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Research Article

Calibration and Testing of FAO AquaCrop Model for Indian Mustard Grown in North-West India and its Sensitivity under Different Scenarios of Rainfall and Temperature

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ABSTRACT

A field experiment was carried out on sandy loam soil of the experimental farm of the Division of Agricultural Physics of IARI, New Delhi, during *rabi* season of 2018-19 for evaluating and validating a water-driven AquaCrop model with three cultivars of mustard viz. Pusa Vijay, Pusa Mustard-21 and Pusa Bold following recommended package of practice. The model parameterization was carried out for crop phenology, biomass and seed yield using data of 2013-14 generated in the same field with the cultivars. The calibrated AquaCrop model had R^2 = 0.89 and 0.99, RMSE = 0.15 t ha^{-1} and 0.32 t ha^{-1}, nRMSE = 5% and 12% and D-index = 0.65 and 0.92 for seed yield and biomass estimation, respectively. The calibrated AquaCrop model was then used to simulate the phenology, final biomass and seed yield and validated for the data generated in the year 2018-19 of field experimentation. The deviation of observed and predicated days of different phenological events varied from -5 to +5 days, 0 to +5 days and -6 to +1 days in the case of Pusa Vijay, Pusa Mustard-21 and Pusa Bold, respectively. The model also predicted the final biomass and seed yield with acceptable accuracy. The validation of the model revealed that it performed well when used to simulate biomass. However, the estimation of seed yield (R^2 = 0.76, RMSE = 0.21 t ha^{-1}, nRMSE = 9.1% and D-index =0.45) lagged behind that of biomass (R^2 = 0.98, RMSE = 0.48 t ha^{-1}, nRMSE = 16.1% with D-index value above 0.9). The results obtained from this model adaptation for mustard revealed satisfactory predictions of phenology, biomass, and seed yield for the selected mustard cultivars. Hence, we suggest that the model could be used to simulate rapeseed-mustard production in semiarid regions of India.

Key words: AquaCrop model, Indian mustard, Phenology, Above ground biomass, Seed yield, Crop weather interaction

Introduction

The ever-increasing human population is putting a considerable strain on natural resources. In the past, the focus was on increasing food production to attain self-sufficiency. However, we still have not achieved self-sufficiency in oilseed production to fulfill the ever-increasing demand. So, to achieve independence in oilseed production, it is essential to know the response of the oilseed crops under existing and changing environmental conditions. Oilseed crops represent one of the influential groups among crops and play a crucial role in India's agricultural and industrial economy. Rapeseed-mustard is the second most important edible oilseed after groundnut sharing 27.8% of the oilseed economy in India (Shekhawat *et al*., 2012). However, its productivity in India (1.49

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t ha^{-1}) is far below the world average (1.98 t ha^{-1}) in the year 2018-19 (USDA). Indian mustard is grown in the *rabi* season (October to April) in the northern plains of India. Due to the sensitivity of this crop to temperature and photoperiod, diverse growth and development patterns were found under different environmental conditions (Neog *et al*., 2005). Current climate prediction models indicate a gradual increase in ambient temperature and an enhancement in the frequency and amplitude of heat stress shortly (Ahuja *et al*., 2010; Mittler and Blumwald, 2010; Mittler *et al*., 2012). In addition, due to climate change, the *rabi* season temperature is expected to increase faster than that of the *kharif* season (Aggarwal and Mall, 2002). An estimated 10-40% loss in crop production in India due to high-temperature stress has been reported. Temperature above 32°C can cause substantial yield losses in *Brassica* species (Angadi *et al*., 2000; Morrison and Stewart, 2002).

