Application of the FAO model AquaCrop for estimating crop yield under conditions of soil water deficit stress in the Cambodian lowlands

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Abstract

The purpose of this study was to test the Aqua Crop model in simulate canopy cover and above ground biomass of maize under three soil water regimes in a semi-humid environment. The trial at the Cambodian Agricultural Research and Development Institute (CARDI), Cambodia, over the 2015-2016 growing season used 3 plots each with three water regimes. The comparison between the observations and simulated values using statistics indicators R^2, RMSE, nRMSE, Nash, D, and MBE were 0.93, 10.9%, 46.6%, 0.36, 0.9, and 0.37t/ha for canopy cover (overestimation) and 0.97, 1.91 t/ha, 46.9%, 0.44, 0.89, and 0.43 t/ha (overestimation) for biomass respectively.

Keywords

Water regime, simulation, canopy cover, biomass, maize.

Introduction

Increasing water use efficiency is a strategy aimed at reducing water allocated to irrigated crops (Molden et al. 2010). The FAO AquaCrop water balance model has been used to predict the wheat yield with acceptable accuracy for irrigation with saline water under various field management situations in the semi-arid regions of northern India (Kumar et al. 2014). Model performance could be improved by adjusting input data (irrigation, drainage, bulk density) in different sectors of the commercial field (de la Casa et al. 2013). When the model was well calibrated for minimum and maximum irrigation treatments (full irrigation and maximum deficit irrigation), it was able to simulate grain yield for any level of irrigation (Mohammadi et al. 2016). Benabdelouahab et al. (2016) concluded that AquaCrop is a suitable tool for simulating the effects of water stress on crop productivity in order to improve irrigation management and thereby optimise water productivity under semi-arid conditions. The evaluation and validation of the AquaCrop model is essential for important crops and the amount of water irrigation applied was a more sensitive factor than other factors (Afsharmanesh et al. 2014). Abedinpour (2016) indicated that the AquaCrop model simulates aboveground biomass more accurately than grain yield.

The effect of water regimes on maize growth and yield on a sandy loam soil study is currently being studied at the Cambodian Agricultural Research Development Institute (CARDI) as a collaborative between Australian and Cambodian partners funded by the Australian Centre for International Agricultural Research (ACIAR) in the project [SMCN/2012/071]: Improving water and nutrient management to enable double cropping in the rice growing lowlands of Lao PDR and Cambodia. This work aims to identify areas of Lao and Cambodia where dry season crop production is feasible. The AquaCrop is the model being used to estimate regional yields.

Methods

Study area

The study is situated at the Cambodian Agricultural Research Development Institute (CARDI) south of Phnom Penh, Cambodia (Latitude 11°28’35.23” N, Longitude 104°48’27.89” E, Altitude 15 m AMSL). The climate is semi-humid, with an annual average temperature of 28 ˚C, with inter-seasonal variation maximum 34 ˚C and minimum 21 ˚C. The average annual precipitation in Cambodia (1994-2004) is 1600 mm (Cambodia 2012). Seventy percent of precipitation occurs in the wet season, May to October. The trial commenced on 20th January 2016 and harvested on 30th April 2016. Table 1 summarises temperature, rainfall and ETo values for the trail period.

Table 1. Monthly average weather conditions over the experimental plots (2015-2016 trails).

Month	Temperature Max (°C)		Temperature Min (°C)		Rainfall	ETo
	Average	STD	Average	STD	(mm)	(mm/month)
Jan	30.2	1.1	21.5	1.4	0	122.3
Feb	33.7	1.7	21.3	1.8	0	167.7
Mar	38.6	1.6	24.6	1	0	230.4
April	39.1	2.1	25.8	0.8	0	240.3

Field experiments

The soil at the site is a sandy loam over lying a puddled layer of higher clay content at ~30 cm and are locally classified as a Prateah Lang (Plinthustalf) (Table 3). Data was collected from nine plots growing maize. Plot layout and harvesting schedule is shown in Figure 1. Date of emergence after sowing, flowering, maturity, and harvest were recorded for all plots.

