CALIBRATION AND EVALUATION OF AQUACROP MODEL IN RICE GROWTH SIMULATION UNDER DIFFERENT IRRIGATION MANAGEMENTS

JAUGEAGE ET EVALUATION DU MODELE AQUACROP POUR SIMULER LA CROISSANCE DU RIZ DANS DIFFERENTS REGIMES D'IRRIGATION

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ABSTRACT

Due to the growing population and demand of food, increasing water productivity holds the key to future water scarcity and food security challenges. To achieve this, a good understanding of crop response to water stress and tools which simplify the complex crop response to various environmental factors, especially to water, are needed. FAO recently developed a water-driven model (AquaCrop) for use as a decision support tool in planning and scenario analysis in different seasons and locations. In this study, the Aquacrop model was calibrated and evaluated for a lowland local rice cultivar (Champa-Kamfiroozi) in the Kooshkak area (semi-arid climate), Fars province, Iran, with data from an experiment with five irrigation treatments in two consecutive years. According in this study, the model efficiency (ME) for canopy cover simulation was 0.34 to 0.82. The simulated grain yield deviated from the observed data with a range of 0.1% to 7.8% in 2000 and -19% to 0.2% in 2001. The model efficiency (ME) for grain yield simulation in 2000 and 2001 were 0.98 and 0.5, respectively. The root mean square error (RMSE) for grain yield simulation in 2000 and 2001 were 0.09 and 0.7 t ha^{-1}, respectively. The AquaCrop model can adequately simulate the canopy cover development and grain yield of rice under different irrigation managements. The model can be used to explore management options to improve rice water productivity.

Key words: *AquaCrop model, Rice, Irrigation management, Water productivity, Fars province, Iran.*

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RESUME ET CONCLUSIONS

En raison de la croissance démographique et la demande de plus en plus du produit ago-alimentaire , la pénurie en eau pour le secteur agricole devient un problème majeur. Plus de 80% des ressources en eau douce en Asie sont utilisés à des fins d'irrigation dont la moitié environ de l'eau d'irrigation totale est consommée pour la production de riz. L'avenir de la production de riz sera donc fortement dépendre de l'efficacité de l'eau dans les systèmes d'irrigation. Cependant, l'augmentation de la productivité de l'eau est la clé du succès dans la lutte contre la pénurie d'eau et les défis futurs de la sécurité alimentaire. Pour cela, une bonne compréhension de la réponse des cultures au stress hydrique et des outils appropriées qui décrivent les réponses complexes des cultures aux divers facteurs environnementaux, en particulier à l'eau, sont nécessaires. La FAO a récemment développé un modèle axé sur l'eau (AquaCrop) pour utilisation comme un outil d'aide à la décision dans la planification et l'analyse des scénarios au cours des saisons et dans des endroits différents. AquaCrop a une structure simple, conviviale, et emploie 33 paramètres d'entrée de culture qui peuvent être observés facilement sur le terrain. Malgré la réduction et la simplification des variables d'entrée, le modèle maintient un nombre important de données de sortie principale, y compris la simulation du couvert végétal, la biomasse et des composants de bilan hydrique du sol sur l'ensemble du cycle de croissance, et le rendement final. Dans cette étude, le modèle AquaCrop a été calibré et validé pour un cultivar de riz local de plaine (Champa-Kamfiroozi) dans la zone Kooshkak (climat semi-aride), la province de Fars, Iran, avec des données d'une expérience de cinq traitements d'irrigation dans les deux années consécutives. Les plantes ont été cultivées sous l'irrigation par aspersion avec de l'eau appliquée égale à l'ET_P et 1.5ETp, l'irrigation intermittente au 1jouret 2-jours d'intervalle et la submersion permanente (comme le contrôle). Selon cette étude, l'efficacité du modèle (ME) pour la simulation de couvert foliaire a été obtenue de 0,34 à 0,82. En outre, les résultats de cette expérience ont montré que le rendement en grain simulé dévié à partir des données observées avec une gamme de 0,1% à 7,8% en 2000 et -19% à 0,2% en 2001. L'efficacité du modèle (ME) pour la simulation de rendement en grains en 2000 et 2001 étaient de 0,98 et 0,5, respectivement. En outre, la racine carré moyenne des erreurs (RMSE) pour la simulation de rendement en grains en 2000 et 2001 étaient de 0,09 et 0,7 t ha^{-1}, respectivement. Les gammes de productivité de l'eau a été obtenue entre 0,187 à 0,285 et de 0,247 à 0,335 kg m^{-3} en 2000 et 2001, respectivement. En outre, les plages de productivité de l'eau due à l'évapotranspiration des cultures ont été obtenues entre 0,37 à 0,76 et de 0,51 à 0,9 kg m^{-3} (ET) en 2000 et 2001, respectivement. Les résultats de cette expérience montraient que le modèle AquaCrop peut simuler de façon satisfaisant le développement du couvert végétal et le rendement en grain de riz sous irrigation différentes, ainsi que d'autres cultures qui s'appliquait auparavant. En outre, le modèle AquaCrop peut être utilisé pour explorer les options de gestion pour améliorer la productivité de l'eau de riz.

