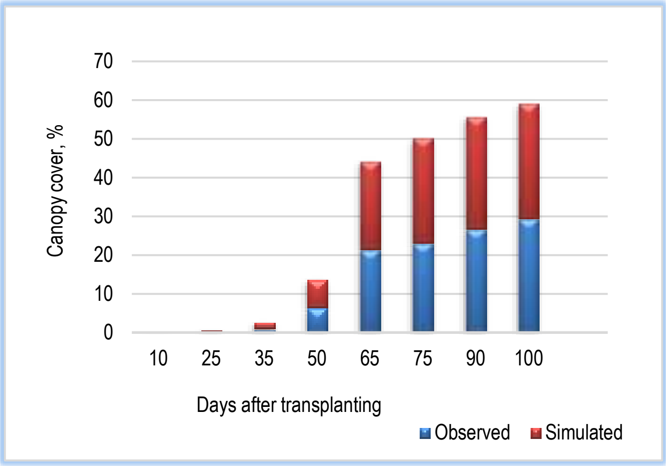


Fig-1 Observed and simulated canopy cover for calibration period

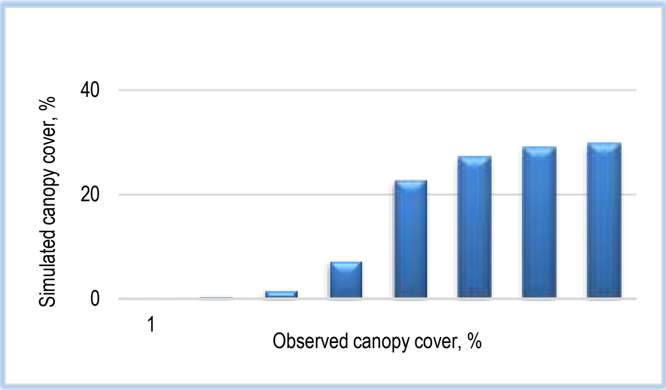


Fig-2 Comparison between observed and simulated canopy cover for calibration period

[Fig-1] clears that there is close match between observed and simulated canopy cover. It is supported by high value of (0.98). Another statistical parameter *i.e.* CRM having value as -0.092, indicates that the model overestimates the canopy cover. From [Fig-1], it is cleared that the canopy cover was overestimated by model particularly during 75 to 90 DAT *i.e.* during development stage.

But, the scatter plot clears that as the canopy cover nearly lie on 1:1 line, there is no consistent over or under estimation. Temporal variation of observed and simulated biomass is presented in [Fig-3] while [Fig-4] shows comparison of observed and simulated biomass.

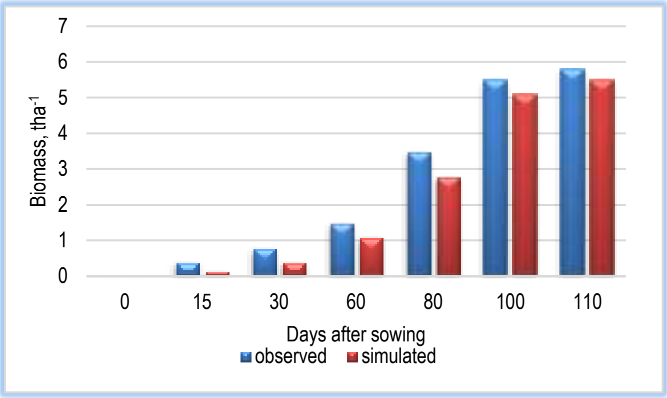


Fig-3 Observed and simulated biomass for calibration period

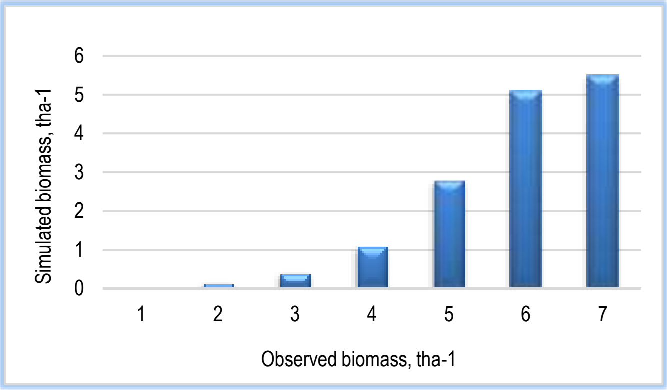


Fig-4 Comparison between observed and simulated biomass for calibration period

[Fig-3] clears that the model overestimate biomass though the value of is high as 0.97. It is supported by another statistical criterion *i.e.* CRM with value of 0.140 indicating model overestimate the biomass, in general. From [Fig-3], it is cleared that the biomass was overestimated by model particularly during 15 to 100 DAT.

