Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 4, No. 6, p. 438-449, 2014
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Evaluation and comparison of aquacrop and FAO models for yield prediction of winter wheat under environmental stresses

Vahid Rezaverdinejad[1*], Afshin Khorsand[1], Ali Shahidi[2]

[1]*Department of Water Engineering, Urmia University, Urmia, Iran*

[3]*Department of Water Engineering, University of Birjand, Birjand, Iran*

Article published on June 18, 2014

Key words: Birjand, Environmental Stresses, Grain Yield, Simulation, Winter Wheat.

Abstract

In this research, two agro-hydrological models: AquaCrop and FAO were evaluated and compared to predict of winter wheat grain yield under water and salt environmental stresses. A field experimental was conducted under factorial split plot design with three salinity levels of irrigation water include: S_1, S_2 and S_3 corresponding to 1.4, 4.5 and 9.6 dS/m and four irrigation levels include: I_1, I_2, I_3 and I_4 corresponding to 50, 75, 100 and 125% of crop water requirement based on the FAO Penman-Monteith method. Experimental was conducted for two varieties of winter wheat: Roshan and Ghods, with three replications in an experimental field of Birjand University during 2005-2006. Based on results, the average mean relative error (MRE) of the AquaCrop and FAO models in grain yield prediction for Roshan were obtained 2.96 and 9.20%, respectively and for Ghods were obtained 6.79 and 26.11%, respectively. The average normalized root mean square error (NRMSE) of the AquaCrop and FAO models were calculated 3.44 and 9.94% for Roshan and 6.02 and 22.10% for Ghods, respectively. The AquaCrop model predicted yield prediction with an appropriate precision in entire range of water and salt Stresses. The FAO model in grain yield prediction of winter wheat showed significant error under high water stress (S_1I_1, S_2I_1 and S_3I_1 treatments) but in other treatments simulated with a high accuracy.

***Corresponding Author:** Vahid Rezaverdinejad ✉ verdinejad@gmail.com

Introduction

Agro-hydrological models can be considered an economic and simple tool for optimizing irrigation water use in regions where water represents a limiting factor for crop yield. In the last two decades, physically based agro-hydrological models have been developed to simulate mass and energy exchange processes in the soil-plant atmosphere (SPA) system (Feddes *et al.,* 1978; Bastiaanssen *et al.,* 2007). One of most appropriate ways to reduce water use in agriculture is by supplying the exact amount of irrigation water to crops when it is required, so that water use efficiency can be maximized. Despite the usual farmer`s experience, irrigation scheduling on the basis of visual observation of a few plants and on the soil often leads to water overuse, a consequence of the low effectiveness of empirical evaluations. However, a precise assessment of irrigation depth and irrigation timing can allow for the optimization of water use (Rallo *et al.,* 2012). The original objective of agricultural producers to maximize yield has been changed to protect environmental quality. Farmers must consider environmental issues; therefore, they have more constraints on their management decisions. In this regard, scientists should provide technical information to guide farmers and policy makers in making decisions that optimize the dual goal of high crop yield and low environmental degradation (Sepaskhah *et al.,* 2006). The acquired parameters in the areas may not be suitable for application in other regions where the salt stress is not existing or weak. In western Canada, although the AquaCrop model may simulate the spring wheat yield and soil water content well, the simulation results were still unknown for winter wheat. In the southern Loess Plateau of China, winter wheat is one of the major crops, and the distinctive soil type and climatic characteristics make it different from most agricultural production areas in China (Zhang *et al.,* 2013). Winter wheat is the main crop on the North China Plain (NCP), and in this region the most limiting factor for the crop is water. The overall results based on extensive validation and revalidation showed that AquaCrop is a valid model and can be used with a reliable degree of accuracy for optimizing winter wheat grain yield production and water requirement on the NCP (Iqbal *et al.,* 2014). 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. The main purpose of deficit irrigation is high water productivity with fewer water supplies to plants (Salemi *et al.,* 2011a). Simulation models have proven to be useful. The AquaCrop model, which has been expanded by FAO, simulates crop yield based on the applied water under conditions of full and deficit irrigation levels (Salemi *et al.,* 2011b). It uses a relatively small number of explicit and mostly intuitive parameters and input variables, requiring simple methods for their derivation (FAO, 2009). AquaCrop model, now one of the newest used plant growth models that were considered in this research. Given that in most arid and semi-arid regions, water deficit is associated with declining water quality in terms of salinity and vegetation in the region in terms of water quality and quantity, may be affected salinity and drought stress are coincident. AquaCrop model version 4 was used for this purpose in 2012 and was presented to quantify the effect of salinity (Raes *et al.,* 2012). The objective of this study was evaluation and comparison of two hydrological models: AquaCrop and FAO, which describes the soil water and salt effects on yield of winter wheat in an arid region of Iran by using experimental data. This paper also presents the calibration results of AquaCrop and FAO agro-hydrological models for the simulation of crop parameters.

