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ASSESSMENT OF AQUACROP MODEL IN THE SIMULATION OF WHEAT GROWTH UNDER DIFFERENT WATER REGIMES

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Abstract

The main purpose of deficit irrigation is high water productivity with lesser water supplies to optimum crop yield. Accurate crop development models are important tools in evaluating the effects of different water applications on crop yields. The FAO-AQUACROP model (Ver. 5.0) simulates attainable yields of several crops as a function of water consumption under rainfed, supplemental, deficit, and full irrigation conditions. The aim of this study; validation and testing of the AQUACROP model for winter wheat under full and rainfed conditions in semi arid condition such as Central Anatolia. Model prediction and actual results were compared. According to statistical evaluation; average deviation (α), standard error (RMSE) and modeling efficiency (E) for biomass and for crop yield was found as 1.16, 1.17 t ha-1 and 0.67 and 0.320, 0.326 t ha-1 and 0.83 respectively. Model predicted soil water content in root zone, canopy cover and grain yields with high accuracy but biomass were predicted higher than actual results.

Key words: *AquaCrop, wheat yield, water use efficiency.*

INTRODUCTION

Agriculture is the biggest consumer about 72% percent of available fresh water resources on global bases (Geerts and Raes, 2009; Andarzian et al., 2011). With the increase in population in many parts of the world, it has become a necessity for an increase in food production. Especially arid and semi arid regions production depends almost entirely on irrigation and irrigation is important factor to improve water use efficiency (Musick et al., 1994; Steven et al., 2009). A lot of studies have shown that one of the encouraging irrigation strategies might be deficit irrigation (Kipkorir, 2002; Debaek and Aboudrare, 2004; Fereres and Soriano, 2007; Ali and Talukder, 2008; Farre and Faci, 2009; Behera and Panda, 2009; Blum, 2009; Geerts and Raes, 2009), since less water than required is applied during the growing period. Investigating the plant response to different irrigation strategies in field and carried out experiments is difficult and expensive. Considering this kind of limitations, accurate crop development models are important tools in evaluating the effects of water deficits on crop yield or productivity and predicting yields to optimize irrigation under limited available water for enhanced sustainability and profitable production (Zairi et al., 2000; Kipkorir et al., 2001; Lobell and Ortiz-Monasterio, 2006; Benli et al., 2007; Heng et al., 2007; Lorite et al., 2007; Pereira et al., 2009; Blum, 2009). The FAO AquaCrop model is a useful model to simulate economic parts of the crops, and is responsive for design and evaluation of irrigation strategies, deficit irrigations scheduling, and rainfed systems subject to soil types, field management scenarios, soil fertility, and climatic conditions (Raes et al. 2009a; Abedinpour et al. 2012; Ahmadi et al., 2015). AquaCrop is user-friendly and maintains a balance between simplicity, accuracy, and robustness (Heng et al., 2009). While most sophisticated crop models, which are suitably developed for research and systems analysis needs intensive data, AquaCrop potentially requires fewer data inputs (Steduto et al., 2009).

AquaCrop crop water productivity model predicts crop yield, water requirement, and water use efficiency under water-limiting conditions (Raes et al., 2009b). This model has been tested for several crops (Hsiao et al., 2009; Heng et al., 2009; Farahani et al., 2009; Garcia-Via et al., 2009; Todorovic et al., 2009; Geerts et al., 2009) under different environmental conditions. The aim of this study was to calibrate and validate this model under full and deficit irrigation and to apply it for simulating the effects of rainfed and irrigated conditions on grain yield and water productivity of wheat in Central Anatolia region of Turkey.

MATERIALS AND METHODS

Study Area Characteristics

Study data were obtained from Ministry of Agriculture in the agricultural enterprise (39°30'N, and 33°17'E, elevation 930 m) in Central Anatolia Region of Turkey (Figure 1).