Crop-weather interaction studies under different temperature and rainfall scenarios can predict crop performance under variable weather conditions. So, crop simulation models can assess the effect of inter-annual variability of weather and climate change. Crop simulation models (CSM), which are computerized representations of crop growth, development and yield, simulate these parameters using mathematical equations as a function of soil conditions, weather and crop management practices and assist in optimizing different inputs for achieving higher input use efficiency. Calibrated crop simulation models, therefore, are increasingly being used as an alternative means for rapid assessment of crop yield over a wide range of environmental and management conditions (Grassini *et al*., 2011; Garcia-Vila and Fereres, 2012; Foster *et al*., 2014). A range of crop simulation models have been reported in the literature, e.g., Decision Support System for Agrotechnology Transfer (DSSAT) (Jones *et al*., 2003), Cropping System Simulation Model (CropSyst) (Stockle *et al*., 2003), The Agricultural Production Systems Simulator (APSIM) (Keating *et al*., 2003), Hybrid-Maize (Yang *et al*., 2004). However, a common feature of most of these models is the requirement for detailed input data and information about crop growth and its parameters that is not available in most locations worldwide. The Food and Agriculture Organization (FAO) developed AquaCrop, a water-driven model, in 2009 to address these limitations. AquaCrop is a multi-crop model that can also simulate the water-limited yield of herbaceous crop types under different biophysical and management conditions (Raes *et al*., 2009; Steduto *et al*., 2009). It requires a relatively small number of explicit and mostly-intuitive parameters to be defined compared to other crop models. It has been validated and applied successfully for multiple crop types across various environmental and agronomic settings (Vanuytrecht *et al*., 2014). Previously, radiation-driven models like DSSAT were evaluated by Deligios *et al*. (2013) for the crop cycle of winter rapeseed. The study reported an RMSE of 0.8 days and d-index = 0.96. Subsequently, the Mean predicted aboveground biomass at final harvest was 3825 kg ha^{-1}, with an RMSE of 1582 kg ha^{-1} (d-index = 0.92). The model estimated specific leaf area (SLA) with an RMSE of 42.3 cm^2 g^{-1} and d-index = 0.78. The predicted grain yield of rapeseed (2791 kg ha^{-1}) agreed with the observed data. Aggarwal *et al*. (2004) indicated a mustard yield gap with the InfoCrop model for rainfed and irrigated conditions. They found that the mean yield gap based on the average of simulated, experimental and on-farm rain-fed potential yields was 460 kg ha^{-1} for mustard. BRASSICA model was calibrated and validated by Neog *et al*. (2006) for two cultivars of Indian mustard, Pusa Jaikisan and Varuna, and they found that the observed and predicted phenological events varied from -5 to +3 days and +3 to +8 days for both the cultivars, respectively and the biomass prediction was within ±3 percent. Using radiation-driven models limits the investigation of water scarcity in rapeseed and mustard production, which restricts its potential use in rainfed regions. Hence, a model incorporating different water scarcity levels for crop-growth simulation is crucial for crop management planning. AquaCrop is a water-driven model that simulates yield, biomass production and water productivity. It facilitates easy normalization of the water productivity parameter under different climatic conditions (Raes *et al*., 2009). Kumar *et al.* (2014) evaluated performance of AquaCrop Model for simulating grain yield and water productivity of salt tolerant and salt susceptible wheat variety under different salinity in semi-arid regions of New Delhi and found that there is good correlation between observed and simulated biomass and yield but water productivity was over predicted for all varieties and salinity levels. They also concluded that the AquaCrop model can be used to predict the wheat yield under different field management situations in the semi-arid regions of northern India with acceptable accuracy. Singh *et al.* (2013) observed a good agreement in simulating wheat yield in Dakshin Dinajpur district of West Bengal. The model simulated wheat yield of 4.01 t ha^{-1} as compared to the actual yield of 3.90 t ha^{-1} during the validation period. Also, Performance evaluation of AquaCrop model was done for maize crop at New Delhi with different irrigation and nitrogen levels. The model predicted error in simulating the grain and biomass yield ranged from a minimum of 0.47% to 5.91% and maximum of 4.36% to 11.05%, respectively. Experimental analysis in rice crop with AquaCrop model in northwest India showed that the model underestimated the above ground dry matter at 30 days after transplanting and overestimated at the time of harvest. Further, the model suggested to irrigate rice transplanted puddled loamy sand soil on every 5th day to obtain higher Irrigation Water Productivity (IWP). Previously documented studies have not simulated the growth and yield of mustard cultivars using a water-driven AquaCrop model for the semiarid region of India. So, to address this research gap, the study was conducted with the following objectives; (i) to calibrate and validate the AquaCrop model for simulation of growth and yield of mustard cultivars grown in north-west India and (ii) to study crop-weather interaction on mustard under different scenarios of rainfall and temperature using AquaCrop model.

Materials and Methods

Experimental area

This research was carried out in the experimental farm (Main Block-4C) of the Division of Agricultural Physics of ICAR-Indian Agricultural Research Institute, New Delhi, situated at 28°37′ N latitude, 77°10′ E longitude (28°36′50″ N 77°10′32″ E) and an altitude of about 228.16 m from mean sea level with naturally leveled topography. The climate of ICAR-IARI is sub-tropical and semiarid with hot and dry summer and cold winter, which comes under Trans-Gangetic plains among the agro-climatic zones of India. During summer, May and June are the hottest months, and the weekly maximum temperature hovers between 35°C and 42°C. The expected onset of the southwest monsoon in Delhi is on the 29th of June and July, August and September are the monsoon months. The experiment was carried out in randomized block design (RBD) with nine replications of three cultivars as V-1 (Pusa Vijay), V-2 (Pusa Mustard-21) and V-3 (Pusa Bold). The treatment was replicated thrice in 5m × 4m plots. The layout of the experimental field of the mustard crop at IARI farm during the *rabi* season 2018-19 is given in Table 1.

Model description and input data

AquaCrop uses a relatively small number of parameters and fairly intuitive input variables, either widely used or essentially requiring simple methods for their determination. In this study, AquaCrop v 6.1 was selected, with four input data types – crop parameters, soil parameters, management parameters as one-time inputs, and daily weather data (maximum and minimum temperature and rainfall) as regular inputs for driving the model. Reference evapo-transpiration (ETo) was a required input calculated from standard weather data according to the formula given by Doorenbos and Kasam (1979). Crop parameters were of two types- conservative and non-conservative. For calibration of the AquaCrop model, crop-specific conservative parameters except the base temperature were adapted from Zeleke et al. (2011). The base temperature (5°C) was obtained from

Table 1. Layout of experimental field of the mustard crop at IARI farm during *rabi* season 2018-19

V-3	V-2	V-1	V-2	V-1	V-3	V-3	V-2	V-1
				Irrigation channel				
V-2	V-1	V-3	V-1	V-3	V-2	V-1	V-2	V-3
				Irrigation channel				
V-1	V-3	V-2	V-3	V-1	V-2	V-3	V-1	V-2

literature related to IARI field experiments (Kumar *et al*., 2010). The conservative parameter values thus obtained are presented in Table 2(a). Non-conservative parameters for calibrating the model were cultivar specific and these were obtained from the field experiment data of the year 2013-14 in the same field and with the same cultivars (Goyal, 2014; Nishad, 2017). Plant density was obtained from the plant spacing, i.e., row to row (45 cm) and plant to plant (10 cm). Thus, the area per plant was calculated and converted into a one-hectare area's plant population. The mustard crop's maximum canopy cover was around 90%, derived from the leaf area index (LAI) as per the formula given by Hasio *et al.* (2009). Phenological input data like time to flowering (i.e., first flower), length of flowering stage (first flower to the end of flowering), time to senescence, time to maturity (physiological), maximum rooting depth, and reference harvest index were collected from literature and generated from earlier experiments in the same field (Goyal, 2014; Nishad, 2017). Thus, Table 2(b) presents the non-conservative parameter values.