***Mots clés :** Modèle AquaCrop, riz, gestion d'irrigation, productivité de l'eau, Province de Fars, Iran.*

(Traduction française telle que fournie par les auteurs)

1. INTRODUCTION

Rice is a basic food of people in Asia and some other parts of the world (FAO, 1995). Water requirements of rice are much higher than the other cereals and it is a function of cultivar, growth stage, growth duration, soil texture, field management and weather conditions. Conventional rice irrigation method in Iran is the continuous flooding during growing season.

Water is the most important factor in sustainable rice production. Therefore, increasing in water productivity with appropriate irrigation management is necessary. To achieve this goal, the plant growth simulation models can be used as a tool. Crop models can be useful for different purposes. Generally, these models interpret experimental results and work as agronomic research tools for research knowledge synthesis and also as decision support tools for system management (Steduto et al., 2009). Simulation of plant-growth stages and consequently forecasting the crop yield permits better planning and more efficient management of crop production processes (Farshi et al., 1987; Pang & Letey, 1998; Zand-Parsa et al., 2006; Pirmoradian & Sepaskhah, 2006). In practice, optimal scheduling of deficit irrigation requires a good understanding of crop response to water stress. More sophisticated and mechanistic simulation models were developed in recent decades (Uehara and Tsuji, 1998; Ahuja et al., 2002). Efforts in crop simulation modeling, aimed primarily at the integration of physiological knowledge, were started in the late 1960s by several research groups; among them that of de Wit and co-workers (Brouwer and de Wit, 1969). Considering that the previous simulation models were complex and required a large number of input parameters, there have been many efforts to achieve a new model to enjoy of accuracy, simplicity and versatility. The AquaCrop Engineering Model (Steduto et al., 2009) is an outcome of such efforts. Relative to other simulation models, AquaCrop requires fewer number of parameters and input data to simulate the yield response to water. Its parameters are explicit and mostly intuitive, and the model has been built to maintain an adequate balance between accuracy, simplicity, and robustness (Steduto et al., 2009). The inputs are stored in climate, crop, soil and management files and can be easily changed through the user interface. The robustness of the model and its ability to describe the effects of water stress occurring at particular times during the growing season are mentioned by Raes et al., (2009). Considering the increasing world population and increasing need for agricultural production and major role of water in agriculture, vis-à-vis water scarcity, AquaCrop model focuses on yield response to water (Steduto et al., 2009). AquaCrop has been developed by FAO to help project managers, consultants, irrigation engineers and agronomists to increase the crop water productivity.

The first crop chosen to parameterize and test the new FAO AquaCrop model was maize (Hsiao et al., 2009). Also, it was used for growth simulation of cotton (Farahani et al., 2009), sunflower (Steduto et al., 2009), barley (Araya et al., 2010a), and Teff (*Eragrostis tef*) (Araya et al., 2010a), under different water regimes. The results of these experiments showed that the AquaCrop model can be used to explore management options to improve water productivity.

Under water constraint environment, there have been needs to evaluate the possibilities of maximizing yield and biomass either through deficit irrigation or optimal irrigation. This can be achieved through the use of a validated water productivity model such as AquaCrop. In addition, the calibration of the model could be vital for generating yield predictions and for improving water use. At present, many interested researchers have established a network to parameterize and calibrate the model for some specific crops (Hsiao et al., 2009). The objective of this study was to calibrate and validate of AquaCrop model version 3.1 for simulating rice yield under five irrigation regimes at Kooshkak study site in south of Iran.