Materials and methods

Field experiments were conducted to investigate the effects of the interaction of salinity and deficit irrigation on yield and yield components of winter wheat, at the agricultural research station of Birjand University in Iran during 2005-2006. Research station is located in latitude and longitude 32° 88′ north, 55° 22′ east and elevation 1480 m. Before planting, from the soil different depths to determine the physical and chemical properties of soil profile, sampling was performed. Surface soil texture was clay loam (CL) and in the lower depths (30 to 90 cm) was silt clay loam (SCL). Other physical and chemical parameters of soil profile are given in Table 1.

Table 1. Physical and chemical properties of soil profile before the experiment.

Soil depth (cm)	Texture	Bulk density (gcm^{-3})	Hydraulic conductivity ($mmday^{-1}$)	Initial EC_e (dSm^{-1})	Initial Water Content (cm^3cm^{-3})	FC (cm^3cm^{-3})	PWP (cm^3cm^{-3})
0-30	CL	1.5	58.4	2.1	0.14	35.2	19.3
30-60	SCL	1.45	65.3	2.7	0.16	32.3	18.2
60-90	SCL	1.39	95.2	2.9	0.16	33.3	21.3

The soil samples after air drying were beaten and passed through 2 mm sieve and saturation mud were made and after 24 hours, extracts were taken. Soil water content was determined by direct method. Table 2 shows summary of the data collected or measured for calibration of the AquaCrop and FAO models at the winter wheat field.

Table 2. Data measured or collected for the winter wheat to simulate by AquaCrop and FAO models.

Parameter	Measurement or collection Method	Frequency
Soil Texture	USDA Method	Once
Bulk Density of Soil	Core Sampler	Once
Saturated Extract Salinity (σ_e)	EC Meter	Each Irrigation
Soil Water Content	Weight Method	Each Irrigation
Irrigation Water Volume (Depth)	Volumetric Counter Gauge	Each Irrigation
Irrigation Water salinity	EC Meter	Each Irrigation
PWP and FC Water Content	Pressure Plates	Once
Meteorological data	Meteorological station	Daily
Crop coefficients	FAO 56	-
Crop yield reduction factor	FAO 56	-
Parameters of the plant sensitivity to salinity	FAO 56	-
Saturated water content	Saturation Mud Method	Once
Root Depth (z_r)	Field Measurement	4-5 times
Reference Evapotranspiration (ET_o)	FAO Penman-Monteith	Daily
Crop grain yield	Field Measurement	Once
Soil Water Depletion (D_r)	Field Measurement	Each Irrigation

There are three wells with different salinity in the experimental field with electrical conductivity: 1.4, 4.5 and 9.6 dSm^{-1}. Table 3 presents the chemical analysis results of wells water. Experimental was conducted with factorial split plot design with three levels of saline irrigation water including: S_1, S_2 and S_3 corresponding to 1.4, 4.5 and 9.6 dSm^{-1} and four levels of irrigation depth including: I_1, I_2, I_3 and I_4 corresponding to 50, 75, 100 and 125 percent of crop water requirement with three replications in Birjand region during 2005-2006. Surface irrigation methods with plot dimensions 4×3 (m×m) and 10 rows cultivation in each plot, with row spacing about 20 cm and length of 3 m were planted by typical density of 400 plants per square meter. Evapotranspiration is one of the upper boundary conditions in both models.

Daily meteorological data to estimate of evapotranspiration were collected from Birjand synoptic meteorology station.

Table 3. Chemical analysis results of wells water research field.

Well number	SAR ($meq^{0.5}lit^{-0.5}$)	PH	EC (dSm^{-1})
1	7.4	8	1.4
2	8.6	7.	4.5
3	9.7	7.7	9.6

Plant parameters have used in the FAO model is shown in Table 4 that had extracted for winter wheat based on FAO 56 (FAO, 1998). based on During the period four stages of growth and with curve draw the crop coefficient according to three points, including the crop coefficient initial stage (Kc_{ini}), middle stage (Kc_{mid}) and end-stage (Kc_{end}), daily crop coefficient had extracted. Figures plant coefficients Table 4, default values had been related of semi-humid regions that the average daily minimum relative humidity 45% and wind speed about 2 m/s. when that the average minimum relative humidity 45% or the average daily wind speed of 2 m/s, more or less were, in Middle and end coefficients, these reforms were carried out (FAO, 1977; FAO, 1979; FAO, 1998).

$$K_{c\,mid} = K_{c\,mid(tab)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)](\frac{h}{3})^{0.3} \quad (1)$$

$$K_{c\,end} = K_{c\,end(Tab)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)](\frac{h}{3})^{0.3} \quad (2)$$

Where the $Kc_{end\ (tab)}$ and $Kc_{mid\ (tab)}$, are middle and end coefficients (Presented in Table 4), u_2 is average daily wind speed in two meters (ms^{-1}), RH_{min} is average daily minimum relative humidity (%) and average plant height h (m) is the middle and end stages (FAO, 1998).