AquaCrop model calibration

The calibration involved fine-tuning the non-conservative parameters for the Indian mustard crop.

Table 2(a). Conservative model parameters used for simulations of mustard cultivars, Pusa Vijay, Pusa Mustard-21 and Pusa Bold

Parameters Conservative	Determination	Values		
		Pusa Vijay	Pusa Mustard-21	Pusa Bold
Base temperature (^oC)	Kumar *et al*. (2010)	5	5	5
Upper temperature (^oC)	Kumar *et al*. (2010)	30	30	30
Cover per seedling (cm^2 $plant^{-1}$)	Destructively measured the seedling leaf area at 90% emergence	5.0	5.0	5.0
Canopy growth coefficient, CGC (% day^{-1})	Derived from the model using time to reach CCx and value of CCx	0.12357	0.12357	0.14417
Canopy decline coefficient, CDC (% day^{-1})	Derived from the model using time to reach senescence	0.08800	0.0800	0.08000
Soil water depletion factor for canopy expansion(upper limit)	P_{upper}	0.20	0.20	0.20
Soil water depletion factor for canopy expansion(lower limit)	P_{lower}	0.55	0.55	0.55
Shape factor for water stress coefficient for canopy expansion	Obtained from Zeleke *et al*. (2011)	3.5	3.5	3.5
Soil water depletion factor for stomatal closure	P_{upper}	0.60	0.60	0.60
Shape factor for water stress coefficient for stomatal closure	Derived from the model	5.0	5.0	5.0
Soil water depletion factor for early canopy senescence	P_{upper}	0.70	0.70	0.70
Shape factor for water stress coefficient for canopy senescence	Derived from the model	3.0	3.0	3.0
Normalized water productivity (WP*) gm^{-2})	Calibrated from the regression of biomass accumulation and ΣTr/ETo	18.6	18.6	18.6
Adjustment for yield formation	Obtained from Zeleke *et al*.(2011)			
Water Productivity normalized for ETo and CO_2 during yield formation (g m^{-2})	Calibrated from the regression of biomass accumulation and ΣTr/ETo	18.6	18.6	18.6

Table 2(b). Non-conservative parameters used for simulation of mustard cultivar Pusa Vijay, Pusa Mustard-21 and Pusa Bold

Parameters	Determination	Values		
Non-conservative		Pusa Vijay	Pusa Mustard-21	Pusa Bold
Plant density (plants ha^{-1})	Using intra- and inter-row spacing	222222	222222	222222
Initial canopy cover (CCo) (%)	Derived from the model using initial seedling leaf area and plant density	1.11	1.11	1.11
Maximum canopy cover (CCx) (%)	Consistent maximum cover read from observed canopy cover curve	90	89	92
Time to maximum canopy cover (days)	Using Canopeo mobile App	65	59	57
Time to flowering (days)	Time taken to when 50% of the plants had formed flowers	49	52	49
Length of flowering stage (days)	Date after 50% flowering to when 50% of the plants had formed pods	31	32	30
Time to senescence (days)	Time to when no new leaves are formed, and at least 10% of plants turned yellow	120	122	120
Time to maturity (days)	Physiological maturity	140	140	140
Maximum rooting depth (m)	Destructive measurement of a full-grown plant at harvesting	1.50	1.50	1.50
Minimum effective rooting depth (m)	Destructive measurement of the seedling root depth at 90% emergence	0.30	0.30	0.30
Reference harvest index (%)	Determined initially from optimum irrigation conditions and calibrated until simulated yield closely matched the observed yield	20	20	21

Tables 2(a) and 2(b) present summarized conservative and non-conservative values derived from the experiment. The parameters were adopted from Zeleke *et al*. (2011) for calibrating and testing the FAO AquaCrop model for Canola in Wagga Wagga, Australia. In this study, the AquaCrop model was calibrated by adjusting the sensitive parameter to the closest fit to the data obtained from the field experimentation during 2013-14 by Goyal (2014). The calibration parameters for all three cultivars of mustard are presented in Tables 2(a) and 2(b).

Soil parameters

The soil parameters used to run the AquaCrop model are presented in Table 3. The different parameters include; bulk density (BD), volumetric water content at saturation, field capacity (FC) and permanent wilting point (PWP), saturated hydraulic conductivity (Ksat) and texture. All these parameters were collected from an experiment conducted in the same field (Thomas, 2013).

Modeling crop weather interaction under different scenarios of rainfall and temperature

The calibrated AquaCrop model was validated with the field experimental datasets of the year 2018-19. After satisfactory calibration and validation of the AquaCrop model, it was tested for sensitivity to different weather conditions and whether it could capture the effect of variable weather parameters (particularly rainfall and temperature) on mustard biomass production and seed yield. It could be done in two ways: 1) by increasing or decreasing temperature and rainfall to a certain extent for the observed existing data set, or 2) by selecting years of *rabi* crop seasons with higher or lower rainfall or temperature for long period average (LPA) values of those parameters. As the second method is more realistic, it was adopted here and the weather record from the last 10 years was scanned.

