Assessment of AquaCrop model in the simulation of durum wheat (*Triticum aestivum* L.) growth and yield under different water regimes

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Abstract

Simulation models that clarify the effects of water on crop yield are useful tools for improving farm level water management and optimizing water use efficiency. In this study, AquaCrop was evaluated for Karim genotype which is the main durum winter wheat (*Triticum aestivum* L.) practiced in Tadla. AquaCrop is based on the water-driven growth module, in that transpiration is converted into biomass through a water productivity parameter. The model was calibrated on data from a full irrigation treatment in 2014/15 and validated on other stressed and unstressed treatments including rain-fed conditions in 2014/15 and 2015/16. Results showed that the model provided excellent simulations of canopy cover, biomass and grain yield. Overall, the relationship between observed and modeled wheat grain yield for all treatments combined produced an R^2 of 0.79, a mean squared error of 1.01 t ha^{-1} and an efficiency coefficient of 0.68. The model satisfactory predicted the trend of soil water reserve. Consequently, AquaCrop can be a valuable tool for simulating wheat grain yield in Tadla plain, particularly considering the fact that the model requires a relatively small number of input data. However, the performance of the model has to be fine-tuned under a wider range of conditions.

Keywords: Crop model, durum wheat, AquaCrop, water stress, Morocco.

Résumé

Les modèles simulant l'effet de l'eau sur le rendement des cultures peuvent être des outils utiles pour améliorer la gestion de l'eau et optimiser l'efficience de son utilisation. Dans cette étude, AquaCrop a été évalué pour la variété de blé dur (*Triticum aestivum* L.) Karim au Tadla. AquaCrop simule la production de biomasse proportionnellement à la transpiration de la plante via un coefficient de productivité de l'eau. Le modèle a été calé sur le régime hydrique non limitant en 2014/15 puis validé sur les autres traitements de 2014/15 et 2015/16. Les résultats ont montré que le modèle permet d'excellentes simulations du taux de couverture du sol, la biomasse et le rendement grain. En combinant tous les traitements, la relation entre le rendement grain observé et simulé a un R^2 de 0,79, une erreur quadratique moyenne de 1,01 t ha^{-1} et un coefficient d'efficacité de 0,68. Le modèle prédit globalement la tendance du stock hydrique du sol. En conséquence, AquaCrop peut être un outil précieux pour simuler le rendement grains du blé, compte tenu en particulier du nombre relativement faible de données d'entrée. Cependant, la performance du modèle doit être évaluée dans un large éventail de conditions.

Mots clés: Modèle de culture, blé dur, AquaCrop, stress hydrique, Maroc

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important crop plants in world. It grows under a broad range of latitudes and altitudes. It is not only the most widely cultivated crop but also the most consumed food crop all over the world. One of the most important challenges in wheat production is yield limiting factors (FAO, 2008). Crops growth simulation models are important tools for evaluating effects of water deficiency on productivity and yield of crops.

Simulation models have been used for decades to analyze crop responses to environmental stresses and to test alternate management practices (Boote et *al*., 1996; Sinclair and Seligman, 1996). Crop yield response to water has been framed in a few simple equations in the past (Hanks, 1974), while more sophisticated and mechanistic simulation models were developed in recent decades (Uehara and Tsuji, 1998; Ahuja et *al*., 2002). However, the trade-off between simplicity and accuracy of the models remains an issue of concern if their broad application is to be achieved. Recently, the FAO-AquaCrop model is a new model that keeps a good balance between robustness and output accuracy. It is a generic crop model and can be used for a large number of crops (Steduto et *al*., 2009; Raes et *al*., 2009).

This simulation model evolved from the basic yield response to water algorithm in Doorenbos and Kassam (1979) to a daily-step, process-based crop growth model with limited complexity. AquaCrop is described in its conceptual framework and algorithmic solutions in Steduto et *al*., (2009) and Raes et *al*., (2009).

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The present study was carried out with the main objective of calibration and performance evaluation of the AquaCrop model under varying water regimes in Tadla region, Morocco.

Material and methods

Field experiments

This study was carried out during the growing period of 2014/15 and 2015/16 at the Tadla experimental station (X = 32.3°; Y = 6.31'; Z = 450 m) of the National Institute of Agronomic Research (Morocco). The soil was classified as loamy-silt. The climate of this area is semi-arid with a great irregularity of rains. Average annual precipitation is about 268 mm, average temperature is 18°C with a maximum in August which often exceeds 45°C and a minimum in January of approximately 0°C.

The climatic variables for the growing period during experimental years are given in table 1. The climatic data were collected from a local meteorological station. According to table 1, the growing period is characterized by low temperature during the months of January and February with temperatures that can approach 0°C. The end of the cycle (May-June) was hot and dry with maximum temperatures averaging around 35°C. The second crop year was relatively hot and with low rainfall. Over the entire cropping period, the number of rainy days is 26 days with a total of 316 mm in 2014/15. In second crop growing year of 2015/16, the number of rainy days is 12 with a total of only 144 mm.