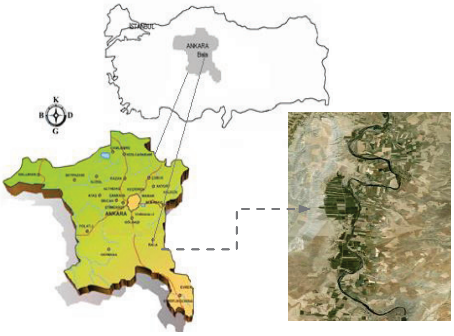

Figure 1. Location of experimental field

Annual average rainfall within the region 350 mm and annual evaporation is about 1250 mm as an average for the past 30 years. Almost no effective rainfall occurs during the summer. The main crops are corn, wheat, barley, beans and forage crops in experimental site.

The soil of the experiment area is mostly ranging in texture from silty clay loam for 0.30 m, clay loam for 0.30 - 0.50 m thick lying on the surface with a layer of clay texture roughly in 1.80 m below the surface. Field capacity on the volume basis of the top and following basement soil layer is described to be 41, 39 and 43 %, and wilting point, 22, 21 and 23 % respectively. Soil physical characteristics such as bulk density, texture, depth, field capacity, permanent wilting point and water content at saturation of the experimental sites were given in Table 1.

Table 1. Soil parameters

Depth (m)	Moisture content (vol. %)		Bulk density (g cm^{-1})	Texture
	Field capacity	Wilting point		
0-0.3	41	22	1.18	SiCL
0.3-0.50	39	21	1.15	CL
0.50-1.80	43	23	1.26	C

SiCL: silty clay loam, CL: clay loam, C: clay

Field Studies

For the purpose of evaluating the validity of the AquaCrop model, data were obtained from field studies conducted at the Agricultural Enterprise Farms for two cropping seasons, 2001-2002, 2002-2003. Winter wheat was planted at 15th of October for 2001-2002 and 18th of October for 2002-2003 cropping seasons. The seed rate was 300 seed m^{-2} with 1.8 cm row spacing. According to soil fertility analysis results commercial N fertilizers were applied in a band about 10 cm to the side of the seed row (200 kg ha^{-1} Ammonium sulfate (21%) were applied before sowing and 250 kg ha^{-1} Ammonium sulfate were applied at spring period). Sufficient phosphates were applied (160 kg ha^{-1} DAP 18-46-0) to ensure adequate P nutrition. Soil samples were taken each plot to make chemical and physical soil analysis. Winter wheat was grown under rainfed and irrigated conditions.

Weather data were obtained from local meteorological station which was within 1 km of the study fields (Table 3). The daily maximum and minimum air temperature (^{o}C), minimum air temperature (^{o}C), mean relative humidity (%), sun shine hours (cal cm^{-2}) and wind speed at a height of 2 m (u_2, m/s) weather data were used for calculation of referent evapotranspiration.

Table 3. Monthly average temperature, humidity, wind speed, sunshine hours, total rainfall

Months	Temperature (^{o}C)		RH %	Wind m/s	Sunshine hours h/day	Rainfall mm
	Max	Min				
October	20.8	4.5	56.5	0.8	8.2	0.5
November	11.5	1.4	72.0	1.2	4.7	76.2
December	5.6	-0.7	77.0	1.3	1.9	1.7
January	7.5	-2.1	72.5	0.8	4.1	3.0
February	9.6	-1.8	67.5	1.5	3.9	21.9
March	18.1	3.9	58.9	1.6	6.3	20.5
April	19.1	5.3	60.5	1.4	7.7	30.4
May	21.0	7.8	61.4	1.1	7.6	76.0
June	29.1	12.5	47.2	1.6	12.4	1.0
July	33.8	17.8	51.6	1.7	12.0	0.0

Soil water content was measured gravimetrically. Volumetric water content was obtained from gravimetric content and bulk density. Irrigation water was applied three times at sowing and stems elongation and stage of the crop. Wheat irrigated by basin method and soil moisture was reached to the field capacity. Irrigation date and applied water amount (mm) was given in Table 2.