Table 3. Different soil parameters and their respective values used to run the AquaCrop model

Depth (cm)	B.D. (g cm^{-3})	Saturation (%)	θ (FC) (cm^3 cm^{-3})	θ (PWP) (cm^3 cm^{-3})	Ksat (mm day^{-1})	Texture
0-15	1.51	39.4	0.20	0.08	242.4	Sandy loam
15-30	1.68	39.9	0.21	0.09	240.0	Sandy loam
30-60	1.68	40.1	0.24	0.09	220.0	Sandy loam
60-90	1.71	41.4	0.22	0.10	215.0	Sandy loam
90-120	1.75	41.1	0.26	0.11	210.0	Sandy loam

Model validation and evaluation criterion

Validation of AquaCrop model was done by simulating the phenology, biomass and seed yield using the calibrated model. The performance evaluation of the model was done by estimating the coefficient of determination (R^2), root mean square error (RMSE), normalized RMSE (nRMSE) and index of agreement so, called D-index (Wilmott, 1981) between predicted values by model and experimentally observed values. In the case of the D-index, the closer the value to one gives better agreement between the two variables being compared. The RMSE (Eq. 1), nRMSE (Eq. 2) (expressed in percentage) and D-index (Eq. 3) were computed as:

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(Pi - Oi)^2}{n}} \quad \ldots(1)$$

$$\text{nRMSE} = \frac{RMSE}{\bar{O}} \times 100 \quad \ldots(2)$$

$$\text{D} - \text{index} = 1 - \frac{\sum_{i=1}^{n}(\text{Pi} - \text{Oi})^2}{\sum_{i=1}^{n}(|\text{Pi} - \text{O}| + |\text{Oi} - \text{O}|)^2} \quad \ldots(3)$$

Where,

P_i = i^{th} model predicted or simulated value

O_i = i^{th} observed value

n = number of observation

$\bar{O}$= mean of n observed values

Results

Model calibration

Above ground biomass

AquaCrop Model (v 6.1) was run with the daily weather data of the *rabi* season of 2013-14 for aboveground biomass calibration for three mustard cultivars: Pusa Vijay, Pusa Mustard-21 and Pusa Bold. The simulated biomass of Pusa Vijay, Pusa Mustard-21 and Pusa Bold obtained at ten-day intervals is presented in figures, respectively (Fig. 1). The observed biomass values for the cultivars mentioned above were depicted as a point diagram in the corresponding figures. The calibrated final biomass was 12.70 t ha^{-1}, 11.05 t $ha^{-1}$and 9.81 t ha^{-1}, respectively. The difference in observed and simulated final biomass was +1.35%, +1.80% and -1.6%, respectively. Thus, there was a 10% variance or less in the final biomass calibration.

Seed yield

The AquaCrop model was calibrated for seed yield, biomass accumulation and phenological stages for the weather data of 2013-14. Subsequently, the simulated seed yield was obtained for three mustard cultivars, Pusa Vijay, Pusa Mustard-21, and Pusa Bold, along with the observed values in Table 4. The simulated and observed seed yield differences were -9.20, +3.32, and +2.47% (i.e., within ± 10%).

Model validations

The calibrated AquaCrop model v 6.1 was validated with the weather and crop management data

Table 4. Seed yield calibration of three mustard cultivars

Cultivars	Observed seed yield (t ha^{-1})	Simulated seed yield (t ha^{-1})	% Difference
V-1	2.50	2.27	-9.20
V-2	2.11	2.18	3.32
V-3	1.90	1.95	2.47