Table 4. Crop parameters for the winter wheat to simulate by FAO model.

Crop parameter	value
Planting date	14/11/2005
harvesting date	18/05/2006
Coefficient of readily available water, p (-)	0.55
Maximum rooting depth, Z_{rm} (m)	0.65 - 0.75
Maximum crop height (m)	0.95
Yield reduction factor, K_y	1.05
During the initial growth period (day)	20
During the development stage (day)	65
During the middle growth period (day)	70
During the reaching period (day)	31
The first stage of growth Crop coefficient	0.4
The development stage Crop coefficient	1.15
The reaching stage Crop coefficient	0.4
Threshold salinity, $\sigma_{e,th}$ (dSm^{-1})	6
Yield reduction coefficient, b (dSm^{-1})	7.1
Constant coefficient a	1

The AquaCrop model description

AquaCrop uses six input files for simulation: climate file, crop file (time to emergence, maximum canopy cover, start of senescence, maturity), soil file, management file, irrigation file, and initial soil water conditions; all these are user specific. The climate file consists of three sub-files: i: minimum and maximum air temperature, ii: ET_o, and iii: rainfall, all with daily values (Raes *et al.,* 2009). The crop file contains both conservative parameters (that do not change with location) and user-specific parameters (non-conservative) (Iqbal *et al.,* 2014). Yield response to water describes the relationship between crop yield and water stress as a result from insufficient supply of water by rainfall or irrigation during the growing period. In the FAO Irrigation and Drainage Paper

(Doorenbos and Kassam, 1979) an empirical production function is used to assess the yield response to water:

$$\left(1-\frac{Y}{Y_X}\right)=K_y\left(1-\frac{ET}{ET_X}\right) \quad (3)$$

Where: Y_x and Y are the maximum and actual yield, ($1-Y/Y_x$) is the relative yield decline, ET_x and ET are the maximum and actual evapotranspiration, ($1-ET/ET_x$) is the relative water stress, and K_y the proportionality factor between relative yield decline and relative reduction in evapotranspiration. AquaCrop (Steduto *et al.,* 2007; Raes *et al.,* 2009; Hsiao *et al.,* 2009) evolves from the K_y approach by separating the actual evapotranspiration (ET) into soil evaporation (E) and crop transpiration (Tr):

$$ET = E + Tr \quad (4)$$

The separation of ET into soil evaporation and crop transpiration avoids the confounding effect of the non-productive consumptive use of water (soil evaporation). This is important especially when ground cover is incomplete early in the season or as the result of sparse planting; (ii) the final yield (Y) into biomass (B) and harvest index (HI):

$$Y = HI \times B \quad (5)$$

The separation of yield into biomass and harvest index allows the partitioning of the corresponding functional relations as response to environmental conditions. These responses are in fact fundamentally different and their separation avoids the confounding effects of water stress on B and on HI. The changes described leads to the following equation at the core of the AquaCrop plant growth engine:

$$B = WP.\sum Tr \quad (6)$$

Where Tr is the crop transpiration (mm) and WP is the water productivity parameter (kg of biomass per m^2 and per mm of cumulated water transpired over the time period in which the biomass is produced). This step-up from Eq. (3) to Eq. (6) has a fundamental implication for the robustness of the model due to the conservative behavior of WP (Steduto *et al.,* 2007). It is worth noticing, though, that both equations have water as driving force for growth. Crop transpiration (Tr) is calculated by multiplying the evaporating power of the atmosphere with the crop coefficient (Kcb) and by considering water stresses (Ks):

$$Tr = Ks\left(Kcb_x CC^*\right)ET_o \quad (7)$$

Where the evaporating power (ET_o) is expressed by the reference grass evapotranspiration as determined by the FAO Penman-Monteith equation. The crop transpiration coefficient (Kcb) is proportional to the fractional canopy cover (CC) and as such continuously adjusted to the simulated canopy development. The proportional factor (Kcb_x) integrates all the effects of characteristics that distinguish the crop transpiration from the grass reference surface. As the crop develops, Kcb_x is adjusted for ageing and senescence effects. In Eq. 7, CC is replaced by CC* to account for interrow micro advection which make extra energy available for crop transpiration. When canopy cover is not complete the contribution is substantial (Fig. 1). Either a shortage or an excess of water in the root zone might reduce crop transpiration. This is simulated by considering water stress coefficients (Ks). When water shortage in the root zone provokes stomatal closure a stress coefficient for stomata closure (Ks_{sto}) is considered. When the excess of water results in anaerobic conditions, the effect of stress on transpiration is expressed by the coefficient for water logging (Ks_{aer}). According to the general rule in AquaCrop, the water stress coefficients range between 1, when water stress is non-existent and 0, when the stress is at its full strength and crop transpiration is completely halted. The aboveground biomass production for every day of the crop cycle is obtained by multiplying the WP* with the ratio of crop transpiration to the reference evapotranspiration for that day (Tr/ET_o). The production of biomass might be hampered when the air temperature is too cool irrespectively of the transpiration rate and ET_o on that day. This is simulated in AquaCrop by considering a temperature stress coefficient (Ks_b) (FAO, 2012):

$$B = Ks_b \times WP^* \times \sum_i \left(\frac{T_c}{ET_o}\right)_i \qquad (8)$$