Table 2. Irrigation dates and irrigation amount (mm)

Growing stage	Irrigation time		Irrigation amount	
	2001–2002	2002-2003	2001-02	2002-03
Sowing	17 Oct.	19 Oct.	92	90
Stem elongation	16 April	16 April	110	125
Grain filling	20 May	18 May	145	165

Crop inputs of the model such as plant density, grain and biomass yield, sowing, emergency, flowering, senecence and maturity date were collected for the growing period. Emergence date was considered when 90% of seedlings had been emerged. Senescence was assumed to be reached when canopy start to decline whereas maturity date was assumed when the canopy cover reached nearly zero (Raes et al., 2009a).

Soil physical characteristics initial soil water content, field capacity, permanent wilting points and saturated hydraulic conductivity at field site were measured in the Soil and Fertilizer and Water Resources Research Institute Laboratories. The soil water content in the root zone was measured by gravimetric methods throughout the season.

Description of AquaCrop (Version 5.0)

AquaCrop is the crop growth model developed by FAO deals with yield response to water. The model evolved from concepts of yield response to water as presented in Doorenbos and Kassam (1979) to a concept of a normalized crop water productivity (Steduto et al., 2009). The advantage of the model is accurate, robust and requires fewer data inputs (Hsiao et al., 2009; Steduto et al., 2009). Detailed description of the model was given by Steduto et al. (2009). One of the important key features of AquaCrop is the simulation of green canopy cover (CC) instead of leaf are index (LAI). 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 model reproduces the canopy cover from daily transpiration taking into account leaf area expansion and canopy development, senescence and harvest index (Steduto et al., 2009; Araya et al., 2010)

Wheat crop parameters in AquaCrop were presented in Tables 4 and 5. Some of them were assumed to be conservative (Table 3) according to AquaCrop manual appendix (Raes et al., 2009b). These parameters are presumed to be applicable to a wide range of condition and not specific for a given crop cultivar. In addition to conservative parameters, some crop parameters are cultivar-specific and some depending on management and environmental conditions and cannot be broadly applied. Those non conservative parameters were estimated using measured data of 2001–2002 cropping season experiment (Table 3). AquaCrop was run in growing degree day (GDD) calculated from temperature data.

Table 4. Conservative parameters used to simulation runs (Raes et al., 2009b)

Description	Value
Cut-off temperature	26
Canopy cover per seedling at 90% emerg. (CC_o)	6.46
Canopy growth coefficient (CGC) per GDD*	0.68 %
Maximum canopy cover (CC_x)	95 %
Crop coefficient for transpiration at CC = 100%	1.10
Canopy decline coefficient (CDC) at senescence	0.56 %
Water productivity	15
Leaf growth threshold p-upper	0.20
Leaf growth threshold p-lower	0.65
Leaf growth stress coefficient curve shape	5.0
Stomatal conductance threshold p-upper	0.65
Stomata stress coefficient curve shape	2.5
Senescence stress coefficient p-upper	0.70
Senescence stress coefficient curve shape	2.5
Reference harvest index (HI)	42

* GDD, growing degree days; HI, harvest index.

Model Calibration

Calibration is the process where the model's input parameters are changed to obtain the optimal agreement between the predicted and observed system variables (Singh et al., 2006). The model was calibrated using measured soil water content over the root depth data set for 2001-2002 growing season in AquaCrop.

Model Validation

Validation is an important step of model verification. It involves a comparison between independent field measurements data and output simulated by the model (Andarzian et al. 2011). Soil water content, dry biomass and grain yield were considered in this study for model validation. The performance of the calibrated model was evaluated against the independent data sets (experimental data of 2002–2003 growing seasons) which were not used for model calibration.

Table 5. Non-conservative parameters adjusted to simulate the response of the wheat

Description	Value
Latitude	39° 30'
Longitude	33° 17'
Altitude	930
Sowing rate	160
1000 seed mass	31.60
Germination rate	85
Cover per seeding	1.5
Plant density	430.4
Sowing	15 October
Time from sowing to emergence	13 (131)
Time to reach max canopy cover	177 (903)
Time from sowing to max. root depth	140(604)
Time to start senescence	224 (1546)
Time from sowing to reach maturity	269 (2415)
Time to reach flowering	184 (992)
Length Building up of HI	75 (1210)
Duration of flowering stage	16 (185)
Total period from emergence to maturity	257 (2284)
Minimum effective root depth	0.3
Maximum effective root depth	1.5
Base temperature	0