Before the experiment started, soil samples were collected from soil layers 0-30, 30-60 and 60-120 cm for analyses. Some physical and chemical properties of the soil were determined. They are presented in table 2.

Table 2: Some physical and chemical properties of the experimental field soil

Properties	Soil layer (cm)		
	0 – 30	30 – 60	60 - 120
Clay (%)	27.7	43.3	47.4
Fine silt (%)	3.9	15.9	16.6
Coarse silt (%)	49.2	2.8	19.3
Fine sand (%)	12.3	11.2	11.3
Coarse sand (%)	5.7	27.6	6.1
Organic matter (%)	1.91	1.08	1.08
pH	7.97	8.22	8.43
Electrical conductivity (mS/cm)	1.03	0.45	0.53
Field capacity Fc (%)	27.0	28.0	27.0
Wilting point Wp (%)	16.0	17.0	16.0
Bulk density	1.38	1.46	1.57

In order to illustrate the impact of water deficit on yield and some agronomic characteristics of wheat, an experiment was conducted as randomized complete blocks design with a split plot layout and three replications during 2014/15 and 2015/16. The experimental treatments were rain-fed regime as control (T0) and three levels of irrigation: 100% (T1), 67% (T2) and 33% (T3) of water requirement (ETc). Water regimes were considered as the main plots and ten wheat cultivars (Karim, Faraj, Louiza, IDyT 4, IDyT 5, IDyT 17, IDyT22, DwayT 214, DawryT 104 et DawryT 106) as subplots.

The plots have a dimension 3.6 m * 8 m. Spaces of 4 m were left between plot's treatments in order to minimize the risk of water transfer between compared treatments.

Table 1: Climatic data of the experimental station in the growing periods (2014-15 and 2015-16)

Year/Month	Mean Tmax (°C)	Mean Tmin (°C)	Total precipitation (mm)	ET_0 (mm)
2014/15 - November	20.2	10.1	172.2	60.5
- December	18.1	7.5	27.8	40.1
- January	14.9	2.4	41.8	33.4
- February	16.1	4.7	20.3	43.7
- March	20.9	7.5	77.1	72.2
- April	27.4	15.2	3.0	102.5
- May	32.3	17.9	33.3	85.6
2015/16 - November	25.1	10.4	8.4	51.0
- December	23.1	9.1	0	40.5
- January	20.9	6.0	17.8	46.5
- February	20.1	5.1	55.3	57.5
- March	21.5	6.1	51.7	88.0
- April	24.3	10.5	16.6	115.7
- May	25.6	13.2	0	137.0

Irrigation technique used in his study is drip irrigation. For that, the setup was made of 40 cm spaced ramps with 40 cm spaced integrated drippers of a nominal flow rate of 2 l/h. To accurately measure the amount of water applied, we installed 9 flow-meters at the entrance of few plots of the three water regimes in a diagonal distribution.

Wheat was sown with a seed drill on the 20^{th} of November 2014 and harvested on the 6^{th} of June of the following year. In the second year, sowing occurred on 19^{th} of November 2015 and harvest on 26^{th} of May 2016. For both years, the seed rate was 305 seed m^{-2}, with a row spacing of 0.20 m. Before sowing, 70 kg/ha N and 82 kg/ha P_2O_5 were applied to all plots. The amount of the required fertilizers was recommended from the analysis of soil samples. To ensure optimal nitrogen nutrition during all the crop cycle, 65 kg/ha N was added at early tillering stage. Insecticides and herbicides were applied to limit the effect of pests and weeds.

Theoretic water deficit (TWD, mm) for each treatment was calculated as:

$$\mathbf{TWD = Kc.ajst.\ ET_0.\ k_{rc}} \quad (1)$$

Where $K_{c.ajst}$ is adjusted crop coefficient determined using the method given in FAO paper n°56 and ET_0 is the reference evapotranspiration (mm day^{-1}). The reduction coefficient K_{rc} defines the irrigation treatments. It was set to 1, 2/3 and 1/3 for T1 (100% ETc), T2 (67% ETc) and T3 (33% ETc) respectively. ET_0 was calculated using the FAO Penman Monteith (Allen et *al.*, 1998) using ET_0 calculator. Under such conditions, applied water amounts vary between treatments (Table 3). Water was supplied from a well located near the experimental site. It is of high water quality with an electrical conductivity of 0.4 dS/m and a pH of 7.2.

The irrigation schedule was timed to meet the crop water requirements of treatment T1 at a 7 days interval if rainfall is missing. The irrigation amount under full irrigated treatment (T1) is set as the previous 7-day evapotranspiration (TWD) of the crop. For the other regimes (T2 and T3), amount of water applied was reduced according to equation 1.

In order to run the model, cultivar-specific parameters such as plant density, time to emergence, maximum canopy cover, start of senescence, flowering and maturity time, evolution of canopy cover (CC) and biomass (B) and soil water reserve (SWR) were measured. Canopy cover was measured at every 7 days interval, using a camera and suitable software to analyze photographs. Dry matter measurements were carried out weekly by sampling and removal of biomass on a linear meter for each treatment. Grain yield and yield components were determined at maturity.

