Modeling and Evaluation of AquaCrop for Maize (*zea mays* L.) under Full and Deficit Irrigation in Semi-Arid Tropics

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**ABSTRACT**

FAO AquaCrop is a simulation model that predicts the effects of soil, climate, water and crop growth on water productivity, yield and its attributes of various crops. In the present study, performance evaluation of AquaCrop model for maize was assessed for *rabi* maize during 2015 at Water Technology Centre, College of Agriculture, Rajendranagar, Hyderabad. The experiment was laid in a randomized block design with eight treatments in three replications. The treatments comprised of surface and drip irrigation schedules based on Epan viz., surface irrigation at 0.6 IW/CPE ratio (*T*₁), 0.8 IW/CPE ratio (*T*₂), 1.0 IW/CPE ratio (*T*₃), 1.2 IW/CPE ratio (*T*₄), drip irrigation at 0.6 Epan (*T*₅), 0.8 Epan (*T*₆), 1.0 Epan (*T*₇) and 1.2 Epan (*T*₈). The model was evaluated using crop data resulted from the experiment under varying water application methods and levels. Simulation performance was assessed with statistical parameters viz., statistical co-efficient of determination (*R*²), prediction error (Pe), model efficiency (E), root mean square error (RMSE) and mean absolute error (MAE). The model results are in quite agreement with practical values for grain yield, biomass and water productivity with model efficiency of 0.99, 0.92 and 0.71, coefficient of determination (*R*²) of 0.90, 0.91 and 0.93 with an RMSE of 0.24, 0.10 and 0.05, respectively. The model prediction errors in simulation of grain yield, biomass and water productivity under all treatments ranged from 1.4% to 11.9%, 1.4% to 16.1% and 4.85% to 25.9%, respectively. The highest and lowest prediction accuracy for grain yield, biomass and water productivity were in drip irrigation at 1.2 Epan and surface irrigation at 0.6 IW/CPE ratios. It is inferred that FAO AquaCrop model is suitable for predicting grain yield, biomass, water productivity and green canopy cover with acceptable range of under and over predictions for maize in semi-arid tropical climate.

Key words: AquaCrop model, Drip irrigation, Maize, Model efficiency, Surface irrigation.

**INTRODUCTION**

Water is the most important and critical input for agriculture and the demand for efficient use of irrigation water for the crops are intensifying in view of global concern for food security and environmental sustainability. On the other hand, water supplies are decreasing day by day due to extended drought periods, decline in the groundwater levels and diversion of water from irrigation to other uses. Shortage of water coupled with increase in population necessitated the researchers to develop protocols for enhancing crop water productivity in most parts of the world, particularly in arid and semiarid regions (Debaeke and Aboudrare, 2004; FAO, 2008). Further the increased water demand led the farmers to consider the options of growing less water demanding crops like maize even though they are less profitable. The basic information required to optimize irrigation includes precise knowledge of the relationship between water use and crop yield. *i.e.* water production functions. In this context, deficit irrigation (DI) has been widely investigated as a valuable strategy, where water is the limiting factor in crop cultivation in arid and semiarid regions (Pereira, 2006; Fereres and Soriano, 2007).

Crop simulation models are used to study the interactive effects of various environmental and management strategies and could simulate scenarios under different conditions of soil, atmosphere, irrigation strategies, and agricultural management (Kloss *et al.*, 2012; Homayounfar *et al.*, 2014 and Singh, 2014). The short simulation time-step demands that a large amount of input data *viz.* climate parameters, soil characteristics and crop parameters to be available for running the model. These models usually offer the possibility of specifying management options and they can be used to investigate a wide range of management strategies at low costs (Kumar and Ahlawat, 2004). FAO AquaCrop model, is a powerful user friendly modeling software, that simulates economic organs of crops which are responsible for the design and evaluation of irrigation strategies, deficit irrigation scheduling and rainfed systems subject to soil types, field
AquaCrop model has been tested under different environmental conditions and mostly on crops like maize, wheat and cotton. Fewer studies have also been reported on canola, quinoa, rice, barley, sunflower, sugar beet and vegetables like cabbage, tomato, and potato. Limited studies have been reported on the performance evaluation of maize crop and simulating the maize growth and yield in the semi-arid regions of Telangana. Thus the present investigation was carried out on modeling and evaluation of FAO AquaCrop model for rabi maize grown under different irrigation regimes to estimate optimum irrigation schedules under deficit irrigation conditions.