2. MATERIALS AND METHODS

2.1. Data collection

The required data to calibrate and validate of model were obtained from an experiment described by Pirmoradian et al. (2004). The experiment was conducted at Kooshkak Agricultural Research Station, of Shiraz University in Iran (Lat. 30°7′ N; Long. 52°34′ E; Elevation of 1650 m.) using a local cultivar of low land rice, Champa-Kamphiroozi during the two consecutive growing seasons of 2000 and 2001. The experimental site was the irrigated area of Doroodzan Irrigation District located at south of Iran. Rainfall, daily sunshine hours, wind speed, temperature and relative humidity data were obtained from meteorological station site. The soil at the experimental site was fine, carbonatic, and mesic Aquic Calcixerepts soil. The soil and climate parameters of the experimental site are shown in Table 1.

Table 1. Some properties of climate and soil at experimental site (Tableau 1. Certaines caractéristiques climatiques et chimiques du sol du site expérimental)

Climate parameters during growing season	2000	2001	Soil parameters		
Shortwave radiation, MJ m^{-2} d^{-1}	27.0	27.3	Sampling depth, cm	0–30	30-60
Mean daily of min. temp., °C	14.2	16.2	Sand, %	30	25
			Silt, %	39	32
Mean daily of max. temp., °C	33.7	36.4	Clay, %	31	43
			Electrical conductivity, dS m^{-1}	1.4	1.1
Relative humidity, %	32.5	28.7	pH	7.1	6.9
Evaporation, mm	1047	1188	Total nitrogen, %	0.035	0.033
Precipitation, mm	0	0			

The treatments consisted of five irrigation regimes: (i) sprinkler irrigation with applied water equal to crop potential evapotranspiration, ET_p, (ii) sprinkler irrigation with applied water equal to $1.5ET_p$, (iii) continuous flooding irrigation, (iv) intermittent flooding irrigation at 1-day interval, (v) intermittent flooding irrigation at 2-day interval, all with 4 replicates. The land was prepared from 8 to 10 July in 2000 and from 28 to 30 June in 2001. A local cultivar (Champa-Kamphiroozi) of rice seedlings with low tillering ability was transplanted with 16 hills m^{-2} on 11 of July 2000, and with 25 hills m^{-2} on 1 of July 2001. For the first 10 d, all of the treatments were irrigated with continuous flooding to establish the seedlings. In each plot, a sample area of 1 m^2 was used for measuring LAI at 7-d intervals in the growing season. A water meter measured the volume of the water delivered to the plots. At the end of the growing season, yield samples for grain and biomass were harvested from a 1×1m area in the middle of the plots. Samples were air dried for 5 d before being oven dried at 70 °C for 48 h. The amounts of applied irrigation water during the growing seasons of 2000 and 2001 at the different treatments are shown in Fig. 1.