Data analysis

A statistical evaluation of model reliability was performed by comparing measured and simulated soil water content, dry biomass and grain yield. The agreement between predicted and measured values was quantified by calculating average absolute deviations (α), the root mean square error *(RMSE)* and coefficient of model efficiency *(E)*. The average absolute deviation was calculated for each test period as given in equation [1] (Janssen and Heuberger, 1995).

$$\alpha = \frac{\sum_{i=1}^{n} |O_i - S_i|}{n} \qquad [1]$$

The root mean standard error *(RMSE)* was calculated as in Equation [2] (Lyman, 1993).

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - S_i)^2} \qquad [2]$$

The RMSE in Eq. 2 represents a measure of the overall, or mean, deviation between observed and simulated values, that is, a synthetic indicator of the absolute model uncertainty. In fact, it takes the same units of the variable being simulated, and therefore the closer the value is to zero, the better the model simulation performance. The coefficient of model efficiency *E* has been widely used to evaluate the performance of solute transfer models. Nash and Sutcliffe (1970) defined the coefficient of efficiency (*E*) as in Eq. [3]:

$$E = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - O_{avg})^2} \qquad [3]$$

where *n* is the total number of observations; O_i is the observed value of the i^{th} observation; S_i the predicted value of the i^{th} observation; and O_{avg} the mean of the observed values (i = 1 to n). *E* values ranges from minus infinity to 1.0, with a value of 1.0 representing a perfect prediction, a value of 0 (zero) representing a prediction no better than using the mean of measured values, and lower values representing a progressively worse prediction. Values of *E* between 0.50 and 1.00 are considered acceptable.

Model application

After model validation, the model was used to evaluate the effects of irrigation on above ground biomass and grain yield The crop parameter values given in Tables 3 and 4 and the soil characteristics of Agricultural Enterprise and irrigation practices (Tables 1 and 2) were used for the simulation.

RESULTS AND DISCUSSIONS

Soil water content

The results show that the model performed very well for simulating water dynamics (Figures 2 and 3).

Average absolute deviations (α), the root mean square error *(RMSE)* and coefficient of model efficiency *(E)* were found 16.08 mm, 17.81 mm, 0.96 mm for rainfed and 21.23 mm, 25.39 mm and 0.81 for full irrigation treatment respectively.

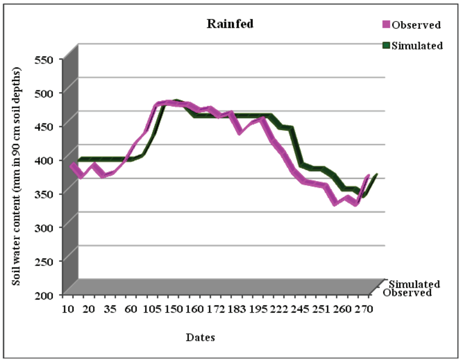

Figure 2. Simulated and observed soil water content for rainfed condition

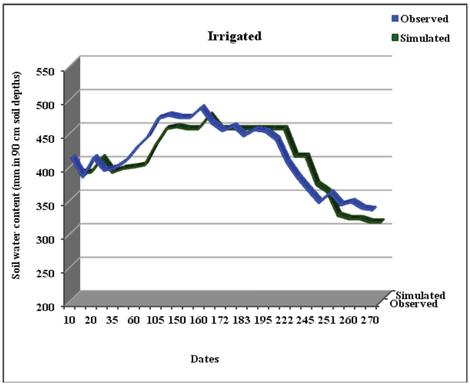

Figure 3. Simulated and measured soil water content for full irrigation

Canopy cover development

Potographs were taken from plots on the experimental field and were digitized with the processing programs (Greencrop of Tracker) to calculate canopy cover (Figure 4). Canopy cover development also were simulated by AquaCrop for irrigated and rainfed conditions.

The simulated canopy cover was close to the observed values from sowing to flowering over 2000–2001 growing season, but after flowering there was a slight mismatch in the last senesced CC measurement, with measured CC declining slightly faster compared with simulated CC (Figure 5).