MATERIALS AND METHODS

Experimental area

The experimental site was located in the dry tropical and semi-arid climate with latitude 17°19′25.2″ N, longitude 78°24′31″ E at an altitude of 534 m above mean sea level. The mean weekly maximum and minimum temperatures during the crop growth period ranged from 28.6°C to 33.4°C and 11.1°C to 21.1°C, respectively. The mean relative humidity and bright sunshine hours varied from 41 to 86% and 5.8 to 9.6 hours, respectively. The mean daily wind speed ranged from 0.1 to 2.4 km h⁻¹ while the mean pan evaporation data (USWB-class A pan) during the crop growth period ranged from 3.4 to 4.7 mm d⁻¹ with an average of 4.0 mm d⁻¹. The South-West monsoon was observed from second week of June to second fortnight of October, having 40-50 rainy days. The experimental soil was sandy loam in texture and slightly alkaline in reaction. It was low in organic carbon and available nitrogen (100 kg ha⁻¹), medium in available phosphorus (33 kg ha⁻¹) and high in available potassium (392.44 kg ha⁻¹) with a moderate infiltration rate of 3.2 cm h⁻¹. A total of 23.3 mm rainfall was received in 5 rainy days during the crop growth period.

Agronomic and field management practices

The experiment was conducted during rabi, 2015-16 using maize hybrid DEKALAB super 900M in a randomized block design with eight treatments, replicated thrice. The treatments comprised of four surface irrigations at 0.6 IW/CPE ratio (T₆), 0.8 IW/CPE ratio (T₈), 1.0 IW/CPE ratio (T₁₀), 1.2 IW/CPE ratio (T₁₂), four drip irrigations at 0.6 Epan (T₆), 0.8 Epan (T₈), 1.0 Epan (T₁₀) and 1.2 Epan (T₁₂). Crop was grown in 60 cm x 20 cm spacing under surface irrigation, 80 cm x 15 cm under drip irrigation to maintain uniform plant population of 83,333 plants ha⁻¹. The recommended dose of -200 kg N, 80 kg P₂O₅ and 80 kg K₂O, respectively was applied as basal dose.

Irrigation scheduling

Irrigation scheduling for maize was done based on pan evaporation replenishment for both surface and drip irrigations. In drip system, irrigation was scheduled at an alternate day interval with predetermined pan evaporation replenishment levels for T₆ to T₁₀ treatments, while in surface irrigation, IW/CPE ratios of 0.6, 0.8, 1.0 and 1.2 were followed in the treatments viz., T₆, T₈, T₁₀ and T₁₂, respectively. The depth of irrigation water applied was 50 mm and irrigation was rescheduled whenever the cumulative pan evaporation (CPE) reached to 83.3 mm, 62.5 mm, 50 mm and 42 mm in T₆, T₈, T₁₀ and T₁₂ treatments, respectively. During rainy days the volume of water applied to each treatment was adjusted for the effective rainfall received. The application rate and irrigation time required for scheduling irrigation through drip system was calculated using the following formulae.

Application rate (mm h⁻¹) = \( \frac{Q}{DL \times DE} \)

Irrigation time (minutes) = \( \frac{\text{Pan evaporation (mm)}}{\text{Application rate (mm min⁻¹)}} \times 60 \)

Where, Q was dripper discharge (L h⁻¹), Dₘ was distance between lateral spacing (m) and Dₛ was distance between dripper spacing (m).