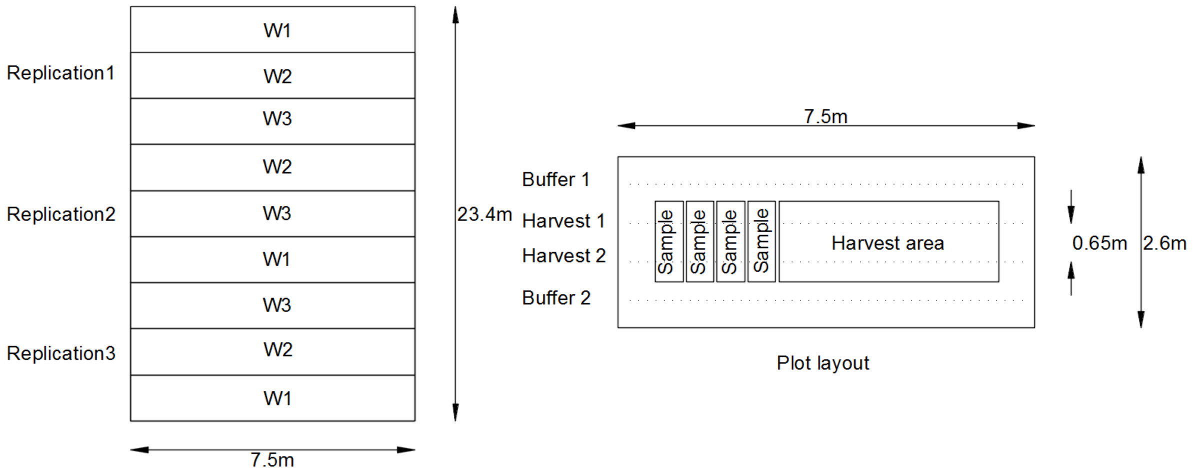

Figure 1. Plot design for 2015-2016.

Table 2. Experimental conditions of the field study.

No.	Water deficit	Replication	Year	Area (m^2)	Sowing date	Harvesting date	Irrigation frequency	Total amount (mm)
1	W1	1	2016	19.5	21-Jan	30-April	21	320
2	W2	1	2016	19.5	21-Jan	30-April	18	268
3	W3	1	2016	19.5	21-Jan	30-April	17	243

Table 3. Soil physical properties.

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	OM (%)	Gravel (%)	Compaction	pH/H_2O (1:5)	EC/H_2O (1:5) (ms/cm)	PWP (% Vol)	FC (% V)	SAT (% V)	Ksat (mm/day)	Soil Classification
0-20	62	28	10	0.73	0	1.2	5.69	0.23	6.5	13.7	28.2	207.6	Sandy loam
20-40	58	27	15	0.42	2.51	1.2	7.02	0.04	9.3	16.8	27.2	71.28	Sandy loam
40-60	56	28	16	0.34	2.17	1.2	8.22	0.08	9.8	17.6	27	53.28	Sandy loam
60-80	53	31	16	0.23	15.69	1.2	8.49	0.11	9.8	18.2	26.8	46.56	Sandy loam

Observation of canopy cover development were recorded weekly, biomass was recorded three times (vegetative, flowering and harvest stages) while grain yield and root depth were recorded at the final harvest. Fertiliser was applied 2 days before and 3 weeks after sowing.

Data

The soil types are classified as Plinthustalfs. Sixteen soil samples were collected from all water regimes to 4 depths. All components were resulted by tool Soil Water Characteristics V.6.02.74 (Table 3)

AquaCrop: presentation and parameterisation

AquaCrop is a crop model developed by FAO that simulates crop and soil response to water stress under various climatic, soil and crop management conditions (Hsiao et al. 2009). At the flower stage, HI increases linearly as a function of time after a latent phase, up to near physiological maturity (Allen et al. 1998). AquaCrop Version 5.0, is built to integrate the soil-plant-atmosphere continuum. It consists of five main components: (i) climate, (ii) crop parameters, (iii) soil type (Table 3), (iv) field management (Table 2), and

(v) irrigation management. AquaCrop provides default parameter values, called conservative parameters that relate to the crops being studied (Steduto et al. 2012). The non-conservative parameters were based on observations at the site. In order to calibrate and validate the model for maize, data from the 2015-2016 CARDI trials were used. The accuracy of model was described using R (Pearson Correlation Coefficient), RMSE (root mean square error), nRMSE (normalised root mean square error), EF (Nash-Sutcliffe model efficiency coefficient), D (Willmott's index of agreement), and MBE.

Model application

The crop trials featured a factorial design with three levels of water applied three replicates. W1 is a full water application based on the preferable level (Rhoads and Stanley), irrigating when GB (Gypsum Block) reading $\geq$30 kPa, W2 irrigating when GB reading $\geq$50 kPa, and W3 irrigating when GB reading $\geq$80 kPa. The plots had a hard layer in depth of 30 cm, therefore 30 cm was assumed to be the maximum root zone depth. The plots were grown on raised beds and water applied by sprinkler (21-Jan-2016 to 26-Feb-2016) and by furrow (29-Feb-2016 to final harvesting).

Results and discussions

Figure 2 (left) shows the relationship between observed and simulated maize canopy cover (CC%) for water regime level 1 (W1), with an R^2 value of 0.90, RMSE 6.4%, nRMSE 22.3%, and Nash 0.86%. The Nash proofs indicated that the model produced simulated values close to field observations. The positive value of MBE (0.86%) indicated that the model produced a simulated canopy cover, which overestimated the measured values.

Figure 2 (right) shows the calibrated and simulated relationship of biomass (t/ha) with statistical indicators: R^2, RMSE, nRMSE, Nash, MBE, with value 0.95, 1.63t/ha, 33%, 0.8, and 0.8t/ha, respectively. The Nash value indicated the good fit of model estimates to observed field data and the modelling of W1 provided an MBE = 0.8 t/ha of the above ground biomass which means the modelling is likely to overestimate yield.