V-1 = Pusa Vijay, V-2 = Pusa Mustard-21 and V-3 = Pusa Bold

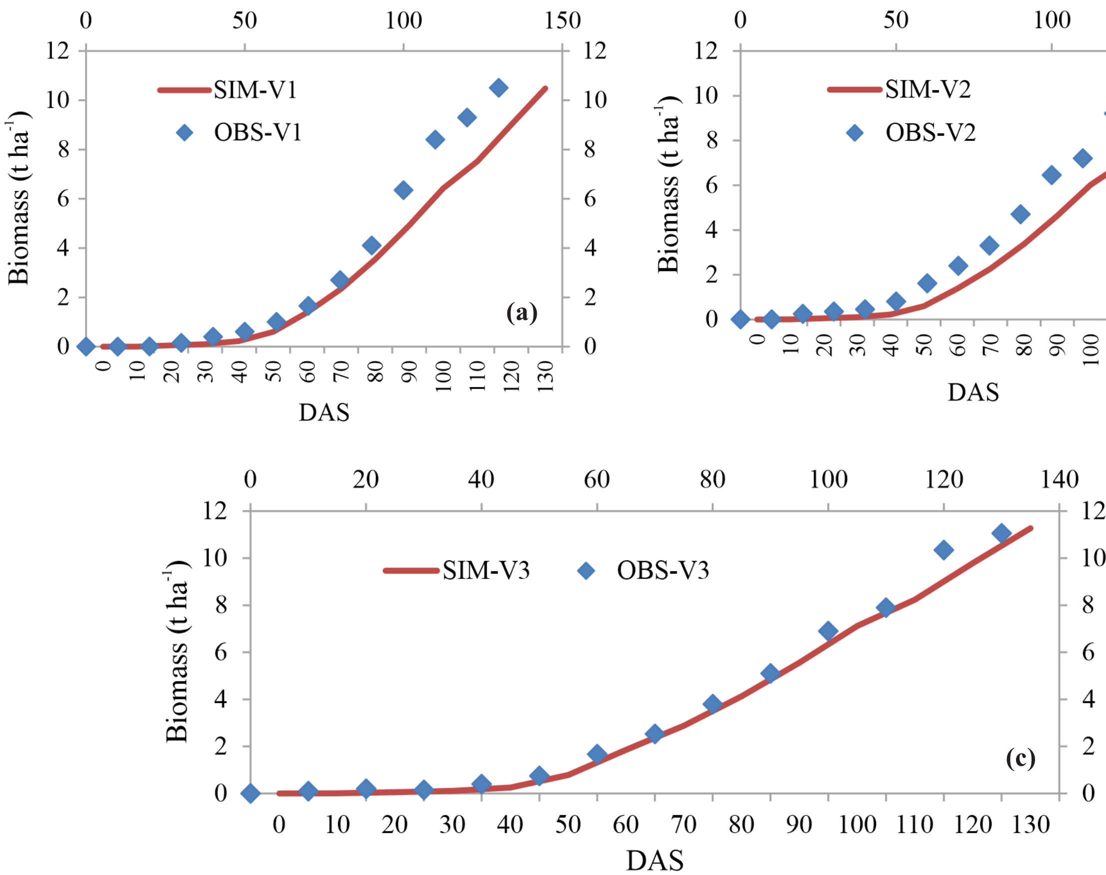

Fig. 1. Simulated above ground biomass calibration for (a) Pusa Vijay (b) Pusa Mustard-21 and (c) Pusa Bold

of the *rabi* season in 2018-19 along with the same crop, soil and management parameters used in calibration. Validation was done for above-ground biomass, seed yield, and profile soil water content.

Above ground biomass

AquaCrop model was run with the weather data of *rabi* season 2018-19 to simulate above-ground biomass for three mustard cultivars, Pusa Vijay, Pusa Mustard-21 and Pusa Bold. In general, it was observed that the entire phenological development was well simulated in the case of Pusa Mustard-21(V-2) and Pusa Bold (V-3). However, the model overestimated the simulated biomass during the reproductive stage (flowering to seed filling, 50-130 days after sowing) for the cultivar Pusa Vijay. But the simulated biomass was almost nearer to the observed values during oil accumulation and physiological maturity (130-140 days after sowing). The model predicted final biomass of 13.5, 11.91 and 11.88 t ha^{-1} for the three cultivars with the difference of +5.97%, -0.75% and +0.25% over the observed final biomass of 12.74, 12.0 and 11.85 t ha^{-1} for Pusa Vijay, Pusa Mustard-21 and Pusa Bold respectively (Table 5).

Table 5. Observed and simulated the final biomass of three mustard cultivars during the *rabi* season, 2018-19

Cultivars	Final biomass (t ha^{-1})		
	Observed	Simulated	Difference (%)
V-1	12.74	13.50	5.97
V-2	12.00	11.91	-0.75
V-3	11.85	11.88	0.25

Model performance for biomass accumulation

AquaCrop model performance was also evaluated for final aboveground biomass and it was

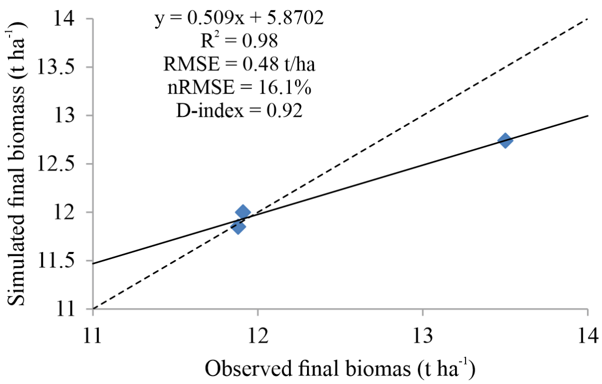

Fig. 2. Performance evaluation of AquaCrop for above ground biomass

found that the model performed well for above-ground biomass simulation with $R^2 = 0.98$, RMSE = 0.48 t ha^{-1}, nRMSE = 16.1% with D-index value above 0.9 (Fig. 2).

Seed yield

Along with simulated biomass, simulated seed yield was also obtained as output for all three mustard cultivars after running the AquaCrop model with the weather data of the *rabi* season of 2018-19 and is presented in Fig. 3(a). Side by side, the observed seed yield obtained through field experiments was shown in the same figure. The model simulated seed yield for Pusa Mustard-21(+1.33% deviation) and Pusa Bold (-4.62% deviation) satisfactorily within ± 5% deviation but in the case of Pusa Vijay, the model overestimated the yield (+15.77% deviation).

Model performance for seed yield

AquaCrop model performance evaluation for seed yield of all three cultivars was done and it was found that yield performance is satisfactory for mustard cultivars with $R^2 = 0.76$, RMSE = 0.21 t ha^{-1}, nRMSE = 9.1% and D-index value of 0.45 (Fig. 3b).