Input data and interpretation

AquaCrop model requires minimum input data usually stored in the climate, crop, soil and management files and they can be easily changed through the user interface. The weather data used in the model being daily maximum and minimum air temperature (T), daily rainfall, daily reference evapo-transpiration (ET₀) and the mean annual CO₂ concentration in the atmosphere. The first four were obtained...
from Agro Meteorological Station, the CO₂ concentration data was obtained from the Mauna Loa Observatory record Hawaii. ET₀ was calculated by using FAO CROPWAT model. Canopy development was observed at different crop growth stages, leaf area and above ground biomass was recorded on bi-weekly basis. Date of emergence, maximum canopy cover (CC), days to flowering, start of senescence, and maturity were also recorded. In each crop growth stages, green leaves were separated and leaf area of each plant observed by LI 3100 leaf area meter to compute leaf area index (LAI), which was converted to crop canopy cover (CC).

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Dry biomass of above ground portion at each crop growth stage was calculated by using FAO CROPWAT model. The canopy decline coefficient, crop coefficient for transpiration at full canopy cover, soil water depletion thresholds for inhibition of leaf growth and stomatal conductance, acceleration of canopy senescence were recorded from the literature (Hsiao et al., 2009). Some of other parameters used in the model were presumed based on its wide range of conditions and not specific for a given crop cultivar (Heng et al., 2009). The actual harvestable part of biomass and yield were calculated using the harvest index (HI) and by the equation (Steduto et al., 2009).

\[
Y = B \cdot HI, \quad \text{where, } Y = \text{Yield, } B = \text{Biomass and } HI = \text{Harvest index}
\]

Canopy component is most significant in Aquacrop. It is expressed as percentage of green canopy ground cover, such that where there is no water stress for the crop, canopy expansion from emergency to full development follows exponential growth and decay during first and second halves of full development, respectively, as shown in equation below.

\[
CC = CC_0 - (CC_X - CC_0) \cdot e^{-CGC \cdot t}
\]

Where, CC is canopy cover at time t, CC₀ is canopy cover at t=0, CGC is canopy growth coefficient in fraction per day or per degree days, CCₓ is maximum canopy cover and t is the time in days or degree days.

**Soil data**

Soil profile was divided into different horizons on its physical characteristics and indicative values provided by AquaCrop for various soil textural classes found in USDA triangles were used as input for values regarding soil. The required soil data on volumetric water content at saturation (θsat), field capacity (θFC) and permanent wilting point (θPWP) were presumed as available in the literature (Steduto et al., 2009). The experimental site was not having any impervious or restrictive soil layer to obstruct the expansion of root growth and hence, the curve number (CN) of the site was used to estimate surface runoff from rainfall that occurred during the experiment.

The crop input data required for running the model were obtained from the field experiment conducted and the AquaCrop model was run by comparing observed and simulated maize yields.