Change in the soil water content was measured 2 or 3 times a month, before each irrigation event and at harvest. Conventional oven dry (gravimetric) method was used to evaluate soil water content at soil layers 0-20, 20-40, 40-60, 60-80, and 80-100 cm. During the 2^{nd} year, more soil water content measurements were taken in all treatments using PR2 probe (Delta T Devices Ltd).

Table 3: Irrigation water amounts applied (mm) to the different treatments

Crop year	Treatment	Number of irrigations	Irrigation water applied (mm)
2014/15	T1	10	338
	T2	10	209
	T3	8	127
	T0	0	0
2015/16	T1	10	356
	T2	10	264
	T3	10	218
	T0	2	100

Model description

AquaCrop is a water-driven crop growth model (Steduto et *al.*, 2009; Raes et *al.*, 2009). The biomass growth rate is linearly proportional to transpiration through the following equation:

$$\mathbf{AGB = WP \times Tc/ET_0} \quad (2)$$

Where AGB is the aboveground biomass rate; WP is the water productivity (biomass per unit of accumulated water transpired); Tc is the crop transpiration; and ET_0 is the reference evapotranspiration, used to normalize Tc.

Soil water balance is performed on a daily basis including the processes of infiltration, runoff, deep percolation, crop uptake, evaporation, transpiration, and capillary rise. The model keeps track of the rainfall and irrigation, and separates evaporation from transpiration through the percentage of canopy cover as described in detail by Raes et *al.*, (2009). AquaCrop does not calculate ET_0, and it is one of the weather inputs in the model. In this study, ET_0 was calculated from the nearby meteorological stations using the FAO Penman–Monteith approach (Allen et *al.*, 1998) included in ET_0 calculator. Water stress is triggered through the soil water content in the root zone, including three stress response functions: canopy growth reduction, stomata closure, and acceleration of canopy senescence.

The yield is determined through a dynamic harvest index (HI) that partitions biomass into yield and evolves during the yield formation phase until reaching a maximum value. Water stress can either enhance or reduce HI depending on the growth pattern of the crop (determinate or not determinate), and stress timing and severity (Hsiao, 1993; Hsiao et *al.*, 2007; Steduto et *al.*, 2009).

Calibration of the model

The model was calibrated for the full irrigation treatment T1 in 2014/15. The calibration was done through an iterative process using the measured crop growth variables, observed phenological stages, parameters estimated from available data, derived growing coefficients, and parameters used in other studies. Initially, soil, weather, and irrigation files were prepared.

Thereafter, measured and estimated crop parameters were inserted in the model. The final phase of calibration consisted in the refinement of other parameters so that simulated values fit well with observed data. In fact, the parameters were changed manually around the default values until the best fitting with measured data was achieved.

Model performance evaluation and sensitivity analysis

The model validation were based on the comparison between simulated and observed data for all treatments other than those used in model calibration: T2, T3 and T0 treatments in 2014/15 and T1, T2, T3 and T0 in 2015/16. The following parameters were analyzed: (i) canopy cover evolution over the growing cycle (ii) biomass growth over the whole growing cycle, final biomass and grain yield and (iii) soil water reserve (SWR).

In addition to graphical comparisons, there are several statistical indices to compare between predicted and observed values. The model results were evaluated using two performance criteria: the root mean square error (RMSE) and the coefficient of efficiency (Ce) of Nash-Sutcliffe (ASCE, 1996; ASCE: American Society of Civil Engineers). These indices take the following form:

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^{n} \left(P_i - O_i\right)^2 \right]^{0.5} \qquad (3)$$

and

$$Ce = \left[1 - \left[\sum_{i=1}^{n} \left(P_i - O_i\right)^2 / \sum_{i=1}^{n} \left(P_i - \overline{O_i}\right)^2 \right] \right] \qquad (4)$$

Where, n is the number of cases, O is observed value, $\overline{O}$ is mean of observed values and P is predicted value.

A sensitivity analysis is useful to indicate which input parameters have the most significant effect on the model output. Sensitivity of a certain model output to a given parameter can be defined as the rate of change in the output value resulting from a change of this input parameter keeping all other parameters constant (Wöhling, 2005 cited by Khaledian et *al.*, 2008). The sensitivity index, SI, proposed by Ng and Loomis (1984) was selected for this purpose in the present study. The SI is calculated in (%) by:

$$SI = \frac{\left(100/N\right) \times \sum_{i=1}^{N} \left(Xni - Xci\right)/Xci}{\Delta} \qquad (5)$$

Where X_{ni} is the new value of the ith data point with a changed value of the input parameter; X_{ci} the value of output for the ith point in the control simulation run; N the number of points; Δ is the absolute change in the input parameter. SI in the given form is a measure of the percentage change in the output from that in the control simulation resulting from a one percent change in the value of the input parameter. A variation of ± 25% was adopted for all parameters. In this study, sensitive analysis was carried out using 2014/15 weather and experimental conditions under treatment T1.

For calibration, validation and evaluation of AquaCrop model under Tadla conditions, we used the experimental results on the *Karim* variety for both growing years. *Karim* cultivar was used as it is the recommended cultivar for Tadla region.

