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Validation of Aqua Crop Model for Drip Irrigated Capsicum under Polyethylene Mulch

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ABSTRACT: *Response of capsicum to different formulated drip irrigation schedules under mulch condition using calibrated AquaCrop model was evaluated. The formulated alternative delivery schedules were optimized based on water use efficiency. Simulations were carried out with calibrated model during the period 24 December 2013 to 22 April 2014. Harvest index, a model parameter, was fixed as 80% for capsicum. Irrigation schedule S_6 (75% ET_c) was observed to be the best water saver* i.e. *26.67% over control treatment (100% ET_c) with only 3.84% reduction in the yield of capsicum and water use efficiency as 13.25%.*

Keywords: *Crop water productivity, Water use efficiency, AquaCrop.*

INTRODUCTION

With 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. Irrigation, being the major water user, its share in the total freshwater demand is bound to decrease from the present 83% to 68% due to more pressing and competing demands from other sectors by 2050 AD [1](GOI, 2013), and the country will face water scarcity if adequate and sustainable water management initiatives are not implemented.

There is a need to double annual foodgrain production from about 264 million tonnes (2013) to 420 million tonnes by 2050. Since land is a shrinking resource for agriculture, the pathway for achieving this goal has to be higher productivity per unit of arable land and water [2] (Swaminathan, 2006; GOI, 2013). Water use efficiency is presently estimated to be only 35 to 40% for canal irrigation and about 65-75% for groundwater irrigation schemes [1] (GOI, 2013). As such, the need for improving the present level of water use efficiency in general and for irrigation in particular assumes a great significance in perspective water resource planning.

Capsicum is one of the leading vegetable crop. India contributes one fourth of world production of capsicum with an average annual production of 0.9 million tons from an area of 0.885 million hectare with a productivity of 1266 kg per hectare [3] (Sreedhara *et al.* 2013).

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. The yield loss due to water stress follows the FAO relationship [4] (Doorenbos and Kassam 1979). It simulates crop yield response to water, and is particularly suited to address conditions where water is a key limiting factor in crop production.

Taking into account the importance of improving of water productivity, the present study aimed to optimize the irrigation schedules for capsicum. Improved irrigation schedules which enable to

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increase the water use efficiency of irrigation system were formulated. The formulated alternative schedules were tested using AquaCrop without changing basic infrastructure of irrigation system, to improve water productivity *i.e.* more crop per drop of water.

MATERIAL AND METHODS

Data Collection

Meteorological data for the period December 2013 to April 2014 was obtained from Meteorological Observatory, Central Institute of Agricultural Engineering, Bhopal. It comprised of daily temperature, relative humidity, sunshine hours, wind speed, rainfall and evaporation.

AquaCrop model requires crop-specific parameters like plant density, yield, biomass, effective rooting depth, crop growth stages, green canopy cover (CC), and user-specific parameters like crop cultivar, timing of crop cycle, water management and agronomic practices. The required data was obtained from a field experiment conducted on capsicum during 24 December 2013 to 22 April 2014. The experiment consists of three treatments having three replications as T_1 (Irrigation scheduling at 100% crop evapotranspiration under polyethylene mulch with drip irrigation), T_2 (Irrigation scheduling at 80% crop evapotranspiration under polyethylene mulch with drip irrigation) and T_3 (Irrigation scheduling at 60% crop evapotranspiration under polyethylene mulch with drip irrigation).

To characterize the soil at experimental plot, physico-chemical analysis of soil sample from 0-45cm depth was carried out and presented in Table 1.

Table 1
Physico-chemical properties of soil at experimental site

Soil depth cm	*Sand %*	*Silt %*	*Clay %*	*Textural class*	*Bulk density gcm^{-3}*	*Water retention at, cm^3cm^{-3}*		*Saturated moisture content, cm^3cm^{-3}*	*K_s, $cmday^{-1}$*	*EC dS/m*	*pH*
						0.33 bar	*15 bar*				
0-45	18.8	29.2	52.0	Clay	1.39	0.30	0.15	0.40	22.10	0.19	7.53

Aqua Crop 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* [5] (Doorenbos *et al.*, 1979) represented an important source to determine the yield response to water of field, vegetable and tree crops, through the following equation:

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

where

Y_X and Y_a - Maximum and actual yield,

ET_X and ET_a- Maximum and actual evapotranspiration, and

Ky - Crop yield factor

The model estimates maximum evapotranspiration using Penman-Monteith method [6] (Allen *et al., 1998)*, while maximum yield was specified as described by breeder of the variety.

Calibration and Validation of Model

Data from open field for treatment (T_1) was used for calibration of AquaCrop model, while data of other treatments in open field was used to validate the model. AquaCrop version 4.0 was used in the study. Initial canopy cover, harvest index (HI) and water productivity were model parameters. During calibration and validation, the model parameters were adjusted manually until canopy cover matches to the observed one and performed satisfactorily in terms of selected performance criteria.