Model performance for profile soil moisture simulation

Soil profile water content up to 1.0 m depth was simulated for the *rabi* season, 2018-19, using the AquaCrop model. Fig. 4a shows the profile's simulated soil water content, including two irrigations (at 42 DAS and 78 DAS of around 60 mm) and rainfall during the crop growing period. A line diagram of simulated and observed profile water content was plotted and compared, and it shows that the AquaCrop model simulated profile water content satisfactorily with little overestimation (except on 49 days after sowing), as shown in Fig. 4a & b.

Model performance evaluation for profile soil water content

AquaCrop model performance was evaluated for the simulated and observed profile soil moisture content (mm). The model underestimated the profile soil moisture content with $R^2 = 0.55$, RMSE = 25.8 mm, nRMSE = 14.8%, and a D-index value of 0.99 (Fig. 4c).

Sensivity of AquaCrop model under different scenarios of rainfall and temperature

Analyzing the previous data, it was found that the *rabi* season of 2012-13 was the wettest, with 121.6% excess rainfall, and the *rabi* season of 2017-18 was the driest (Table 6), with 82.9% deficit rainfall from seasonal normal. Hence, the *rabi* season of

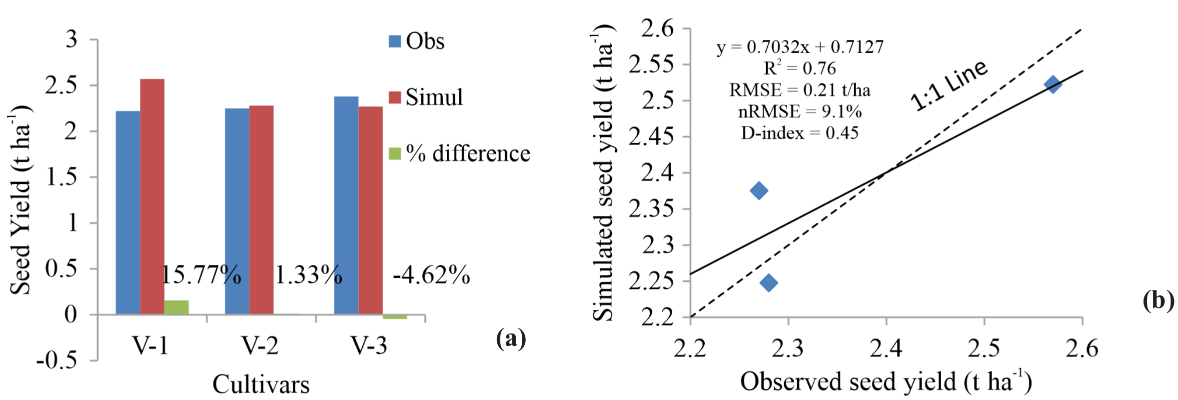

Fig. 3. (a) Simulated seed yield of three mustard cultivars and (b) Performance evaluation of AquaCrop for seed yield

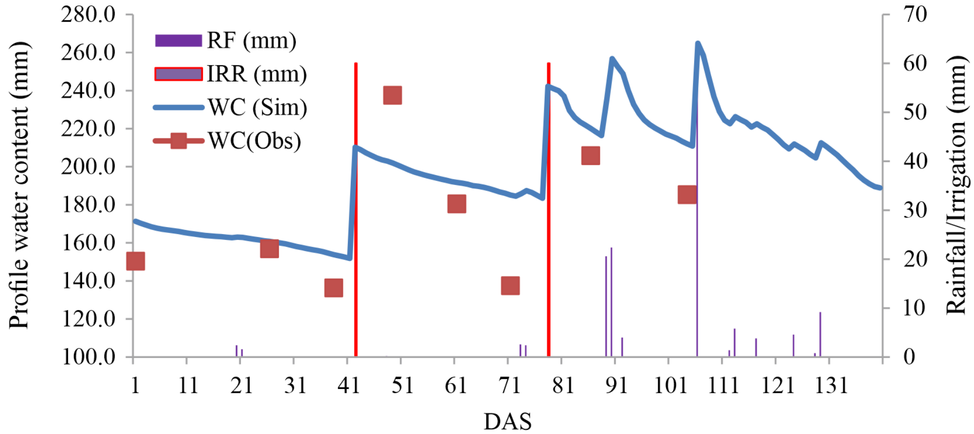

Fig. 4a. Profile soil water content simulation during the *rabi* season, 2018-19

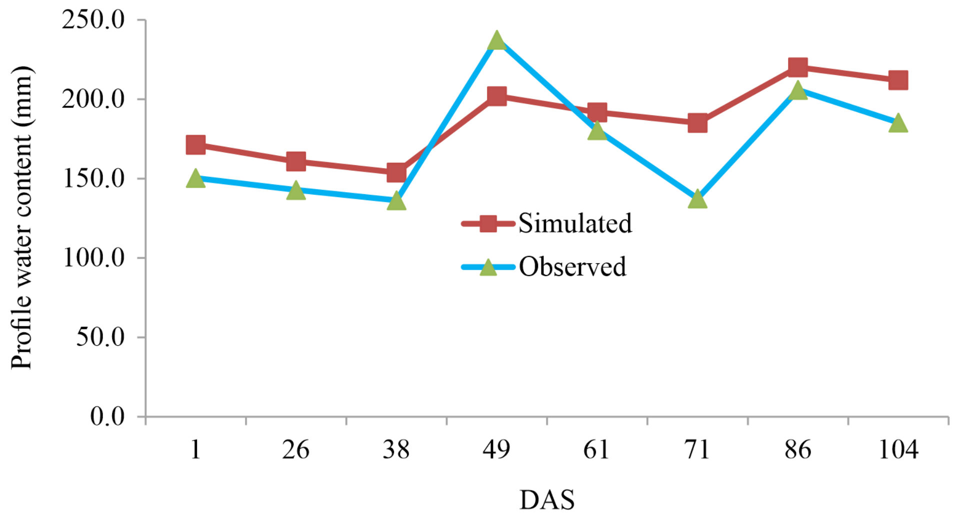

Fig. 4b. Observed and simulated profile soil moisture content during the *rabi* season, 2018-19