**Model evaluation criterion**

Model simulation results for maize yield, biomass and WP

| Table 1: Input data used in AquaCrop model. |
|--------------------------------------------|
| Parameters                                  | Value | Unit  |
| Base temperature                            | 8     | °C    |
| Cut off temperature                         | 37    | °C    |
| Canopy growth coefficient (CGC)             | 12.4  | % day⁻¹|
| Canopy decline coefficient (CDC) at senescence | 7.0   | % day⁻¹|
| Maximum basal crop coefficient (Kcb)        | 1.25  | Unit less |
| Time from sowing to emergence               | 6     | days  |
| Time from sowing to start flowering         | 51    | days  |
| Time from sowing to start senescence        |       |       |
| T1: 0.6 IW/CPE                              | 102   | days  |
| T2: 0.8 IW/CPE                              | 103   | days  |
| T3: 1.0 IW/CPE                              | 105   | days  |
| T4: 1.2 IW/CPE                              | 107   | days  |
| T5: 0.6 Epan                                | 107   | days  |
| T6: 0.8 Epan                                | 110   | days  |
| T7: 1.0 Epan                                | 110   | days  |
| T8: 1.2 Epan                                | 112   | days  |
| Time from sowing to maturity                | 115   | days  |
| Length of the flowering stage               | 10    | days  |
| Stomatal conductance threshold (Pₑᵤₜₑₑ)     | 0.50  | Unit less |
| Stomatal stress coefficient curve shape      | 1.8   | Unit less |
| Expansion stress coefficient (Pₑᵤₜₑₑ)       | 0.14  | % of TAW |
| Expansion stress coefficient (Pₑᵤₜₑₑ)       | 0.30  | % of TAW |
| Expansion stress coefficient curve shape     | 1.3   | % of TAW |
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were compared with the observed values form the experiment. The goodness of fit between the simulated and observed values was corroborated by using the prediction error statistics. The prediction error ($P_e$), coefficient of determination ($R^2$), mean absolute error (MAE) and root mean square error (RMSE) and model efficiency (E) were the error statistics to evaluate the results of the model. The $R^2$ and E were used to access the predictive power of the model while $P_e$, MAE and RMSE indicated the error in the model prediction.

$$R^2 = \left(\frac{\sum(O_i - O) (S_i - S)}{\sum(O_i - O)^2 \sum(S_i - S)^2}\right)^2$$

$$P_e = \frac{(S_i - O_i)}{O_i} \times 100$$

$$E = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

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

$$MAE = \frac{\sum_{i=1}^{n}|S_i - O_i|}{n}$$

Where, $n$ = No. of observations, $O_i$ = Observed value and $S_i$ = Simulated value.

Model efficiency (E) and $R^2$ approaching one and $P_e$, MAE and RMSE close to zero were indicators for better model performance.

The AquaCrop model simulated and evaluated using the data collected during rabi 2015-16 for maize crop under varying water application methods and levels. The data collected on crop growth parameters, soil and climate were used as inputs to AquaCrop model to simulate maize green canopy cover, grain yield, biomass and water productivity.

**RESULTS AND DISCUSSION**

**Canopy Cover (CC)**

The observed and simulated green canopy covers (CC) under surface and drip irrigation regimes are depicted in Fig 1. Among all the treatments, the observed and simulated maximum canopy cover was noticed in drip irrigation at 1.0 Epan (99.03 and 99.00%) and minimum in surface irrigation at 0.6 IW/CPE ratio (89.00 and 93.15%). The best fit values for drip and surface irrigation treatments ranged from 0.93 to 0.95. Highest and lowest $R^2$ values were observed in drip irrigation at 1.0 Epan (0.95) and at 0.6 Epan (0.93). It is attributed to frequent application of adequate irrigation water for the crop to avoid moisture stress and obtaining minimum canopy cover due to adoption of long irrigation intervals that created moisture stress, resulted in reduced plant growth.

**Above ground biomass**

The observed and simulated above ground biomass by AquaCrop model with its prediction errors are presented in Table 2 and Fig 2. The minimum and maximum prediction errors for biomass were observed in 1.0 Epan and 0.6 IW/CPE ratio with 1.4% to 16.1% under drip and surface irrigation, respectively. The model efficiency (E) and coefficient of determination ($R^2$) were 92 and 74%, respectively with RMSE (0.10) and MAE (0.52) with average values of all observed and simulated biomass of 9.48 and 8.91 (t ha$^{-1}$) (Table 3). The prediction error was minimized by adjusting the harvest index and canopy decline coefficient. Higher deviations were observed in surface stress treatments and

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**Table 2:** Observed (Obs) and simulated (Sim) grain yield, biomass and water productivity of maize.