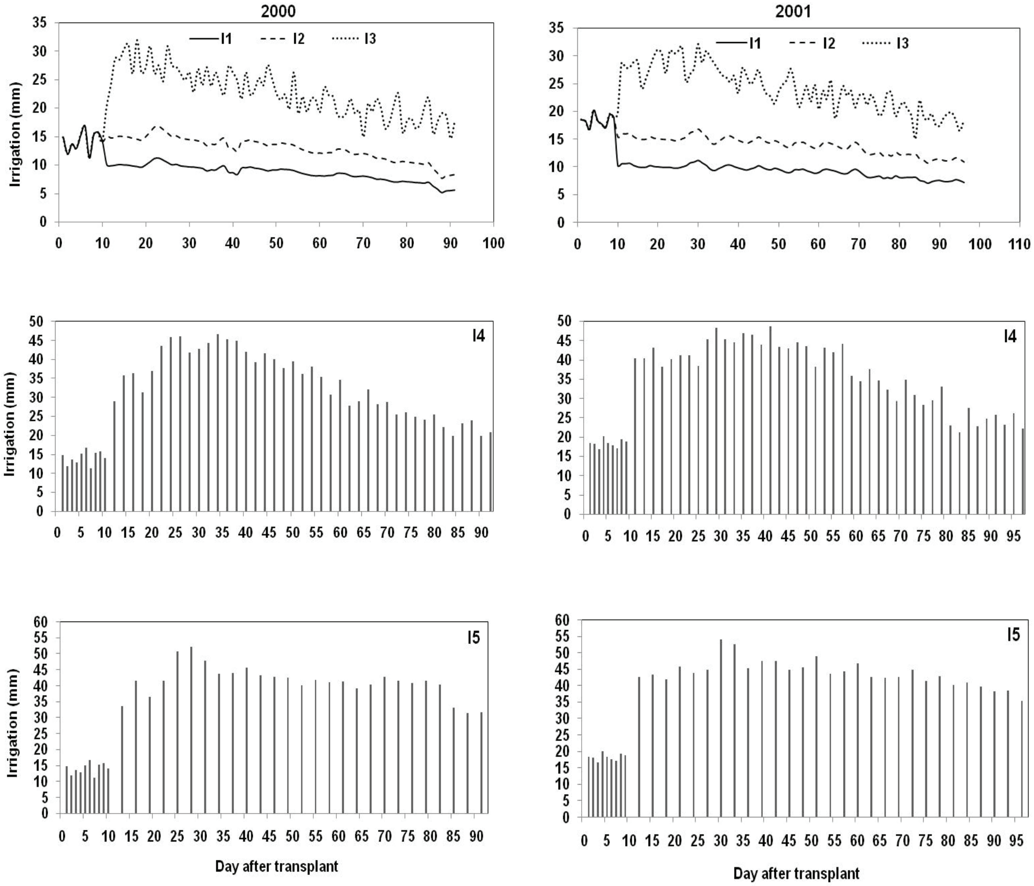

Fig 1. The amounts of applied irrigation water during the growing seasons of 2000 and 2001 at the different treatments (I1: sprinkler irrigation ($1ET_p$), I2: sprinkler irrigation ($1.5ET_p$), I3: continuous flooding irrigation, I4: int. flooding irrigation (1-day int.), I5: int. flooding irrigation (2-day int.)

The daily reference evapotranspirations (ET_o) of Kooshkak site for the growing season 2000 and 2001 were computed using full set of data based on FAO Penman–Monteith method as described in Allen et al. (1998) with the help of the ET_o calculator software (FAO, 2009). The AquaCrop model needs the canopy cover values during growing season. To calculate the canopy cover due to measured LAI values, the following equation was used (Ritchie, 1972; Ritchie et al., 1985; Belmans et al., 1983).

$$CC = 1 - \exp^{(-K*LAI)} \quad (1)$$

Where CC is canopy cover, K is extinction coefficient and LAI is leaf area index. The values of extinction coefficient for rice are between 0.4 – 0.7 (Hay and Walker, 1989).

2.2. Model description

AquaCrop relates its soil-crop-atmosphere components through its soil and its water balance, the atmosphere (rainfall, temperature, evapotranspiration and carbon dioxide concentration) and crop conditions (phenology, crop cover, root depth, biomass production and harvestable yield) and field management (irrigation, fertility and field agronomic practices) components (Raes et al., 2009a; Steduto et al., 2009). AquaCrop calculates a daily water balance and separates its evapotranspiration into evaporation and transpiration. Transpiration is related to canopy cover which is proportional to the extent of soil cover whereas evaporation is proportional to the area of soil uncovered. The crop responds to water stress through four stress coefficients (leaf expansion, stomata closure, canopy senescence, and change in harvest index). The normalized crop water productivity (WP*) is considered constant for a given climate and crop. WP* for C_3 crops like rice is set between 15 and 20 gm^{-2} (Raes et al., 2009b). Using the normalized crop water productivity, AquaCrop calculates the daily aboveground biomass production (Hsiao et al., 2009; Steduto et al., 2009). In this model, yield is obtained by multiplying biomass by harvest index. The adjustment of HI in relation to the available water depends on the timing, severity and duration of water stress (Hsiao et al., 2009; Raes et al., 2009a; Steduto et al., 2009). HI is adjusted for five water stress coefficients namely coefficient for inhibition of leaf growth, for inhibition of stomata, for reduction in green canopy duration due to senescence, for reduction in biomass due to pre-anthesis stress and for pollination failure (Raes et al., 2009a; Steduto et al., 2009). HI for crop like rice is set between 35 and 50 percent.