Model Performance

Nash Sutcliffe coefficient and coefficient of residual mass (CRM), a dimensionless statistical measure, were used to judge the performance of model.

(a) Nash-Sutcliffe coefficient of efficiency: Nash-Sutcliffe coefficient of efficiency (R^2_{NS}) is used to assess predictive power of model. R^2_{NS} is described mathematically as below [7] (Nash and Sutcliffe, 1970).

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

where,

Q_o - observed values

Q_s - simulated values

Q_{av} - mean of observed values

(b) Coefficient of Residual Mass: Coefficient of residual mass (CRM) checks the estimation ability of model and is mathematically described as below.

$$CRM = \frac{\left[\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} S_i\right]}{\sum_{i=1}^{n} O_i} \quad (3)$$

where,

O_i - Observed value at time i

S_i - Simulated value at time i

Formulation of Irrigation Schedules

Daily reference ET_o was estimated from daily pan evaporation data and pan coefficient as 0.8 (ET_o=Epan x Kp), while crop evapotranspiration (ETc = ETo x Kc) was computed on daily basis using values of crop coefficients [8] (Holsambare, 1988). Ten schedules were formulated considering various levels of water application under polythene mulch with drip irrigation as S_1(110%ETc), S_2(105%ETc), S_3(95%ETc), S_4(90%ETc), S_5(85%ETc), S_6(75%ETc), S_7(70%ETc), S_8(65%ETc), S_9(55%ETc), and S_{10}(50%ETc).

Effectiveness of Formulated Schedules

The calibrated model was used to evaluate the impacts of different drip irrigation schedules on performance of capsicum. Water use efficiency (WUE) refers to the ratio between the total yield of irrigated capsicum and total irrigation water applied [9] (Michael, 1974).

$$WUE = \frac{\text{Total irrigated capsicum yield, kg}}{\text{Total irrigation water applied, m}^3} \quad (4)$$

RESULTS AND DISCUSSION

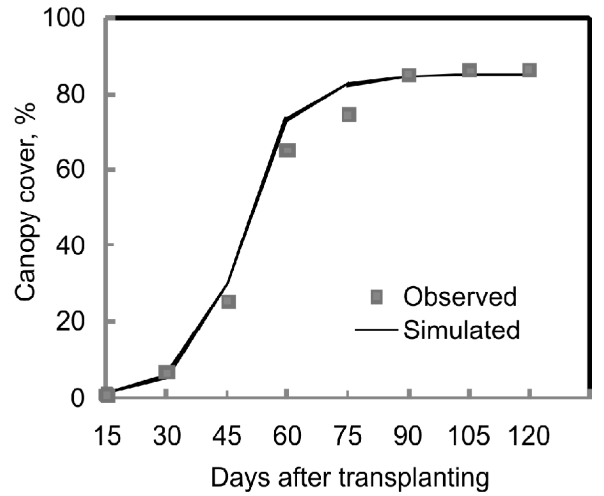
Calibration of AquaCrop Model

AquaCrop model was set up by providing initial values for the following parameters.

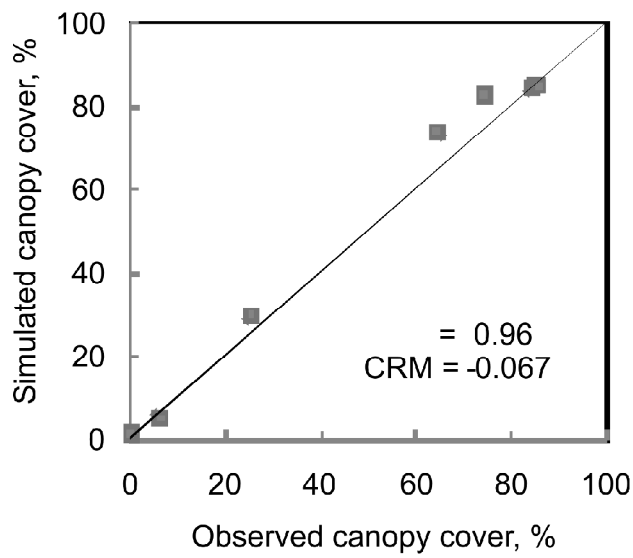
Table 2
Conservative and cultivar specific parameters

Description	*Value*
Base temperature, ^{0}C	10
Upper temperature, ^{0}C	40
Crop type	Vegetable crop
Date of transplanting	24-12-2013
Date of harvesting	22-04-2014
Growing cycle, days	120

To judge the performance of model, observed values of canopy cover (CC) of capsicum were compared with simulated outputs. Temporal variation of observed and simulated canopy cover is presented in Fig. 1a, while Fig. 1b shows comparison of observed and simulated canopy cover.