RESULTS AND DISCUSSION

Model Calibration

Before calibration, crop parameters measured under the water treatment T1 were introduced in the model. Considering a base temperature of 0°C, the thermal time needed for germination was set at 200 GDD. Indeed, field observations showed that full wheat germination took place at about 08 December 2014. The initial canopy cover measured after full germination is 4.45 %. However, this parameter was calibrated and set at 3.9% which corresponds to the value measured at the beginning of December 2014.

Monitoring of canopy cover showed that the maximum value CCx was 98.7%, reached at mid-March coinciding with heading stage. This date corresponds to the thermal time of 987 GDD. Monitoring of leaf area index shows that the maximum value of LAI was 6.15 and reached at flowering stage. The senescence, which is the beginning of CC reduction, took place at the beginning of the 3rd week of April. This date corresponds to a thermal time of 1993 GDD. The thermal time of physiological maturity corresponding to the stage where the grain reached a moisture content of about 14% was reached at 2831 GDD. Physiological maturity took place around the 4th week of May. Flowering occurs at about 25 March, witch corresponded to thermal time of 1353 GDD.

Maximum rooting depth Rmax was set as 80 cm. Several studies have shown that the root mass is concentrated in the first 50 cm. Thermal time required to reach Rmax was set as 1300 GDD. This value corresponds to the beginning of flowering. Indeed, several studies have shown that without water stress, the root system reached its potential size at flowering stage (Khaledian et *al.*, 2008). The duration of flowering was set as 15 days which corresponds to a thermal duration of 149 GDD. The maximum harvest index (HI_0) was evaluated using observations at maturity. Its value was set as 46%.

To improve the simulation of canopy cover under the T1 water regime, both parameters of canopy expansion rate (CGC) and canopy decline rate (CDC) were calibrated to 0.668 and 0.415 respectively. Kcmax was adjusted for Tadla conditions according to the method proposed in FAO paper No. 56 and set to 1.13. Normalized water productivity WP* has been slightly modified from the default value (15 g/m^2) to 15.3 g/m^2. To improve the simulation of canopy cover during senescence phase, the coefficient Ks_{sen} that controls senescence during the final stage was calibrated and set as 0.55.

The crop parameters used in this study are presented in table 4. The values obtained during the calibration procedure are classified in the tables as to whether they were default data, or were calibrated data derived manually by changing the default value, or were data estimated from the available information and in field measurements and observations.

Calibrated parameters were used to simulate canopy cover, biomass, grain yield and soil water reserve under unstressed irrigation treatment T1 (year 2014/15) and results are presented in figures 1, 2 and 3.

According to figure 1a and 2a, the model simulates perfectly canopy cover and biomass growth during the growing season. However, the model showed an overestimation of CC during the senescence phase. According to measurements in the field during this period, drop of CC was fast as it ranged from 99% in 14 April to 73% after one week (21 April). The value simulated by the model on that date was 97%. Regarding the biomass yield obtained on T1 (16.1 t ha^{-1}), AquaCrop model showed a good estimation and simulation of 16.7 t ha^{-1}. Regression analysis of canopy cover and biomass growth vs. measured data confirmed performance of the model (Figure 1b and 2b). Regarding grain yield obtained at maturity (7.4 t/ha), the model showed a slight underestimation of about 4%.

Evolution of measured and simulated SWR by the model during the growing season is illustrated in figure 3a. In general, predictions of soil water reserve are satisfactory. Values of RMSE and Ce were 13.9 mm and 0.74 respectively. However, as shown in figure 3a, we can clearly distinguish two periods. During the period from sowing to the end of February, model simulations were accurate with statistical indices of 0.88 and 10.20 mm for Ce and RMSE respectively. This period is characterized by heavy rains that homogenized distribution of soil water content in the experimental plot. The 2nd period was from early March to maturity. During this period, the model does not properly reproduce values measured with statistical indices of around 0.48 and 19.13 mm for Ce and RMSE respectively.

The gaps between simulated and measured SWR can be attributed to the gravimetric method used when estimating soil water content (change of site at each sampling of soil) under drip irrigation. Thus, a transaction can take place at the wetting bulb and the next time can take place between two wetting bulbs. This implies high soil water content variation that the model does not take into consideration. We are witnessing underestimates or overestimates depending on the sampling method. After the last irrigation applied May 6, 2015, the model simulated well again SWR measured on 28/05/2015 and that of harvest.