2.3. Criterions of model validation

AquCrop was calibrated using the measured data sets in 2000 and validation of the model was done using independent data sets of the cropping seasons of 2001. Due to the observed and simulated data, the model validation was conducted using the relative error (E_r), coefficient of residual mass (C_{RM}), root mean square of error (RMSE) and model efficiency (ME) Criterions. Values of the E_r, C_{RM} and RMSE close to zero indicate the best fit of the model. Also, ME ranges from negative infinity to positive 1; the closer to 1, the more robust the model.

3. RESULTS AND DISCUSSION

3.1. Results of model calibration

The model was run after preparing the input data files consist of meteorological data, precipitation, evapotranspiration, irrigation, plant, and soil information for growing season of 2000. The model calibration was conducted by changing the model parameters and based on the best matching between the outputs and measured data. Some of the model calibrated parameters were shown in Table 2. In some cases such as upper and lower thresholds for canopy expansion, canopy senescence stress coefficient and upper threshold for stomata closure, the recommended default values by model guidelines, was considered.

Table 2. Some parameters of AquaCrop model to simulate rice growth (Tableau 2. Certains paramètres du modèle AquaCrop a fin de simuler la croissance du riz)

Description	Value	Units
CC_0	0.48	%
CGC	20.7	%/day
CC_x	83	%
CDC	10	%/day
WP	16	g/m^2
Maximum effective rooting depth	0.4	m
Upper threshold for canopy expansion	0	-
Lower threshold for canopy expansion	0.4	-
Leaf expansion stress coefficient curve shape	3	-
Upper threshold for stomata closure	0.5	-
Stomata stress coefficient curve shape	3	-
Canopy senescence stress coefficient (p_{upper})	0.55	-
senescence stress coefficient curve shape	3	-
Coefficient, HI increased by inhibition of leaf growth at flowering	0.75	-
Coefficient, HI increased due to inhibition of leaf growth before flowering	0	%
Coefficient, HI decreased due to water stress affecting stomata closure during yield formation	5	-
Coefficient, HI increased due to water stress affecting leaf expansion during yield formation	4	-
Aeration stress when waterlogged	0	Vol%

3.2. Model validation

Figure 2 shows the simulated and observed canopy cover values during growing season for different treatments in 2000 and 2001. As shown, the variation of canopy cover development during growing season could be simulated by AquaCrop. The values of RMSE, ME, and C_{RM} for canopy cover simulation are presented in Table 3. As a result, the ranges of model efficiency in canopy cover simulation for different irrigation treatments was obtained between 0.34 to 0.8 in 2000 and between 0.55 to 0.82 in 2001. Also, the ranges of RMSE in these simulations for different irrigation treatments were obtained between 10.42 to 17.32 percent in 2000 and between 9.15 to 14.59 percent in 2001. Due to studies of Hsiao et al. (2009) on maize growth simulation with AquaCrop model, the ranges of RMSE in canopy cover simulations was obtained between 5.06 to 34.53 percent. Therefore, the AquaCrop model has a good simulation for rice canopy cover.