(a)



(b)

Figure 1: Observed and simulated canopy cover for calibration period

Fig. 1a indicates that there is close match between observed and simulated canopy cover. It is supported by high value of (0.96). CRM as -0.067, indicating that the model slightly overestimate the canopy cover. But Fig.1b shows that there is no continuous over or under estimation of canopy cover by the model.

For observed model parameters the final simulated biomass and yield over calibration period were compared with observed value and presented in Table 2.

Table 2
Final simulated biomass and yield

Particular	*Observed*	*Simulated*
Biomass, tha^{-1}	17.90	17.80
Yield, tha^{-1}	14.20	14.34

Capsicum biomass and yield were observed as 17.90, 14.20 and, 17.80, 14.34 tha^{-1}, respectively, for calibration period. The model slightly underestimated the biomass while yield was slightly overestimated by the model. The calibrated model parameters are presented in Table 3.

Table 3
Calibrated Model Parameters

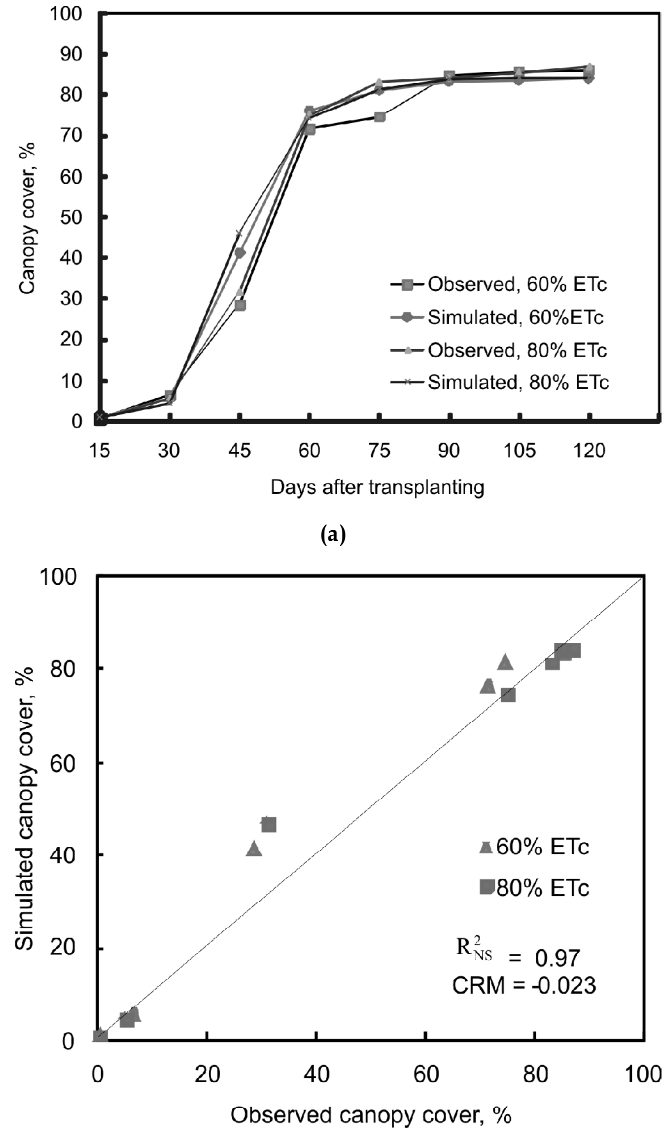
Description	*Measure*
A) Initial canopy cover (CC_o), %	0.40
B) Harvesting index, %	80
C) Water productivity (WP_b), gm^{-2}	18

Model Validation

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 for the data of remaining treatments *i.e.* T_2 and T_3. Temporal variation of observed and simulated canopy cover is presented in Fig. 2a, while Fig. 2b shows comparison of observed and simulated canopy cover.

Fig. 2a infers that there is close match between observed and simulated canopy cover except at certain points during development and mid stage of crop where model overestimated the value of canopy cover. In general, high value of (0.97) confirmed the close match between the simulated and observed values, while CRM as -0.023 indicates slightly overestimation of canopy cover by the model. Beside this, Fig.2b shows that there is no consistent overestimation or underestimation by the model.

The simulated biomass and yield over validation period were compared with observed values and presented in Table 4.



(b)

Figure 2: Observed and simulated canopy cover for calibration period

The observed biomass varied between 17.20 to 17.40 tha^{-1}, whereas observed yield of capsicum varied between 13.60 to 14.10 tha^{-1}. The average variation between observed and simulated biomass is -0.14%, while average variation in yield is found to be 0.19%. Nash Sutcliffe coefficient (R^2_{NS}) and CRM values were found as 0.97, 0.96 and -0.023, 0.009 for biomass and yield, respectively, which shows close match between observed and simulated results. Considering overall acceptability of validation results, it was concluded that the model performs well with relatively high validity.