Table 4: Crop parameters after calibration of the AquaCrop model

Parameters	Value	
Number of plants per ha	3 050 000 plants/ha	(E)
Initial canopy cover (CCo)	4.45	(E)
Canopy size seedling	1.50 cm²/plant	(L)
Maximum canopy cover (CCx)	99%	(E)
Canopy growth coefficient (CGC)	0.668	(C)
Canopy decline coefficient (CDC)	0.415	(C)
Time to start senescence	1993 GDD	(E)
Time to max canopy	987 GDD	(E)
Time to reach flowering	1353 GDD	(E)
Length of flowering stage	149 GDD	(E)
Time from sowing to emergence	200 GDD	(E)
Time from sowing to reach maturity	2831 GDD	(E)
Maximum effective root depth	0.80 m	(L)
Time from sowing to maximum root depth	1300 GDD	(C)
Building up of HI	785 GDD	(C)
Reference harvest index (HI0)	46 %	(E)
Normalized water productivity	15.3 g/m^2	(C)
Base temperature	0.0 °C	(D)
Upper temperature	35.C°	(D)
Kcmax	1.13	(E)
p (upper) canopy expansion	0.50	(C)
p (lower) canopy expansion	0.80	(C)
p (upper) stomatal closer	0.65	(C)
p (upper) early canopy senescence	0.55	(C)

Model validation

The parameters derived from calibration were used for validation and performance evaluation of AquaCrop by using data from two irrigation treatments (T2 and T3) in addition to the rainfed regime in 2014/15 and all treatments in 2015/16. The evaluation of model performances reported in table 5 was done for each treatment separately for canopy cover, biomass growth and SWR during the season under different water supply regimes and also for the whole of the treatments.

According to the results presented in table 5, performance evaluation of the model in 2014/15 shows that the overall biomass simulations are better for all treatments. The

Table 5: Statistical indices derived from evaluating the performance of the AquaCrop models in predicting CC, biomass growth and SWR during the growing season for each experimental treatment used for model validation

Year	Treatment	CC		Biomass		SWR	
		RMSE (%)	Ce	RMSE (t/ha)	Ce	RMSE (mm)	Ce
2014/15	T2	17.5	0.82	0.98	0.97	17.3	0.68
	T3	21.4	0.78	0.82	0.98	18.3	0.78
	T0	15.0	0.83	0.99	0.93	24.5	0.80
	T2; T3; T0	19.3	0.80	0.91	0.94	18.4	0.73
2015/16	T1	14.5	0.82	1.53	0.94	57.4	0.27
	T2	19.6	0.76	1.82	0.87	43.1	0.31
	T3	24.7	0.74	2.03	0.76	46.3	0.28
	T0	33.7	0.51	2.63	0.44	34.6	0.36
	All treatments	26.4	0.61	2.43	0.63	47.6	0.32

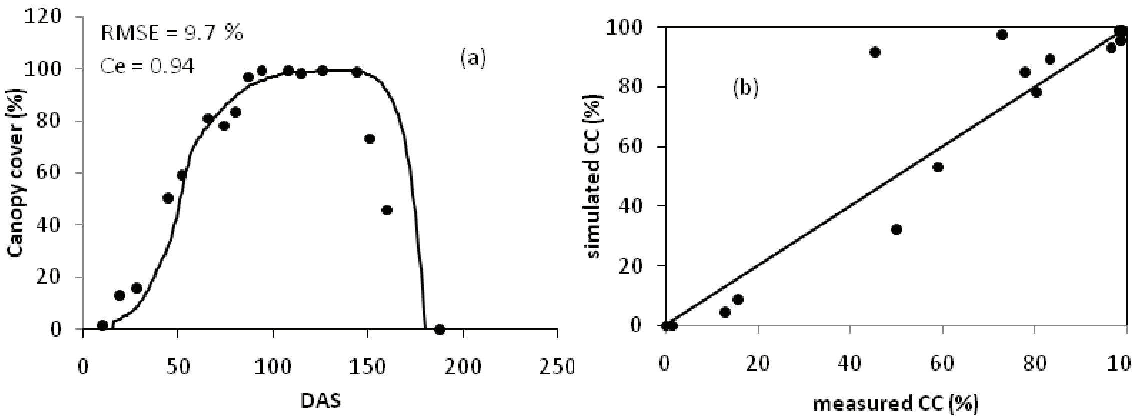

Figure 1: (a) Measured and simulated canopy cover for the unstressed irrigation treatment T1 (calibration) in 2014/15 and (b) on (1/1) graph

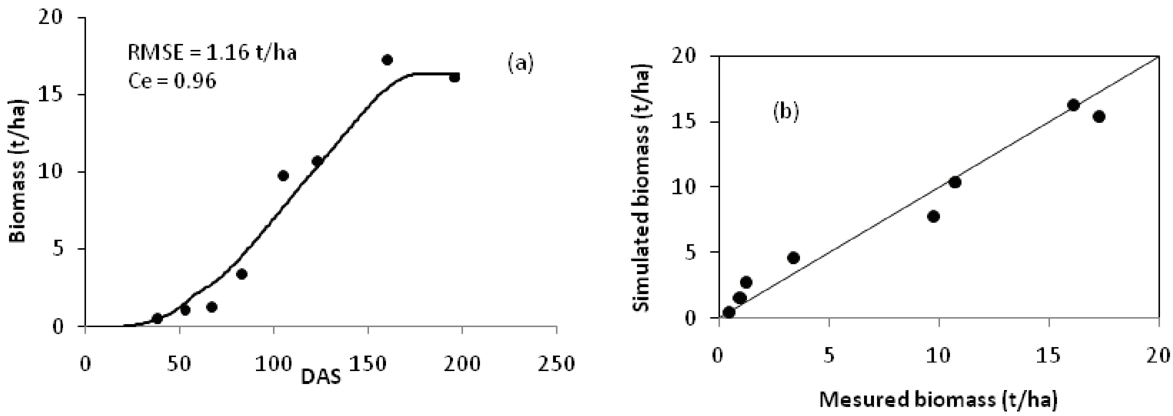

Figure 2: (a) Measured and simulated biomass growth for the unstressed irrigation treatment T1 (calibration) in 2014/15 and (b) on (1/1) graph