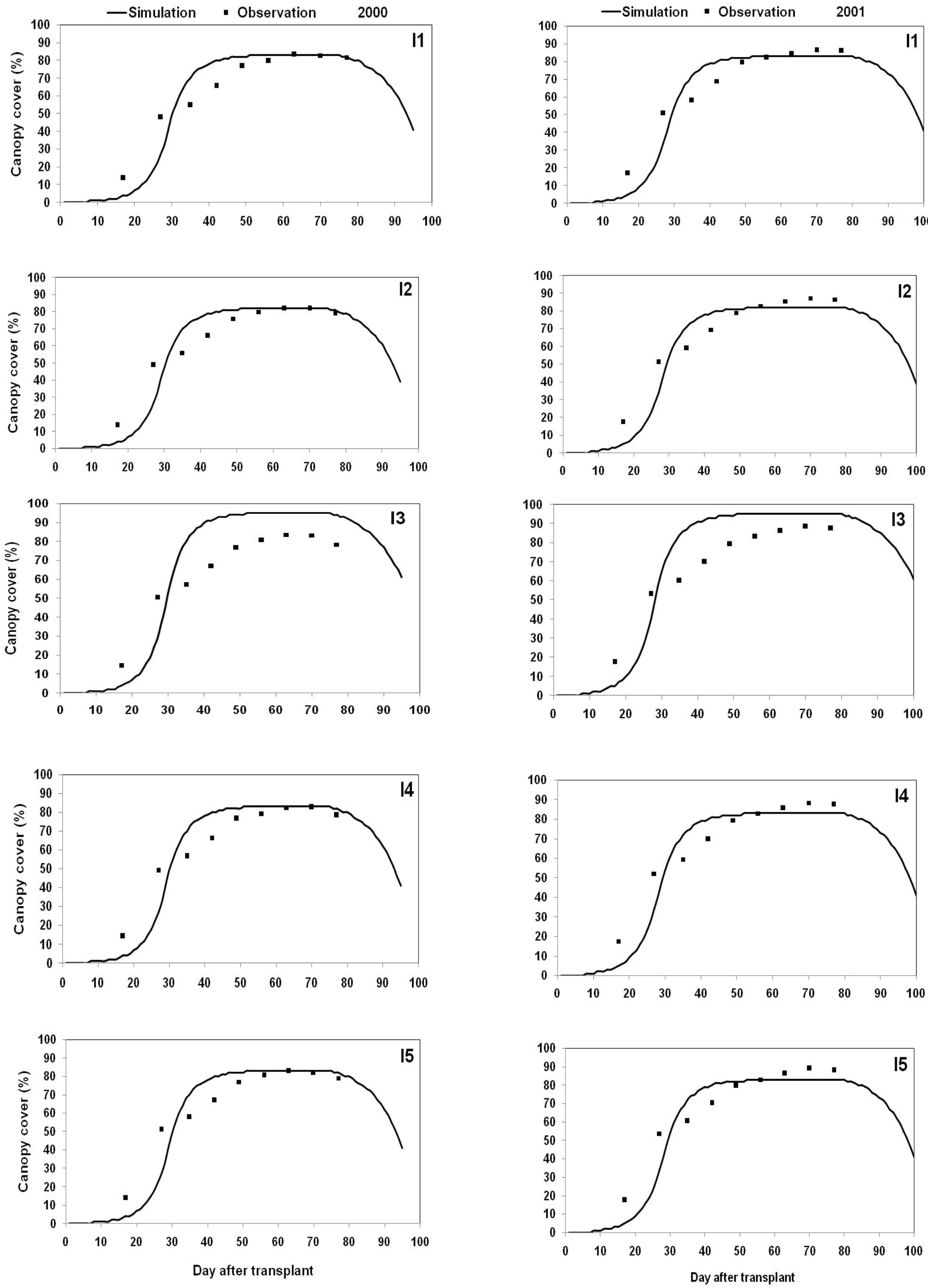

Figure 2. The simulated and observed canopy cover values during growing season for different treatments in 2000 and 2001

Table 3. The values of RMSE, ME, and CRM in canopy cover simulation for different treatments in 2000 and 2001

year	treatment	ME	RMSE (%)	C_{RM}
2000	I1	0.8	10.56	-0.012
	I2	0.76	10.42	-0.007
	I3	0.34	17.32	-0.14
	I4	0.75	10.66	-0.012
	I5	0.745	10.71	-0.005
2001	I1	0.82	9.26	0.015
	I2	0.82	9.15	0.033
	I3	0.55	14.59	-0.11
	I4	0.81	9.5	0.028
	I5	0.804	9.72	0.037

Figure 3 shows the comparison of the simulated and observed yield and biomass in 2000 and 2001. Also, the values of simulated and observed yield and biomass and relative error percentage of those simulations are presented in Table 4. The results showed that the model has simulated better for the grain than the biomass. The values of RMSE, ME and CRM for yield and biomass simulations are shown in Table 5.