If the growing degrees generated in a day drops below an upper threshold, full conversion of transpiration to biomass production can no longer be achieved and Ks_b becomes smaller than 1 and might even reach zero when it becomes too cold to generate any growing degrees (FAO, 2012).

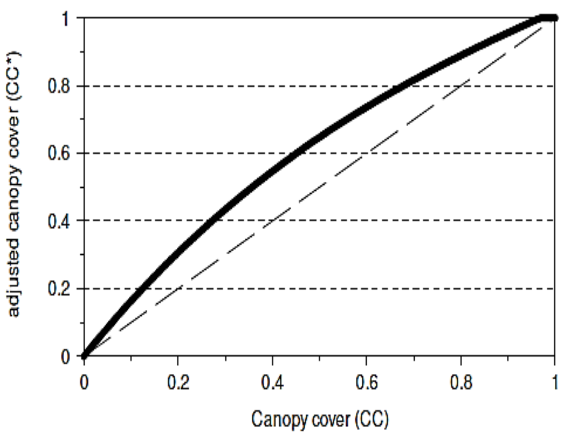

Fig. 1. Canopy cover (CC*) adjusted for micro-advective effects (bold line) for various fractions of green canopy cover (CC)

Yield (Y) is obtained by multiplying the above ground biomass (B) with the adjusted reference Harvest Index:

$$Y = f_{HI} \times HI_O \times B \qquad (9)$$

Where: Y grain yield, B biomass, HI_o Harvest index reference and f_{HI} is a multiplier which considers the stresses that adjust the Harvest Index from its reference value. The adjustment of the Harvest Index to water deficits and air temperature depends on the timing and extent of stress during the crop cycle. The effect of stress on the Harvest Index can be positive or negative. Distinction is made between stresses before the start of the yield formation, during flowering which might affect pollination, and during yield formation (FAO, 2012).

The FAO model description

Daily actual crop evapotranspiration, $ET_{c\text{-}adj}$, is estimated by the following equation (Allen *et al.,* 1998):

$$ET_{c-adj} = K_s K_c ET_o \qquad (10)$$

Where: $ET_{c\text{-}adj}$ is the daily actual crop evapotranspiration (mm d^{-1}); K_s is the soil water stress coefficient, dimensionless; K_c is the crop coefficient, dimensionless; and ET_o is the daily reference crop potential evapotranspiration (mm d^{-1}). The values for crop coefficient K_c for different growth stages are determined by a procedure presented by Doorenbos and Pruitt (1977). The growing period is divided into four stages. Then, by using the values of K_c for initial, mid and late stages for crop, the values of K_c are estimated. Soil water stress coefficient K_s is defined by the following equation (Allen *et al.,* 1998):

$$K_s = \frac{W_{TA} - D_r}{(1-p)W_{TA}} \qquad (11)$$

Where: K_s is the soil water stress coefficient for regular crop and non-saline conditions ($0 \le K_s \le 1$); D_r is the soil water depletion in the root zone (mm), W_{TA} is the total soil available water in the root zone (mm); and p is the fraction of W_{TA}, which is readily available for crop use, dimensionless ($0 < p < 1$). The value of p is influenced by the potential crop evapotranspiration by the following equation (Allen *et al.,* 1998):

$$p = p_t + 0.04(5 - ET_c) \qquad (12)$$

Where: p_t is the standard value for p at ET_c of 5 mmd^{-1}; and ET_c is the potential crop evapotranspiration (mmd^{-1}). Total soil available water is calculated by the following equation:

$$W_{TA} = (\theta_{fc} - \theta_{pwp}) z_r \qquad (13)$$

Where: θ_{fc} and θ_{pwp} are the volumetric soil water contents at field capacity and permanent wilting point

(cm^3cm^{-3}); and z_r is the root depth (mm). The root depth at different growth stages can be estimated by the following equation (Borg and Grimes, 1986):

$$z_r = z_{rm}\left[0.51 + 0.51\sin(3.03\frac{D_{AP}}{D_{TM}} - 1.47)\right] \quad (14)$$

Where: z_{rm} is the maximum root depth (mm); D_{AP} is the time after planting (day); and D_{TM} is the time from planting to reaching the maximum root depth (day).