Table 4
Statistical analysis of validated results for biomass and yield

Sr. No.	*Treatments*	*Biomass, tha^{-1}*		*Yield, tha^{-1}*	
		Observed	*Simulated*	*Observed*	*Simulated*
1	T_2	17.40	17.80	14.10	13.98
2	T_3	17.20	17.08	13.60	13.34
	R^2_{NS}	0.97		0.96	
	CRM	–0.023		0.009	

Effectiveness of Developed Alternative Irrigation Schedules

To optimize irrigation schedule, water use efficiency (WUE) for different developed irrigation schedules was calculated using water applied and simulated yield, and presented in Table 5, while Fig. 3 depicts the variation of yield in reference to water applied.

Table 5
Water use efficiency for different formulated schedules

Schedule	*Water applied, mm*	*Simulated yield, qha^{-1}*	*Variation in water applied %*	*Variation in yield %*	*Water use efficiency, kg m^{3}*
Control, 100% ET_c	420	143.40	-	-	-
S_1	451	143.40	-7.38	-	3.18
S_2	431	143.40	-2.62	-	3.33
S_3	390	139.50	7.14	2.71	3.58
S_4	369	138.00	12.14	3.77	3.74
S_5	349	138.00	16.90	3.77	3.96
S_6	308	137.90	26.67	3.84	4.48
S_7	287	136.30	31.67	4.95	4.75
S_8	267	135.10	36.42	5.79	5.07
S_9	226	126.60	46.19	11.72	5.61
S_{10}	205	125.00	51.19	12.83	6.10

For S_1 to S_{10}, WUE varied from 3.18 to 6.10 kgm^{-3}. Schedule S_{10} resulted in maximum WUE *i.e.* 6.10 kgm^{-3}, while schedule S_1 resulted the lowest WUE *i.e.* 3.18 q/ha-cm. In general, water use efficiency increases as the water applied decreases.

Table 5 and Fig. 4 indicates the decrease of yield in response to decrease in water applied. Maximum water was required in schedule S_1 while lowest was required in S_{10}. It is also cleared that as water applied decreases, the rate of reduction in the yield decreases gradually except for schedules S_1 (110%ETc) and S_2 (105%ETc). It is clear from Table 5 that if water applied decreases by 51.19% (*i.e.*S_{10}), the yield of capsicum decreases by 12.83% as compared to control treatment. Fig.4 also infers that though water applied decreases gradually in schedule S_4, S_5 and S_6, yield of capsicum simulated by model for these schedules is nearly same. Among these schedules, S_6 resulted in maximum saving of water *i.e.* 26.67%, with only 3.84% reduction in the yield as compared to control treatment. WUE for schedule S_6 is observed as 4.48. Water saved with implementation of S_6 *i.e.*26.67% (11.2 $cmha^{-1}$), could irrigate additional 0.36 ha under capsicum with S_6 that might result in 50.15 q production of capsicum. Therefore on the basis of water saving and WUE, schedule S_6 i.e. at 75% of crop evapotranspiration (ETc) is suggested to implement for capsicum production for improved water productivity.

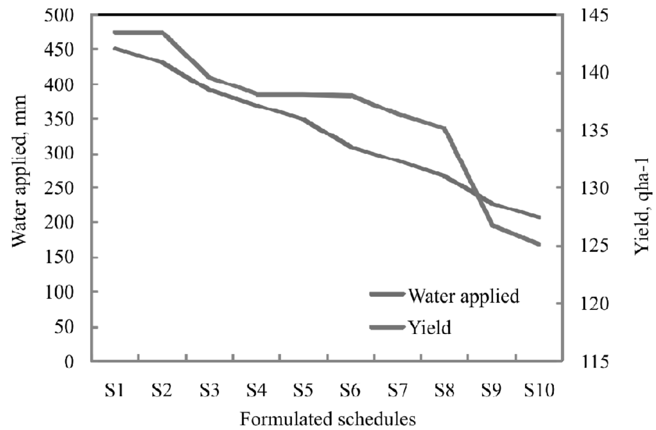


Figure 4: Yield of capsicum as affected by water applied

CONCLUSIONS

Amongst developed alternative irrigation schedules, the irrigation scheduling at 75% of crop evapotranspiration (ET_c) under polyethylene mulch with drip irrigation, was observed to be optimum in terms of water saving (26.67%) and WUE (13.25%) compared over control treatment (100% ETc). By implementing the selected schedule for capsicum production, increase in water productivity as well as water saving can be achieved.

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