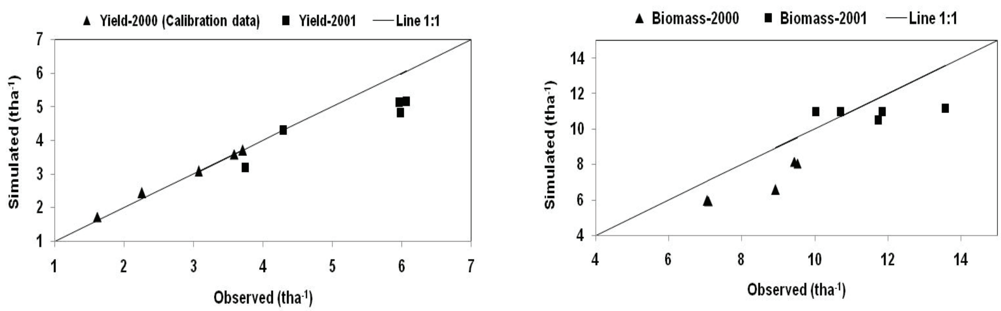

Figure 3. The simulated and observed yield and biomass in 2000 and 2001 (Figure 3. Le rendement en grain et aussi la matière sèche totale simulés et observés en 2000 et 2001)

Table 4. The values of simulated and observed yield and biomass and relative error percentage of those simulations in 2000 and 2001

year	treatment	Biomass (t ha^{-1})		Dev.%	Yield (t ha^{-1})		Dev.%
		Observed	Simulated		Observed	Simulated	
2000	I1	7.063	5.953	-15	1.614	1.726	6.9
	I2	7.095	5.937	-16	2.258	2.434	7.8
	I3	9.526	8.07	-15	3.707	3.712	0.1
	I4	8.925	6.568	-26	3.072	3.087	0.5
	I5	9.45	8.162	-13	3.587	3.591	0.1
2001	I1	10.04	10.989	9.4	3.745	3.187	-14
	I2	11.737	10.489	-10	4.293	4.3	0.2
	I3	13.572	12.176	-10	5.964	5.601	-6
	I4	10.709	10.989	2	6.061	5.165	-14
	I5	11.854	10.989	-7	5.975	4.835	-19

Table 4 shows that the relative errors of simulated biomass and yield were gained between -26% to 9.4% and -19% to 7.8%, respectively. AquaCrop model is calibrated for some specific plants, for example this model could be canopy cover, biomass and yield of barley well to simulate. Due to Araya et al. (2010) to simulate the growth of barley, the simulated grain yield deviated from the observed data with a range of -13% to 15.1% and this range for biomass was -4.3% to 14.6%. Also, Araya et al. (2010) simulated the Teff yield response to water with FAO's AquaCrop model in the Mekelle and Ilala areas in northern Ethiopia. They showed an agreement between the simulated and observed aboveground biomass and grain yield. Accordingly, the results of this study showed that the AquaCrop model could be able to simulate of rice growth.

Table 5. The values of RMSE, ME and CRM for biomass and yield simulation in 2000 and 2001

year	Biomass			Yield		
	ME	RMSE (t ha^{-1})	C_{RM}	ME	RMSE (t ha^{-1})	C_{RM}
2000	0.94	1.5	0.18	0.98	0.09	-0.022
2001	0.27	1	0.04	0.5	0.7	0.11

According to table 5, the values of ME and RMSE show a better simulation for the yield than the biomass. In Araya et al. (2010) study on simulating biomass and yield of barley, the ME values for biomass and yield simulations were obtained between 0.53 to 1 and 0.5 to 0.95 and the RMSE values were obtained between 0.36 to 0.9 t ha^{-1} and 0.07 to 0.27 t ha^{-1}, respectively. Also, in another investigation by Araya et al. (2010) on simulating biomass and yield of Teff, the ME values for biomass and yield simulations were obtained between 0.82 to 1 and 0.64 to 1 and the RMSE values were obtained between 0.2 to 0.92 t ha^{-1} and

0.05 to 0.21 t ha^{-1}, respectively. In Hsiao et al. (2009) to simulate biomass and yield of corn using AquaCrop model, the RMSE values for biomass and yield simulations were obtained between 0.46 to 6.51 t ha^{-1} and 0.65 to 1.33 t ha^{-1}, respectively.

4. CONCLUSIONS

The AquaCrop software was able to simulate well the canopy cover, biomass and yield of rice under different irrigation regimes. Therefore, this model can be used as a decision support tool in increasing water productivity by project managers, consultants, irrigation engineers and farmers. In the other words, this model can be used to simulate the water management effects on yield and handle managements that increase water productivity.

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