Salinity effect on soil water stress coefficient

Under non-saline conditions, the effect of soil water stress on crop yield reduction is presented by the following equation (Stewart *et al.*, 1976):

$$(1 - \frac{y_a}{y_{max}}) = k_y(1 - \frac{ET_{c-adj}}{ET_c}) \quad (15)$$

Where: y_a and y_{max} are the actual and maximum crop yield ($kgha^{-1}$) obtained at actual crop evapotranspiration: ET_{c-adj} and maximum crop evapotranspiration: ET_c, respectively, and k_y is the yield reduction coefficient due to water stress. Under no water stress conditions, soil salinity stress affects crop yield by the following equation modified (Maas and Hoffmann, 1977):

$$\frac{y_a}{y_{th}} = 1 + (a-1)\frac{\sigma_e}{\sigma_{e,th}} \quad \text{for} \quad \sigma_e < \sigma_{e,th} \quad (16)$$

$$\frac{y_a}{y_{th}} = a - (\sigma_e - \sigma_{e,th})\frac{b}{100} \quad \text{for} \quad \sigma_e > \sigma_{e,th} \quad (17)$$

Where: y_{th} is the yield at the soil salinity threshold ($kgha^{-1}$); σ_e is the electrical conductivity of the soil saturation extract (dSm^{-1}); $\sigma_{e,th}$ is the threshold value of σ_e (dSm^{-1}) and b is the yield reduction coefficient due to the salt stress in percent yield reduction per unit increase in soil salinity ($\%/(dSm^{-1})$).By equation (16) and (17), the relative yield (y_a/y_{th}) is unity for σ_e less than $\sigma_{e,th}$, but for some crops, such as sugarbeet, the relative yield (y_a/y_{th}) is greater than unity for σ_e, less than $\sigma_{e,th}$; a is a coefficient greater than one for crops, such as sugarbeet, and equal to one for most of the other crops. Under water and salinity stress conditions together, the soil water–salt stress coefficient K_{ss} presented in FAO 56 is modified as follows (Allen *et al.*, 1998):

$$k_{ss} = 1 + (a-1)\frac{\sigma_e}{k_y\sigma_{e,th}} \quad \text{for} \quad \sigma_e < \sigma_{e,th} \ \& \ D_r < (p)W_{TA} \quad (18a)$$

$$k_{ss} = \left[1 + (a-1)\frac{\sigma_e}{k_y\sigma_{e,th}}\right] \times \left[\frac{(W_{TA} - D_r)}{(1-p)W_{TA}}\right] \quad \text{for} \quad \sigma_e < \sigma_{e,th} \ \& \ D_r > (p)W_{TA} \quad (18b)$$

$$k_{ss} = 1 + \frac{(a-1)}{k_y} - \frac{b(\sigma_e - \sigma_{e,th})}{100k_y} \quad \text{for} \quad \sigma_e > \sigma_{e,th} \ \& \ D_r < (p)W_{TA} \quad (18c)$$

$$k_{ss} = \left[1 + \frac{(a-1)}{k_y} - \frac{b(\sigma_e - \sigma_{e,th})}{100k_y}\right] \times \left[\frac{(W_{TA} - D_r)}{(1-p)W_{TA}}\right] \quad \text{for} \quad \sigma_e > \sigma_{e,th} \ \& \ D_r > (p)W_{TA} \quad (18d)$$

Where: D_r is the soil water depletion in the root zone (mm). It is clear that the value of electrical conductivity of soil saturation extract σ_e, is needed for yield estimation.

Four statistical variables: the normalized root mean squared error (NRMSE), mean relative error (MRE), relative error (RE) and coefficient of determination (R^2) were used to quantify the deviation in modeling results from the data observed. The NRMSE and

MRE were calculated according to the following equations:

$$MRE = \frac{\sum_{i=1}^{n}\left(\frac{|S_i - O_i|}{O_i}\right)\times 100}{n} \tag{19}$$

$$NRMES = \frac{1}{\overline{O}} \times \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - O_i)^2} \times 100 \tag{20}$$

$$RE = \left(\frac{|S_i - O_i|}{O_i}\right)\times 100 \tag{21}$$

Where n is the total number of observations, $\overline{O}$ mean observed values, O_i and S_i are the observed and predicted values, respectively. The NRMSE value less than 10% is ideal for modeling. The NRMSE at the range of 10 to 20% and 20% to 30%, respectively, indicating appropriate and moderate condition in model predicts and more than 30% indicate uncertainty of the model.