According to statistical evaluation average absolute deviations (α), the root mean square error *(RMSE),* coefficient of model efficiency *(E)* and were found 9.00 mm, 11.08 mm and 0.95 for rainfed and 5.88 mm, 6.93 and 0.98 mm for irrigated condition respectively. Regression coefficients were also found 0.94 and 0.96 for treatments. Good agreement was found between the measured and predicted values.

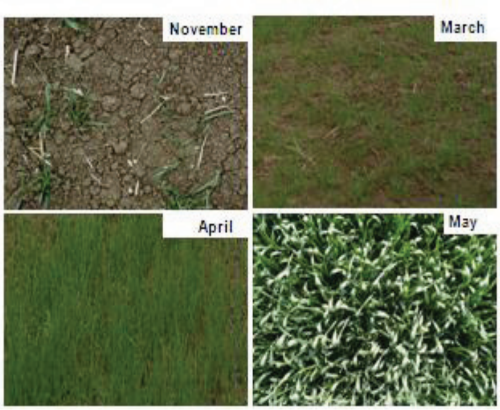

Figure 4. Observed canopy cover on the field

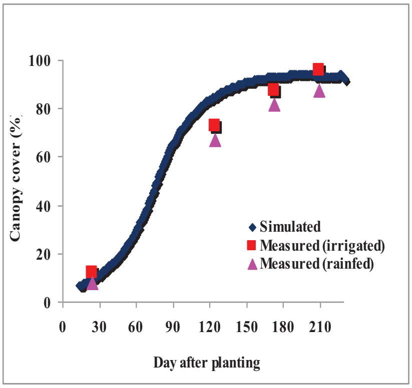

Figure 5. Simulated versus measured canopy cover of wheat under rainfed and full irrigation treatment during 2002–2003 growing season

Above ground biomass and grain yield

As shown at Figure 6 the simulated and observed dry biomass in rainfed and irrigated conditions there was very good agreement between observed and simulated values, even though a slight overestimation by the model. This discrepancies might have been caused by error in measured data and/or the manner which the model simulate crop growth (Andarzian et al., 2011).

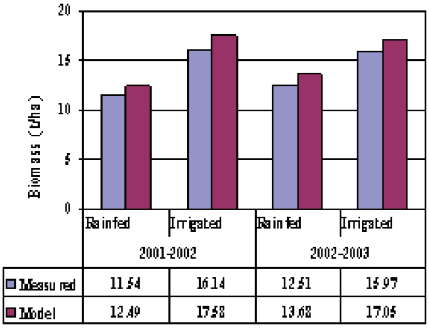

Figure 6. Simulated and measured biomass of winter wheat under irrigated and rainfed conditions

α, *RMS* and *E* were found 1.16 t/ha, 1.17 t/ha, 0.67 for biomass of winter wheat.

Grain yield were given at Figure 7. According to comparison of the simulated and measured grain yield results it could be said that model has acceptable performance to estimate yield.

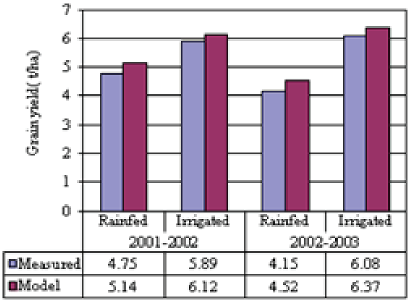

Figure 7. Comparison of simulated and measured grain yield of winter wheat

The simulated wheat yield varied from 5.1 t/ha to 6.1 t/ha, while the measured yield varied from 4.7 to 6.1 t/ha for rainfed and irrigated conditions. Statistical parameter α, *RMS* and *E* were obtained 0.32 t/ha, 0.33 t/ha, 0.83 respectively.

CONCLUSIONS

AquaCrop version 5.0 capable to simulate the soil water in the root zone, the above ground biomass and grain yield of winter wheat under rainfed and irrigated conditions. AquaCrop model can be used with a high degree of reliability in practical management, strategic planning of the use of water resources for irrigation.

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