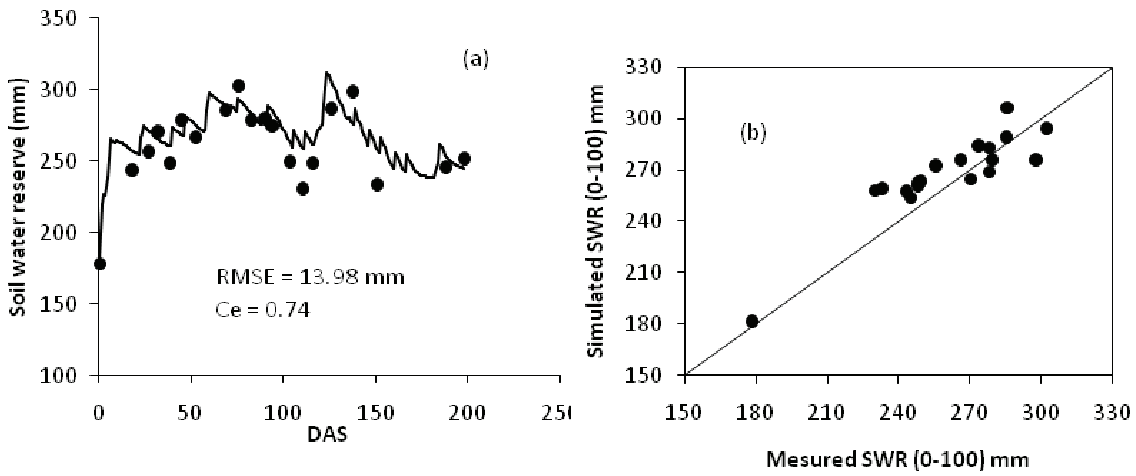

Figure 3: (a) Measured and simulated SWR for the unstressed irrigation treatment T1 (calibration) in 2014/15 and (b) on (1/1) graph

predictions of canopy cover and SWR during the season are satisfactory for all treatments. For all treatments, a general trend of overestimation of canopy cover by the model was observed after the beginning of senescence.

Regarding the 2nd growing year (table 5 and figures 4 and 5), analyzing canopy cover and biomass growth simulations, we can confirm that, as supported by statistic indices, the model is validated on irrigated regimes with a slight decrease in performance from T1 to T3. However, on the T0 regime, there is a remarkable decrease of the model simulations quality. The model underestimated largely both outputs. The statistical indices given in table 5 show that the calibrated parameters are inadequate to simulate biomass and yield of wheat conducted under dry conditions such as the 2nd season which was less rainy (144 mm).

Regarding SWR prediction for treatments used in validation, the quality of simulation is satisfactory under all treatment in 2014/15. The performance of the model was less in well irrigated treatments compared to rainfed. For T0 treatment, RMSE is close to 24.5 mm and Ce to 0.8. Under T2, values were 17.6 mm and 0.68 for RMSE and

CE respectively. For all treatment, the model estimate very low losses by drainage. However, monitoring of tensiometers showed that water losses are significant during the rainy period. This requires accurate measurement of certain parameters of the model for which soil water reserve is sensitive.

In the 2nd crop growing season, the model reproduces poorly measured values (Figure 6). The quality of the simulations for all water regimes was poor as indicated by the values of statistical indices. This is attributed to inaccuracies in the measured values. Indeed, during the 2nd year, a PR2 type probe was used to monitor soil moisture. Direct readings of the probe without field calibration on the plot led to over-estimates and under-estimates of water contents. Therefore, we cannot use these measured values to evaluate the quality of model simulations. First year soil moisture measurements were carried out using the more accurate gravimetric method.

The performance of the model was evaluated considering the final grain yield and biomass for all treatments used for model validation (Figure 7). Final grain yield and biomass were simulated accurately by the model. Values of RMSE and Ce were 1.01 t ha^{-1} and 0.68 for grain yield and 1.51 t ha^{-1} and 0.74 for biomass respectively.