Results and discussion

The NRMSE, MRE and R^2 values for total treatments (12 treatments) are presented in table 5 for each variety. With regard to table 5, the average MRE of the AquaCrop and FAO models for total treatments, in yield prediction for Roshan and Ghods, were obtained 4.88 and 17.66 %, respectively, and the average NRMSE in yield prediction for AquaCrop and FAO models, were obtained 4.73 and 16.02 %, respectively. The maximum NRMSE for the AquaCrop and FAO models were 6.02 and 22.10 %, respectively. The maximum MRE for the AquaCrop and FAO models were 6.79 and 26.11 %, respectively. The AquaCrop and FAO models simulated grain yield of winter wheat with an appropriate precision, the NRMSE and MRE at the range of less than 10% and 10% to 30% were obtained, respectively, that indicates the AquaCrop and FAO models in predict grain yield are fairly accurate.

The RE values for each treatment are presented in table 6. Based on this table, the AquaCrop model in the crop yield, for Roshan variety, the maximum relative error of were related to treatments S_1I_3, S_2I_1 and S_3I_1, that the value of this error, 3.63, 4.59 and 12.05 % respectively, and for Ghods variety, the maximum relative error of were related to treatments S_1I_1, S_2I_1 and S_3I_1, that the value of this error, 3.48, 21.82 and 39.88 % respectively. In Fig. 2, relationship between actual and predicted grain yield of winter wheat for Roshan and Ghods varieties by AquaCrop model has been showed. There is a good relation between actual and predicted grain yield by AquaCrop for both of the varieties. So as to more survey, the relative error (RE) values of treatments in grain yield calibration are presented for two models and two varieties in table 6 as detailed. Regarding table 6, the FAO model in the crop yield, different results predicted. Under conditions of extreme water stress (treatments 50% water requirement: I_1), the predicted values were greater than the actual values and FAO model in this interval and under extreme deficit, over-estimate showed. In conditions of irrigation more than water requirement (treatments 125% water requirement), the measured values were lower than predicted model. In treatments 75 and 100 % water requirement, the predicted and the actual values together matched. For Roshan variety, the maximum relative error of were related to treatments S_1I_1, S_2I_1 and S_3I_1, that the value of this error, 20.0, 28.1 and 26.6 % respectively, and for Ghods variety, the maximum relative error of were related to treatments S_1I_1, S_2I_1 and S_3I_1, that the value of this error, 61.0, 94.5 and 99.9 % respectively.

In Fig. 3, three treatments S_1I_1, S_2I_1 and S_3I_1, for Roshan and Ghods varieties shown. The AquaCrop predicted yield prediction with an appropriate precision, and FAO model predicted yield prediction with a moderate precision. In terms of the results in tables 5 and 6, we can conclude that both models in combine condition salinity stress (level S_3) and deficit irrigation (level I_1), the maximum error in predicted wheat yield were. With respect to Tables 5 and 6, FAO model forecast error rate yield Ghods variety higher than Roshan variety that one of the reasons most of it can be attributed to equate the value of k_y for the both varieties. There for applying the deficit irrigation and salinity, were caused to decrease the accuracy of the models specially the FAO model.

Table 5. NRMSE and MRE values of total treatments in grain yield calibration for each variety by AquaCrop and FAO models.

Models	**AquaCrop**			**FAO**		
variety	**NRMSE (%)**	**MRE (%)**	**R^2 (-)**	**NRMSE (%)**	**MRE (%)**	**R^2 (-)**
Roshan	3.44	2.96	0.97	9.94	9.20	0.93
Ghods	6.02	6.79	0.97	22.10	26.11	0.90

Table 6. Relative error (RE) values of all treatments in grain yield calibration by AquaCrop and FAO models

Variety	**Roshan**		**Ghods**	
Models	**AquaCrop**	**FAO**	**AquaCrop**	**FAO**
Treatment	**RE (%)**	**RE (%)**	**RE (%)**	**RE (%)**
S_1I_1	1.34	20.0	3.48	61.0
S_1I_2	1.27	3.0	1.75	2.1
S_1I_3	3.63	9.6	2.80	6.4
S_1I_4	1.45	9.2	1.68	9.2
S_2I_1	4.59	28.1	21.82	94.5
S_2I_2	0.55	0.4	0.13	3.3
S_2I_3	0.47	2.6	1.43	3.6
S_2I_4	0.55	2.5	2.62	2.0
S_3I_1	12.05	26.6	39.88	99.9
S_3I_2	1.14	0.3	1.43	12.3
S_3I_3	1.68	1.9	1.32	10.7
S_3I_4	6.83	6.3	3.16	8.5
Average	**2.96**	**9.20**	**6.80**	**26.12**

In Figs. 2 and 3, relationship between actual and predicted grain yield of winter wheat are showed for Roshan and Ghods varieties by the AquaCrop and FAO agro-hydrological models. The simulated yield prediction for Roshan and Ghods varieties agree reasonably well with the measured values in the AquaCrop and FAO agro-hydrological models. Both of the models simulated with a satisfactory approximation the measured values of grain yield.

