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Simulation of wheat yield by AquaCrop model

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ABSTRACT: Crops growth simulation models are important tools for evaluating effects of water deficiency on productivity and yield of crops. One of these models is the AquaCrop model. This model can simulate productivity, yield, water requirement and water use efficiency under condition of water limitation. This research was carried out in order to simulation of some parameters of crops growth under condition of different water regimes on wheat in Sistan region at 2012-13. In this research climate, soil characteristics, plant characteristics and crop cultivation management are from major inputs for model. Place situation, climatic data, soil data, management data are necessary data and information for running model of AquaCrop. The simulation results showed that model simulates biomass and seed yield well. But this model couldn't simulate water use efficiency (WUE) optimally. So that for biomass yield, seed yield and water use efficiency obtained $RMSE_n$ and R^2 equal to (3.20% and 0.99), (5.90% and 0.99) and (16.2% and 0.91) respectively.

***Keywords*:** Wheat, Simulation, AquaCrop model, Sistan region

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 limited factors of yield in wheat (FAO, 2006). 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 tradeoff 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 WP 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).

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

MATERIALS AND METHODS

AquaCrop Modeling

AquaCrop was parameterized and tested using data from a study during 2012-13 that was conducted at Zabol (61°20´ N, 31°2´ E, and 487 m above mean sea level), in Iran earth. The experimental site is characterized by a warm dry climate; mean precipitation is 50 mm.yr-1 with no rainfall during the summer. It has mean minimum, mean maximum and average air temperatures of 16, 30 and 29°C, respectively.

The field experiments had the objective of analyzing the effect of different water regime on wheat yield and water use efficiency. The experimental design was a randomized complete block with four levels of irrigation included: optimum irrigation (field capacity (FC)) moderated stress (80% FC), severe stress (60% FC) and very severe stress (50% FC). The version of AquaCrop (v. 3) used in this study. AquaCrop was parameterized using data from the 2012-13 cropping season that provided the most extensive in-season plant measurements. The performance of the parameterized model was tested by simulating wheat yield and water use efficiency in the 2012-13 season. AquaCrop requires the input data files for climate, crop, soil, irrigation, and initial soil water (SWini) conditions (Raes et al., 2009), which were assembled using the field data described below.

Management Practices

The wheat cultivar of Hamoon was sown by hand during the 1 October, in 25 cm rows, at a density of 400 seeds m^{-2} in 2012-13. The plots were 2 m wide by 4 m long and managed. The first irrigation occurred a few days after seeding, with observed emergence about 6 d later. Field was monitored for pests and weeds, and pesticides were applied as needed. Chemical fertilizer (N, P and K) as urea, super phosphate triple and sulfate potassium were used according to conventional consumption of region. Wheat was harvested by hand in date 10 May 2013.

Model Parameters and Input Data

Weather Data

The weather data required by AquaCrop are the daily values of minimum and maximum air temperature, ETo, rainfall and solar radiation (Raes et al., 2009, Steduto et al., 2009). The standard procedure is to calculate daily reference evapotranspiration (ETo) following the FAO Penman–Monteith equation (Allen et al., 1998).

Soil Data

The required input soil parameters for AquaCrop are the saturated hydraulic conductivity (Ksat), volumetric water content at saturation (θsat), field capacity (θFC), and permanent wilting point (θPWP).These parameters were derived from field measurements.

Wheat Growth Measurements

During the 2006 season, canopy development was monitored in terms of growth stages and aboveground biomass. Before cutting the plants at the ground level, growth stage was recorded.
AquaCrop requires identifying generic growth stages of time to emergence, maximum canopy cover, start of senescence, and maturity. For the purpose of AquaCrop simulation, time to emergence, maximum canopy cover, and start of senescence were based on field observations.

Calibration of AquaCrop

For each of the simulation runs, weather data, soil characteristics, irrigation applications, sowing date, and sowing density were entered as observed. Crop data were obtained from the calibration fields and/or fine-tuned during the calibration runs. Calibrations were based on comparisons between observed biomass yield and seed yield.

Model Evaluation

Several statistics methods were used to compare the simulated and observed results. In this paper evaluated model performance using the root mean square error normalized (RMSEn) (Rinaldy et al., 2003):

$$\mathrm{RMSEn} = 100\left(\sum_{I=1}^{n} (P_i - O_i)^2 / n\right)^{0.5} / O_{mean}$$

Where P_i is the simulated value, O_i is the measured value and n is the number of measurements. RMSE was stated as percentage of simulated amounts than observed amounts. So according to above descriptions, RMSE <

10% is excellent, 10% < RMSE < 20% is well, 20% < RMSE < 30% is moderate, RMSE > 30% is weak (Rinaldy et al., 2003).

Also can for evaluating model use of actual amounts graph (O) than simulated amounts graph (P), and formula of 1:1 linear regression:

O = βO + βP (P)

On the basis of this formula, model is able to exact simulation if after calculating it, between line origin with 1:1 line origin there wasn't any significant different.

RESULTS AND DISCUSSION

Simulation of wheat biomass

Table 1 show results of model simulation for wheat biomass. According to results was recognized that simulated biomass in treatments of optimum and moderate irrigation has adaptation well with observed biomass. So that model simulation was excellent (RMSEn = 3.20%) (Table 1). Regression coefficient had high correlation (R^2>0.99) between simulated biomass with observed biomass (Figure 1).

Hsiao et al., (2009) by AquaCrop simulated the final aboveground biomass within 10% of the measured value for at least 8 of the 13 treatments (6 yr of experiments) and also the grain yield for at least five of the cases. In at least four of the cases, the simulated results were within 5% of the measured for biomass as well as for grain yield. The largest deviation between the simulated and measured values was 22% for biomass, and 24% for grain yield.