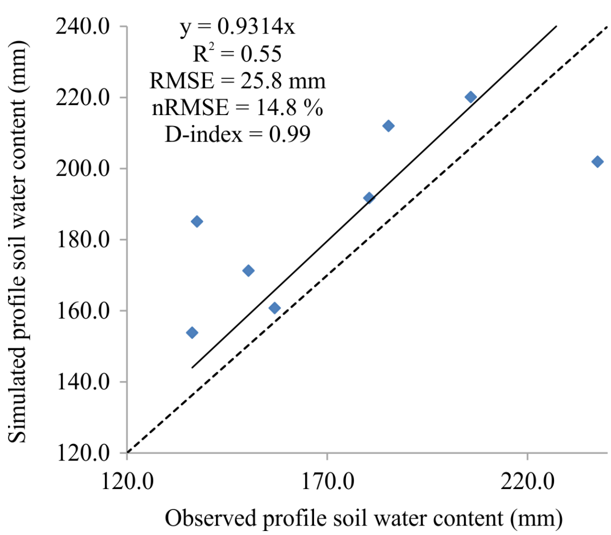

Fig. 4c. AquaCrop model performance evaluation for profile soil moisture content during the *rabi* season, 2018-19

2012-13 was referred to as 'wet,' and 2017-18 was referred to as 'dry.' Thus, sensivity analysis the AquaCrop model was done for two contrasting rainfall scenarios. The seasonal mean temperature of these two seasons was also calculated. Normal sown (second fortnight of October), delayed sown (first fortnight of November) and much delayed sown (second fortnight of November) mustard crops were exposed to mean temperature range, (15.5-15.8°C), (16.4-17.2°C) and (17.8-18.5°C), respectively and the reduction in seed yield was 29% from the normal sown crop was observed when it was sown delayed (sown on 15-25 November) and 59% in much delayed(sown after 25, November) sown crop (Nishad, 2017). So, the AquaCrop model was adopted to simulate the effects of moisture stress (due to low rainfall) and temperature stress due to delayed sowing for the three cultivars with three sowing dates

Table 6. Cumulative rainfall of wet and dry year's *rabi* seasons

Rabiseasons	Rainfall (mm)	LPA* (mm)	Deviation (%)	Consideration
2012-13	173.8	78.1	+121.6	Wet year
2017-18	13.4	78.1	-82.9	Dry year

LPA*(Long Period Average) = Seasonal Normal Rainfall

in both dry and wet years under the semiarid climate of the Delhi region.

Final biomass and seed yield simulation in the dry and wet year

The AquaCrop model was run to simulate the final biomass and seed yield for all three cultivars with three dates of sowing. Three dates of sowing were i) normal sowing (D1= 26 October), ii) late sowing (D2 = 15 November), and iii) very late sowing (D3= 25 November). Final biomass accumulation simulated as 14.59, 13.24, and 13.91 t ha^{-1} for normal sown Pusa Vijay, Pusa Mustard-21 and Pusa Bold, respectively, in wet year/ *rabi* season. There was a decrease in biomass production of the respective cultivars by 17.5, 19.3 and 19.1% in dry years under normal sown conditions (Table 7). As the sowing was delayed a reduction in biomass production was found in the range of 11.2-11.4% for D2 and 16.8-18.3% in a wet year, and similarly, it was 15-18.3% for D2 and 25.6-28.5% for D3 sown crops in dry years. The reduction was more due to delayed sowing in dry years. Late sown crop (D2) decreased in the range of 15.0-18.3%, whereas very late sown (D3) yield recorded a 25.6 to 28.5% reduction. The wet year with more rainfall could somewhat compensate for the biomass reduction due to delayed sowings. Cultivar-wise, normal sown Pusa Vijay was least affected (-17.5%) and much delayed sown Pusa Mustard-21 was most (-29.4%) involved in the dry year regarding biomass production. Maximum seed yield (2.93 t ha^{-1}) was obtained in simulation when Pusa Vijay was sown in normal time in the wet year. Under the same condition, Pusa Mustard-21 simulated 2.67 t ha^{-1} and Pusa Bold

Table 7. Final biomass and yield of three mustard cultivars in wet and dry seasons with three dates of sowing

Treatments	Final Biomass (t ha^{-1})			Seed Yield (t ha^{-1})		
	Wet Year	Dry Year	Difference (%)	Wet Year	Dry Year	Difference (%)
D1V1	14.59	12.04	-17.5	2.93	2.40	-18.0
D2V1	12.95	10.10	-22.0	2.59	2.00	-22.8
D3V1	12.14	8.86	-27.0	2.54	1.79	-29.5
Diff (D1-D2)	-11.2%	-16.1%	-	-11.6%	-16.7%	-
Diff (D1-D3)	-16.8%	-26.4%	-	-13.3%	-25.4%	-
D1V2	13.24	10.69	-19.3	2.67	2.17	-18.7
D2V2	11.73	8.73	-25.6	2.42	1.79	-26.0
D3V2	10.82	7.64	-29.4	2.33	1.53	-34.3
Diff (D1-D2)	-11.4%	-18.3%	-	-9.4%	17.5%	-
Diff (D1-D3)	-18.3%	-28.5%	-	-12.7%	-29.5%	-
D1V3	13.91	11.25	-19.1	2.66	2.09	-21.4
D2V3	12.33	9.56	-22.5	2.35	1.77	-24.7
D3V3	11.47	8.37	-27.0	2.25	1.49	-33.8
Diff (D1-D2)	-11.4%	-15.0%	-	-11.7%	-15.3%	-
Diff (D1-D3)	-17.5%	-25.6%	-	-15.4%	-28.7%	-