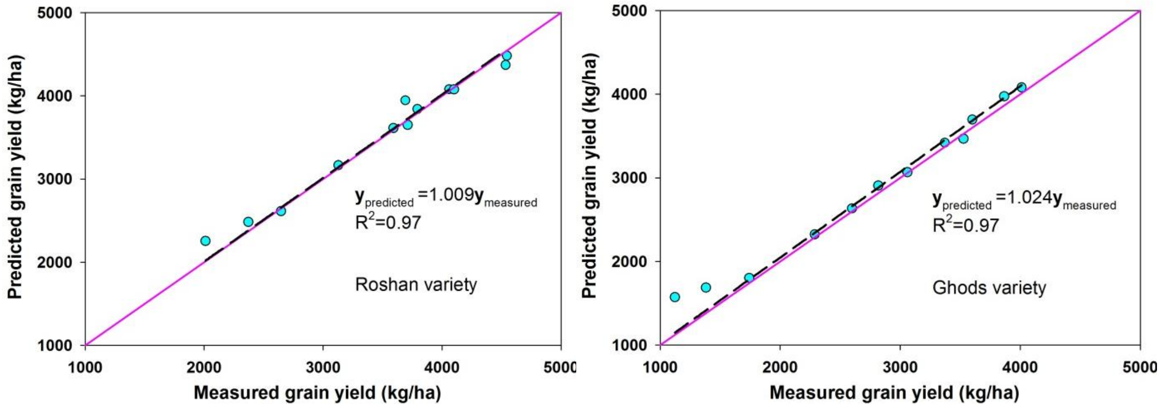

Fig. 2. Relationship between actual ($y_{measured}$) and predicted ($y_{predicted}$) grain yield of winter wheat for Roshan and Ghods varieties by AquaCrop model.

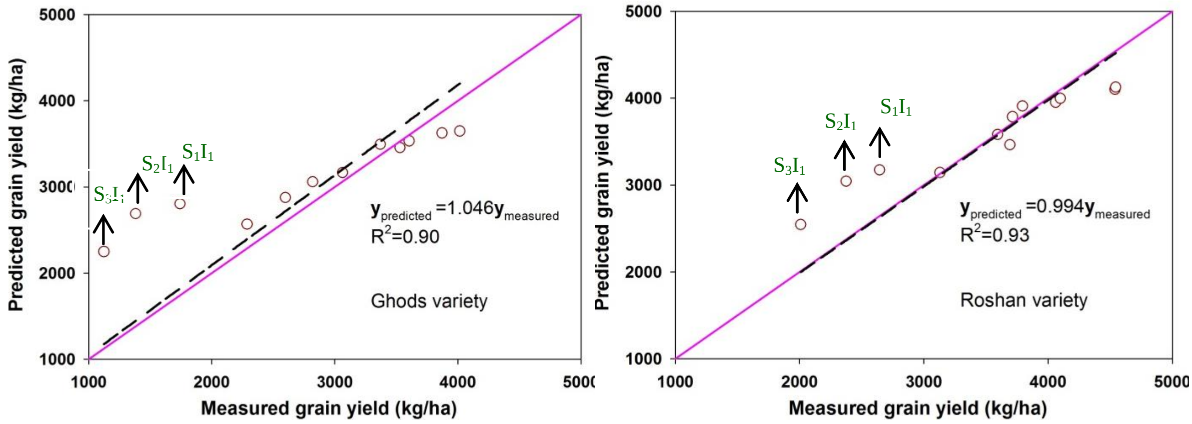

Fig. 3. Relationship between actual ($y_{measured}$) and predicted ($y_{predicted}$) grain yield of winter wheat for Roshan and Ghods varieties by FAO model.

Conclusions

This paper shows the comparison between AquaCrop and FAO agro-hydrological models to yield prediction. In this study, the FAO and AquaCrop models to predict grain yield under water and salinity stresses, were evaluated for Roshan and Ghods varieties of winter wheat. The AquaCrop and FAO agro-hydrological models simulated grain yield of winter wheat with an appropriate precision, the NRMSE at the range of less than 10% and 10% to 30% were calculated, respectively, that indicates the AquaCrop and FAO agro-hydrological models in predict grain yield are fairly accurate. The FAO model in grain yield prediction of winter wheat showed significant error under high water stress (S_1I_1, S_2I_1 and S_3I_1 treatments) but in other treatments simulated with a high accuracy. Generally the AquaCrop model simulated grain yield of winter wheat for Roshan and Ghods varieties more accurately than the FAO agro-hydrological model. These models are a valuable tool for farm irrigation water management in the study area under different levels of irrigation water salinity.

References

Allen RG, Pereira LS, Raes D, Smith M. 1998. Crop evapotranspiration. Irrigation and Drainage Papers, No. 56, Food and Agriculture Organisation (FAO), Rome, Italy 300pp.