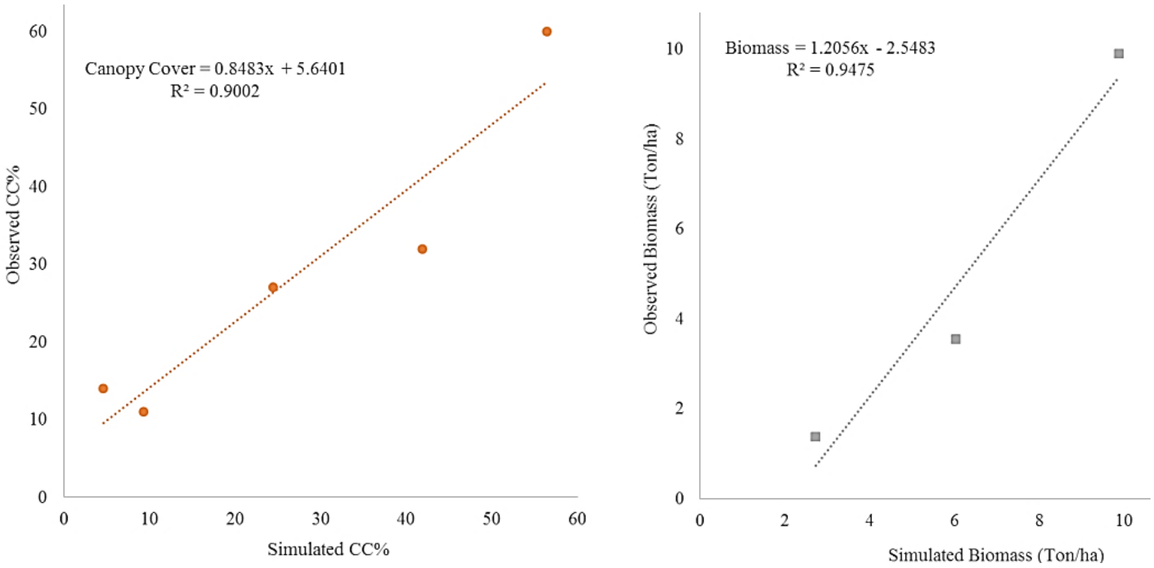

Figure 2. Model calibration for canopy cover under water regime level 1 (left) and biomass under water regime level 1 (right).

Validation of simulation

The results of model validation are summarised in Table 4 and 5. MBE values indicate values are mainly overestimated but on several occasions MBE underestimated. The Nash value for W1 show good agreement for both biomass and canopy cover as indicated by rankings of 0.67 to 0.85. Performance was poorer for W2 and W3, the two less irrigated treatments. The Nash value for canopy cover were ranked from 0.45 to 0.88, averaging 0.73. In most cases, the R^2 values were close to 1.0, which confirms that model provides a good correlation between the observed and simulated values. nRMSE for canopy cover and biomass are higher than 20%, and indicated a higher error value between simulation and observation. In general, the model was satisfactory for water regime level 1 where water deficit stress was minimal. Where water was higher (W2 and W3), the model did not estimate maize canopy cover or biomass as well (Tables 4 and 5).

Table 4. Validation results of canopy cover under different water regimes with the 3 replications.

Water level	W1			W2			W3		
Replication	1	2	3	1	2	3	1	2	3
R2	0.92	0.95	0.93	0.92	0.9	0.92	0.96	0.97	0.9
RMSE	8.40	6.4	9.1	10.7	12.5	10.8	13.1	11.7	15.4
nRMSE	30.40	23.3	29.1	44.7	58.9	44.2	60.1	51.7	77.1
NASH	0.67	0.85	0.85	0.51	0.36	0.42	-0.13	0.27	-0.5
D	0.94	0.97	0.95	0.91	0.89	0.91	0.86	0.9	0.81
MBE	0.66	0.85	0.82	0.51	0.35	0.42	-0.12	0.26	-0.4

Table 5. Validation results of biomass under different water regimes with the 3 replications.

Water level	W1			W2			W3		
Replication	1	2	3	1	2	3	1	2	3
R2	0.99	0.97	0.96	0.97	0.97	0.99	0.95	0.99	0.96
RMSE	1.42	1.57	2.08	1.97	2.27	1.71	2.28	1.57	2.33
nRMSE	29.2	32	41.5	48.4	60.3	45.2	62.9	37	65.3
NASH	0.79	0.79	0.77	0.42	-0.04	0.44	0.13	0.56	0.09
D	0.95	0.94	0.92	0.88	0.83	0.9	0.83	0.9	0.82
MBE	0.79	0.78	0.76	0.41	-0.03	0.43	0.13	0.56	0.08

Conclusion

This study investigated the performance of a model in estimating maize production at 3 levels of water deficit stress. The research found that the AquaCrop maize model was a good predictor of maize productivity when water was readily available, but under conditions of stress as could occur in situations of supplementary irrigation, canopy cover and maize biomass simulation was poorer and indicated that further calibration of the model is required to improve its predictability of maize performance in water scarce conditions. Work is proceeding to improve the performance of the model to aid in design of irrigation systems. The study concluded that AquaCrop, with further calibration, is a potentially useful tool for simulating the effects of water stress on crop productivity under the various conditions.

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