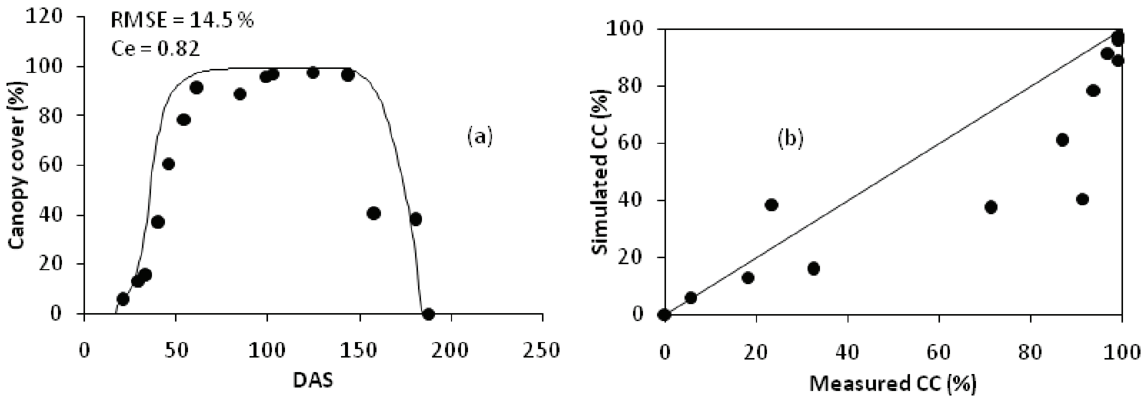

Figure 4: (a) Measured and simulated canopy cover for the unstressed irrigation treatment T1 (validation) in 2015/16 and (b) on (1/1) graph

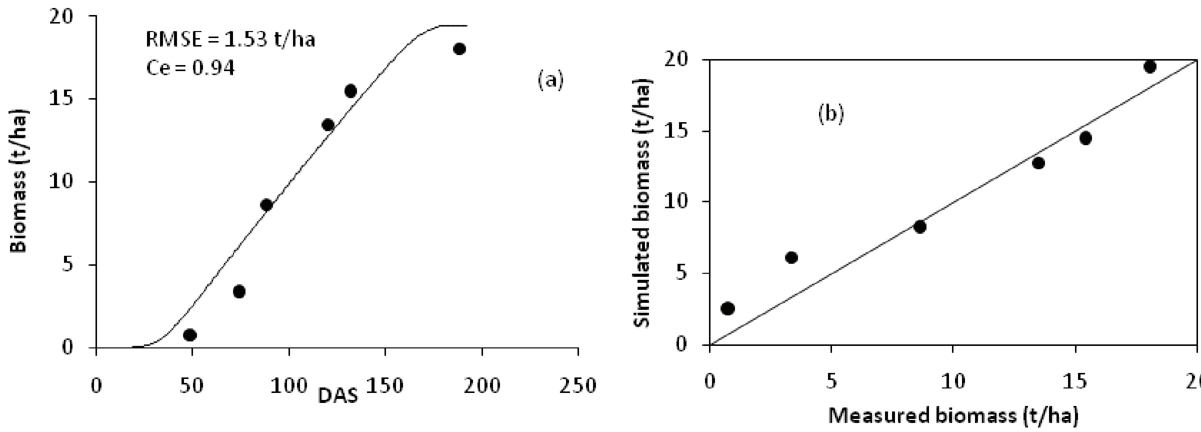

Figure 5: (a) Measured and simulated biomass growth for the unstressed irrigation treatment T1 (validation) in 2015/16 and (b) on (1/1) graph

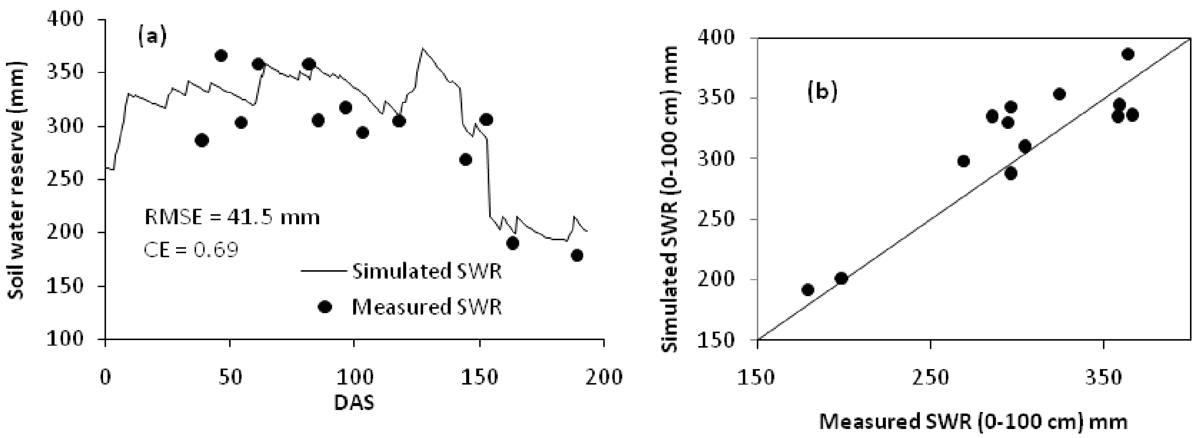

Figure 6: (a) Measured and simulated SWR for the unstressed irrigation treatment T1 (validation) in 2015/16 and (b) on (1/1) graph