D1=26-October, D2=15-November, D3=25-November, V1=Pusa Vijay, V2=Pusa Mustard-21 and V3=Pusa Bold simulated 2.66 t ha^{-1} seed yield. In dry years, a reduction of 18%, 18.7% and 21.4% seed yield was obtained through simulation in the above cultivars under normal sowing conditions. The extent of reduction increased with delay in sowing. The decrease in seed yield was 9.4 to 11.7% for delayed sowing and 12.7 to 15.4% for much-delayed sowing in wet years. Delayed and much-delayed sowings in the dry year aggravated the situation. The maximum reduction was 25.4 to 29.5% in dry years and deferred sown conditions. Seed yield reduction was highest in Pusa Mustard-21 (34.3%), followed by Pusa Bold (33.8%) and Pusa Vijay (29.5%) in the case of much-delayed sowing in dry years. Seed yield was least affected in Pusa Vijay in the dry year under both delayed and much delayed sown.

Discussion

AquaCrop, a crop simulation model developed by FAO, was selected for this study. Unlike other crop simulation models (CERECS, CROPGRO, InfoCrop, which are solar radiation driven), AquaCrop is water-driven (Steduto *et al*., 2009). The model was first calibrated for phenology, and the overall error in different phenological stages was less than five days. The least deviation of 1 day was for 90% germination, and the maximum deviation of -6 days was for the flowering duration in the three cultivars. Later the model was calibrated for biomass and seed yield. The simulated and observed biomass was nearby throughout the growing season, and the difference was within ±5% for all three cultivars.

The difference between simulated and observed final biomass was also within 1% for cultivars Pusa Mustard-21 and Pusa Bold. But for Pusa Vijay, it was overestimated by 6%. High R^2 value (0.98), low RMSE value (0.48 t ha^{-1}), low nRMSE value (16.1%), and high D-index value. Similar results were reported by Dirwai (2021) for the simulation of the final biomass of Canola with $R^2 > 90\%$, d > 0.65. So it indicated that the model was well validated and hence could be used for different applications using the derived calibration coefficients of this study. However, seed yield estimation was not as good as biomass estimation (R^2= 0.78, RMSE= 0.21 t ha^{-1}, nRMSE = 9.1% and D-index = 0.45). Nevertheless, since the yield prediction error was less than 10%, yield simulations can be considered satisfactory. Deligios *et al*. (2013) also observed that under Mediterranean conditions in Italy, simulated grain yields were somewhat lower than the observed value with RMSE 0.2 t ha^{-1}.

Regarding profile soil water content estimation, the model overestimated profile water content with R^2 = 0.55, RMSE = 25.8 mm, nRMSE = 14.8% and D-index = 0.99. These findings are in accordance with what Zeleke *et al*. (2011) reported for Canola using AquaCrop. To examine the sensitivity of the AquaCrop model for higher temperature effect, the model was run with normal, delayed and much-delayed sowing dates for both dry and wet years. Simulated biomass and seed yield reduced when the model was run for delayed sowing dates. As the mustard crop's reproductive stage sown beyond October gets exposed to higher temperatures, it reduces yield (Singh *et al*., 2002). The main limitation of the present study is the simulation of seed yield with lower accuracy as compared to the biomass. It might be due to non-inclusion of genetic information into the model, hence disabling it to factorize the genetic response of the plants to different temperature, water deficits and their interactions (Shirazi *et al*., 2021).

Conclusion

The study was undertaken to evaluate the AquaCrop model for predicting seed yield and biomass accurately for Indian mustard cultivars. The performance evaluation of the AquaCrop model shows that the calibration parameters derived for mustard cultivars in this study are appropriate and hence can be adopted by others either as a starting point for calibrating their varieties in semiarid environments or using them directly in AquaCrop for designing and evaluating an alternative for growth and yield of mustard cultivars under similar climatic conditions. The analysis of different scenarios of temperature and rainfall showed that the highest grain yield (2.93 t ha^{-1} for Pusa Vijay, 2.67 t ha^{-1} for Pusa Mustard-21, and 2.66 t ha^{-1} for Pusa Bold) could be obtained under high rainfall and low-temperature scenario rather than low rainfall and high-temperature scenarios (2.45 t ha^{-1}, for Pusa Vijay, 2.17 t ha^{-1} for Pusa Mustard-21 and 2.09 t ha^{-1} for

Pusa Bold). This simulation study brings out the recommendation in favor of growing Pusa Vijay under dry-year conditions to minimize yield loss. Farmers may sow Pusa Bold even under delayed sowing conditions in a very wet year to reduce yield loss. Therefore, it may be inferred from this study that farmers can cultivate Pusa Vijay with minimal irrigation assurance. They may grow Pusa Bold under wet and late sowing conditions.

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