Table 1. Simulated biomass and observed biomass in wheat

Treatment	observed (kg/ha)	Simulated (kg/ha)
Optimum irrigation (field capacity (FC))	7410	7625
moderated stress (80% FC)	4370	4521
severe stress (60% FC)	3210	3305
very severe stress (50% FC)	2541	2509
$RMSE_n$ (%)	3.20	

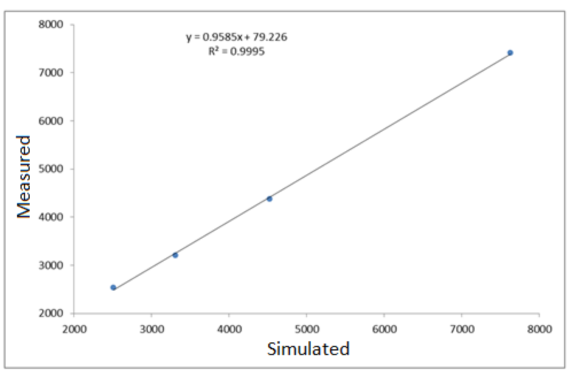

Figure 1. Comparison of Simulated biomass and observed biomass in wheat (kg/ha)

Simulation of wheat seed yield

Table 2 show results of model simulation for seed yield. Similar to results of simulated biomass was seen that simulated seed yield in treatments of optimum and moderate irrigation has coincidence well with observed seed yield. So that model simulation was excellent (RMSEn = 5.90%) (Table 2). Regression coefficient had high correlation (R^2>0.99) between simulated seed yield with observed seed yield (Figure 2). Alizadeh et al, (2010) reported that performance of AquaCrop model in optimum irrigation treatments is higher than low-water treatments.

Table 2. Simulated seed yield and observed seed yield in wheat

Treatment	observed (kg/ha)	Simulated (kg/ha)
Optimum irrigation (field capacity (FC))	3640	3708
moderated stress (80% FC)	2480	2695
severe stress (60% FC)	977	956
very severe stress (50% FC)	547	505
$RMSE_n$ (%)	5.90	

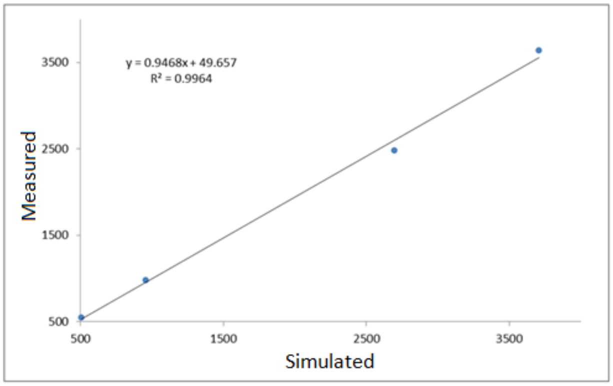

Figure 2. Comparison of Simulated seed yield and observed seed yield in wheat (kg/ha)

Simulation of water use efficiency (WUE)

Table 3 show results of model simulation for WUE in different water treatments. According to results, the highest WUE obtained from moderated stress (80% FC). High WUE in This treatment is because of lower water consumption than optimum irrigation treatment. Also low WUE in treatments of severe stress (60% FC) and very severe stress (50% FC) can be because of (1) seed yield of low in these treatments and (2): negligible rainfall in growth season of wheat in Zabol region.

Model simulates WUE similar to measured WUE as well. From table 3 and figure 3 was concluded that in severe stresses, model show WUE lower than measured amounts and in optimum irrigation treatments WUE is a few higher than measured amounts. Hsiao et al., (2009) in an experiment for corn WUE showed that AquaCrop model couldn't simulate water use efficiency (WUE) optimally, especially in severe drought stresses. Alizadeh et al., (2010) found results similar to this research.

Table 3. Simulated WUE and observed WUE in wheat

Treatment	observed (kg/m^3)	Simulated (kg/m^3)
Optimum irrigation (field capacity (FC))	0.97	1.17
moderated stress (80% FC)	1.25	1.31
severe stress (60% FC)	0.76	0.68
very severe stress (50% FC)	0.65	0.59
$RMSE_n$ (%)	16.28	

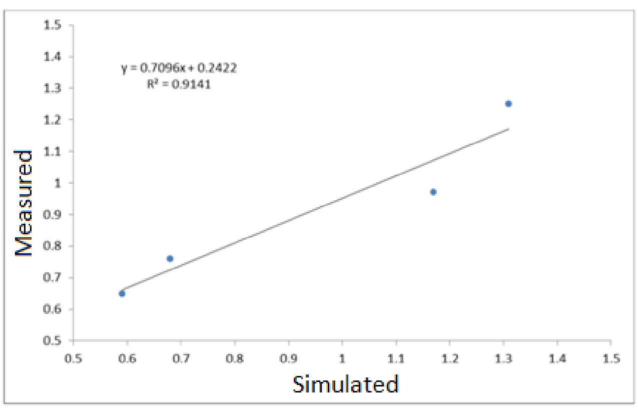

Figure 3. Comparison of Simulated WUE and observed WUE in wheat (kg/m^3)

CONCLUSION

This research was carried out for simulating wheat yield and WUE in Zabol region. Results showed that model can simulate seed and biomass yield of wheat carefully. But it couldn't simulate water use efficiency (WUE) optimally, especially in severe drought stresses.

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