| Treatments | Grain yield (t ha$^{-1}$) | Biomass (t ha$^{-1}$) | WP (kg ha$^{-1}$ mm$^{-1}$) |
|------------|--------------------------|-----------------------|-----------------------------|
|            | Obs | Sim | $P_e$ (%) | Obs | Sim | $P_e$ (%) | Obs | Sim | $P_e$ (%) |
| 0.6 IW/CPE | 2.71 | 2.99 | 10.3 | 7.19 | 6.03 | 16.1 | 8.5 | 10.7 | 25.9 |
| 0.8 IW/CPE | 3.36 | 3.76 | 11.9 | 8.16 | 7.67 | 6.0 | 9.1 | 10.1 | 11.0 |
| 1.0 IW/CPE | 3.95 | 4.4 | 11.4 | 9.34 | 9.06 | 3.0 | 8.4 | 9.5 | 13.1 |
| 1.2 IW/CPE | 4.37 | 4.31 | 1.4 | 9.67 | 8.62 | 10.9 | 7.7 | 8.8 | 14.2 |
| 0.6 Epan   | 4.11 | 4.55 | 10.7 | 9.46 | 8.44 | 10.8 | 13.4 | 15.3 | 14.0 |
| 0.8 Epan   | 4.44 | 4.75 | 7.0 | 10.02 | 9.00 | 10.1 | 11.2 | 12.9 | 15.2 |
| 1.0 Epan   | 5.13 | 4.83 | 5.8 | 11.09 | 10.94 | 1.4 | 10.5 | 12.7 | 21.0 |
| 1.2 Epan   | 4.94 | 5.18 | 4.9 | 10.94 | 11.51 | 5.2 | 8.8 | 9.7 | 10.2 |

**Table 3:** Performance statistics of AquaCrop model for maize crop.

| Model output parameters | Mean | Observed | Simulated | RMSE | MAE | E | $R^2$ |
|------------------------|------|----------|-----------|------|-----|---|------|
| Grain yield (t ha$^{-1}$) | 4.13 | 4.35 | 0.24 | 0.35 | 0.99 | 0.90 |
| Biomass (t ha$^{-1}$) | 9.48 | 8.91 | 0.10 | 0.54 | 0.92 | 0.91 |
| WP (kg ha$^{-1}$ mm$^{-1}$) | 9.70 | 11.21 | 0.05 | 0.75 | 0.71 | 0.93 |
they decreased with increase in moisture availability. The results are in tune with the findings of Abedinpour et al. (2012) and Gebreselassie et al. (2015), who also reported high prediction error under moisture stress conditions for simulation in maize crop under typical semi-arid tropical climate.

Grain yield

Minimum and maximum errors (1.4% and 11.9%) of grain yield predictions were observed in 1.2 IW/CPE and 1.0 IW/CPE ratios under surface and drip irrigations with model efficiency (E) of 99% and coefficient of determination ($R^2$) of 89%, respectively. The average grain yield of observed and simulated were 4.13 and 4.35 t ha$^{-1}$ with RMSE and MAE of 0.24 and 0.35, respectively. The obtained results simulated by AquaCrop model are within acceptable range of under and over estimations and are in agreement with the results reported by Abedinpour et al., (2012), Mhizha et al. (2014) and Ahmadi et al. (2015) in wheat crop under similar agro-climatic conditions.

Fig 1: Observed and simulated green canopy cover (CC) for maize crop under surface and drip irrigation regimes.
Water productivity

Among all the treatments, the minimum and maximum prediction errors (10.2% and 25.9%) were recorded in 1.2 Epan and 0.6 IW/CPE levels of drip and surface irrigation, respectively. The average WP of observed and simulated were 9.70 and 11.21 (kg ha⁻¹ mm⁻¹) with model efficiency of 71%, RMSE and MAE of 0.05 and 0.75, respectively. The results are in quite agreement with the observed data. However, the prediction errors generated for water productivity are quite higher than grain yield and biomass.

CONCLUSION

From this study, it may be concluded that FAO AquaCrop model model is useful for accurate prediction of grain yield, biomass, water productivity and green canopy cover of rabi maize with acceptable range of under and over predictions in the semi-arid tropical conditions.

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