Sensitivity analysis

Table 6 shows variations in canopy cover, biomass, yield and SWR vs. variations in input variables using 2014/15 weather and experimental conditions for wheat (*Karim* variety) under T1 treatment. The results showed that simulated final biomass was most sensitive to maximum rooting depth and normalized water productivity. Predicted biomass is relatively little sensitive to the maximum canopy cover (CCx) and the crop coefficient for transpiration Kcmax. Simulated canopy cover is most sensitive to maximum canopy cover (CC_x), maximum root depth and crop coefficient for transpiration. It is also relatively little sensitive to upper threshold for canopy senescence and upper threshold for stomatal closure. In the case of grain yield, canopy cover was very sensitive to the normalized water productivity, upper threshold for canopy senescence, harvest index and upper temperature. Predicted grain yield is little sensitive to the lower threshold for leaf expansion growth and maximum canopy cover (CCx). simulated SWR was most sensitive to hydraulic conductivity at saturation (Ksat) and water content at saturation θ_{SAT}.

CONCLUSION

In this study, AquaCrop model was used to simulate canopy cover, biomass and grain yield of durum wheat (*Karim* genotype) in responses to deficit irrigation under semi-arid climate of Tadla in Morocco.

The crop parameters calibrated for the model under non stressed treatment in 2014/15 revealed to be efficient for all the other simulations of the irrigated water regimes in 2014/15 and 2015/16. This attests a good robustness of AquaCrop model to conduct irrigation. However, the model's performance was less accurate with water stress in highly drier conditions.

Considering the fact that the model requires a relatively small number of input data, AquaCrop appeared to be a promising simulation tool for simulating wheat grain yield in the Tadla plain. However, the performance of the model has to be re-evaluated and fine-tuned under a wider range of conditions.

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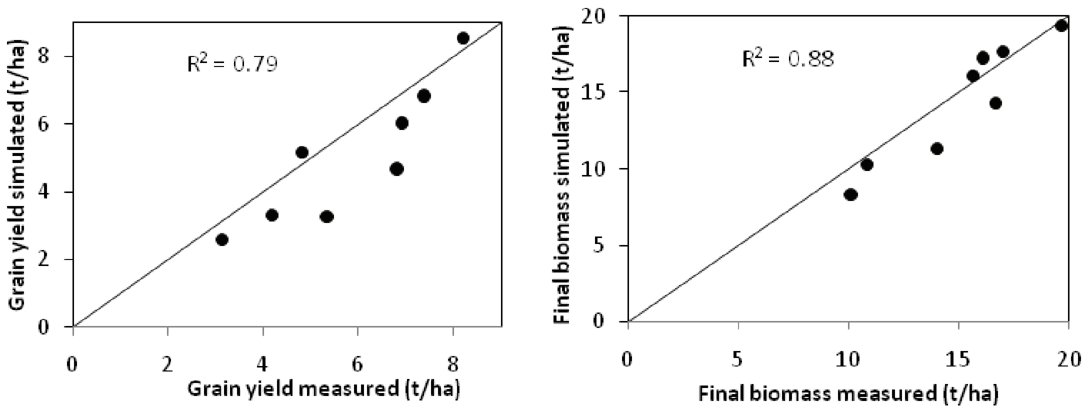

Figure 7: Observed and predicted grain yield and final biomass for all the treatments used for model validation

Table 6: Input parameter sensitivity for wheat with ± 25% changes in input parameters

Parameter	Canopy Cover		Biomass		Grain yield		SWR	
+25%		-25%	+25%	-25%	+25%	-25%	+25%	-25%
Initial canopy cover (CC_0), %	0,320	-0,402	0,380	-0,440	0,158	-0,246	-0,005	0,004
Maximum canopy cover (CC_x), %	1,064	-0,91	0,521	-0,41	0,682	-0,76	-0,002	0,01
Canopy decline coeffi cient per day	-0,268	0,405	-0,037	0,034	-0,240	0,255	0,009	-0,014
Maximum root depth, m	-1,970	0,754	-1,144	0,452	-3,510	2,059	0,319	-0,054
Upper temperture	-0,107	0,123	-0,005	0,016	1,062	-0,762	-0,001	-0,006
Crop coefficient for transpiration	-0,808	0,864	0,453	-0,612	-0,283	0,901	-0,070	0,120
Normalized water productivity	0,000	0,000	1,014	-0,987	1,697	-0,576	-0,001	-0,001
harvets index	0,000	0,000	0,000	0,000	1,280	-0,286	-0,001	-0,001
Upper threshold for leaf expansion growth	0,078	-0,080	0,024	-0,026	0,596	0,459	-0,001	0,000
Lower threshold for leaf expansion growth	0,39	-0,598	0,08	-0,201	0,817	-0,056	-0,004	0,005
Upper threshold for stomatal closure	0,01	0,585	0,00	-0,102	0,0536	0,556	-0,001	0,064
Upper threshold for canopy senescence	0,625	-1,214	0,080	-0,388	1,019	-2,426	-0,025	0,092
θ_{SAT}	0.42	-0.53	0.11	-0.09	0.762	-0.872	-0.768	1.360
K_{sat}	0.247	-0.354	0.032	-0.064	0.654	-0.754	-1.265	1.642

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