**Yield of Bitter gourd**

Temporal variation of observed and simulated yield is presented in [Fig-5] while [Fig-6] shows comparison of observed and simulated yield.

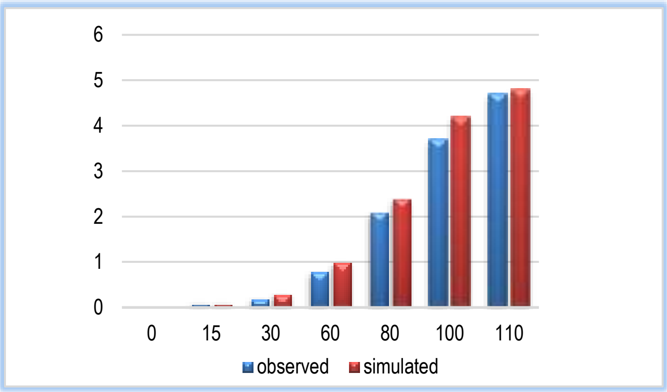


Fig-5 Observed and simulated yield for calibration period

**Calibration period**

Bitter gourd head yield was observed as 4.7 tha$^{-1}$ for calibration period. For harvesting index of 85%, the model predicted yield was 4.8 tha$^{-1}$. Nash Sutcliffe coefficient as 0.98 indicates that the observed and simulated yield was closely match. Coefficient of residual mass as -0.103 indicated that the model slightly underestimates the yield. Above results showed that the model calibration was satisfactory as the observed and simulated.

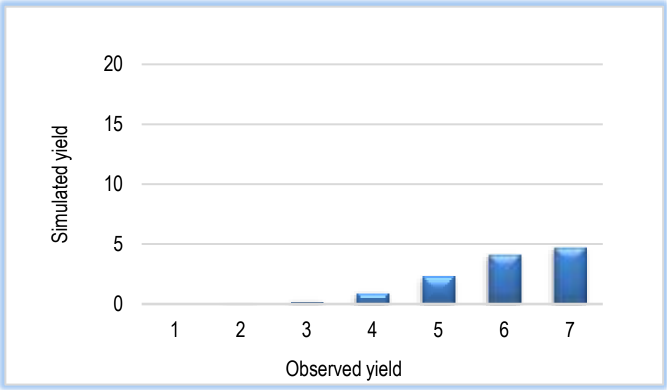


Fig-6 Comparison between observed and simulated yield for

**Conclusion**

1. AquaCrop model proved its capability in simulating canopy cover, biomass and yield. The AquaCrop model was calibrated for daily irrigation schedule at 100% $ET_c$.
2. The calibrated model parameters *i.e.* initial canopy cover, harvesting index and water productivity were observed as 0.21, 85% and 26 gm$^{-2}$, respectively.
3. Six alternative irrigation schedules were formulated for better mulch condition. These alternative irrigation schedules were optimized on the basis of water use efficiency.
4. WUE efficiency is found maximum for schedule $S_4$ with reduction in the yield as -30.16%, while schedule $S_3$ saved 26.04% water, with only 1.81% reduction in the yield of bitter gourd head.
5. It is better bitter gourd production under polyethylene mulch with drip irrigation having daily irrigation schedule fixed at 85% of $ET_c$.

**Application of research**: In deficit irrigation management of winter bitter guard in semi-arid region. Simulation of models that clarify the effect of water on crop yield are useful tools for improving level water management and optimizing water use efficiency.

**Research Category**: Agricultural Engineering

**Abbreviations**:

% : Percent
Cm : Centimetre
Div. : Division
Drain. : Drainage
ETo : Reference Evapotranspiration
ETc : Crop Evapotranspiration
FAO : Food and Agricultural Organization
FC : Field capacity
Ha : Hectare
Hrs : Hours
LAI : Leaf Area Index

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**Conflict of Interest**: None declared

**Ethical approval**: This article does not contain any studies with human participants or animals performed by any of the authors.

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