Bastiaanssen WGM, Allen RG, Droogers P, D`Urso G, Steduto P. 2007. Twenty-five years modeling irrigated and drained soils: State of the art. Agric. Water Manage **92**(3), 111–125. http://dx.doi.org/10.1016/j.agwat.2007.05.013

Borg H, Grimes DW. 1986. Depth development of roots with time: an empirical description. Transactions of the ASAE **29,** 194–197. http://dx.doi.org/10.13031/2013.30125

Doorenbos J, Pruitt WO. 1977. Crop water requirement. Irrigation and Drainage Paper No. 24, Food and Agriculture Organisation (FAO), Rome, Italy, 193pp

Doorenbos J, Kassam AH. 1979. Yield response to water. Irrigation and Drainage Paper n. 33. FAO, Rome, Italy, 193 pp.

FAO. 1977. Crop water requirement. Irrigation and Drainage Paper No. 24, Rome.

FAO. 1979. Yield response to water. Irrigation and Drainage Paper No. 33, Rome.

FAO. 1998. Crop evapotranspiration; guidelines for computing crop water requirements. Irrigation and Drainage Paper No. 56, Rome.

FAO, 2009. AquaCrop: The FAO Crop-Model to Simulate Yield Response to Water. http://www.fao.org/nr/water/aquacrop.html (accessed January 2010).

FAO, 2012. AquaCrop, Reference Manual. Annexes. Available at: http://www.fao.org/nr/water/docs/aquacrop31/AquaCropV31Annexes.pdf.

Feddes RA, Kowalik PJ, Zaradny H. 1978. Simulation of field water use and crop yield, Pudoc. Wageningen, pp.189.

Hsiao TC, Heng L, Steduto, P, Rojas LB, Raes D, Fereres E. 2009. AquaCrop-The FAO crop model to simulate yield response to water: III. Parameterization and testing for maize. Agronomy Journal, **101**(3), 448-459. http://dx.doi.org/10.2134/agronj2008.0218s

Iqbal M, Shen Y, Stricevic R, Pei H, Sun H, Amiri E, Penas A, delRio S. 2014. Evaluation of the FAO AquaCrop model for winter wheat on the North China Plain under deficit irrigation from field experiment to regional yield simulation. Agricultural Water Management **135,** 61-72. http://dx.doi.org/10.1016/j.agwat.2013.12.012

Mass EV, Hoffman GJ. 1977. Crop salt tolerance current assessment, J.Irrigation and Drainage Division, ASCE **103**(IR2), 115-134.

Raes D, Steduto P, Hsiao TC, Fereres E. 2009. AquaCrop the FAO crop model to simulate yield response to water. II. Main algorithms and software description. Agron. J. **101**(3), 438–477. http://dx.doi.org/10.2134/agronj2008.0140s

Raes D, Steduto P, Hsiao TC, Fereres E. 2012. Reference manual AquaCrop, FAO, Land and Water Division, Rome, Italy.

Rallo G, Agnese C, Minacapilli M, Provenzano G. 2012. Comparison of SWAP and FAO Agro-Hydrological Models to Schedule Irrigation of Wine Grapes. Journal of Irrigation and Drainage Engineering **138**(7), 581-591. http://dx.doi.org/10.1061/(asce)ir.1943-4774.0000435

Salemi HR, MohdSoom MA, Lee TS, Mousavi SF, Ganji A, KamilYusoff M. 2011a. Application of AquaCrop model in deficit irrigation management of winter wheat in arid region. African Journal of Agricultural Research **610,** 2204–2215.

Salemi HR, MohdSoom MA, Mousavi SF, Ganji A, Lee TS, Yusoff MK, Verdinejad VR. 2011b. Irrigated Silage Maize Yield and Water Productivity Response to Deficit Irrigation in an Arid Region. Pol. J. Environ. Stud. **20**(5), 1295-1303.

Sepaskhah AR, Bazrafshan-Jahromi AR, Shirmohammadi-Aliakbarkhani Z. 2006. Development and Evaluation of a Model for Yield Production of Wheat, Maize and Sugarbeet under Water and Salt Stresses. Biosystems Engineering **93**(2), 139–152.
http://dx.doi.org/10.1016/j.biosystemseng.2005.11.005\

Steduto P, Hsiao TC, Fereres E. 2007. On the conservative behavior of biomass water productivity. Irrig. Sci. **25**(3), 189-207.
http://dx.doi.org/10.1007/s00271-007-0064-1

Stewart JI, Hagan RM, Pruitt WO. 1976. Water Production Functions and Predicted Irrigation Programs for Principle Crops as Required for Water Resources Planning and Increased Water Use Efficiency. Water Science and Engineering Section, Department of Land, Air and Water Resources, University of California, Davis.

Zhang W, Liu W, Xue Q, Pei H, Chen J, Han X. 2013. Evaluation of the AquaCrop model for simulating yield response of winter wheat to water on the southern Loess Plateau of China. Water Science and Technology **68.4,** 821-828.
http://dx.doi.org/10.2166/wst.2014.055