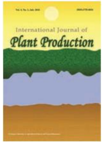

International Journal of Plant Production 10 (4), October 2016
ISSN: 1735-6814 (Print), 1735-8043 (Online)
www.ijpp.info

GUASNR

Assessment of the AquaCrop Model for simulating Canola under different irrigation managements in a semiarid area

S.F. Mousavizadeh, T. Honar*, S.H. Ahmadi

Irrigation Department, Shiraz University, Shiraz, I.R. of Iran.
*Corresponding author. E-mail: toorajhonar@yahoo.com

Received 7 February 2016; Accepted after revision 24 June 2016; Published online 10 August 2016

Abstract

Field experiments were conducted in 2005-2006 and 2007-2008 and the data were used to calibrate and validate yield and biomass of AquaCrop Model for canola (Brassica napus l.). The model was calibrated with the first year and then was validated with the second year data. Five water stress treatments at different growth stages were performed including fully irrigated during whole growing period (I_1), water stress at vegetative stage in spring (I_2), water stress at flowering stage (I_3), water stress in grain filling stage (I_4) and severe water stress conditions during whole growing period with supplemental irrigation in planting and germination stage (I_5). AquaCrop model coefficients were calibrated for I_1 in 2005-2006 and the calibrated parameters were used for other treatments in both year. In this simulation model was assessed based on measured values of the water content in root zone, evapotranspiration, canopy cover and final yield and dry matter that the latter are the important trait for the farmers The accuracy of the model in calibration was tested using RMSE, NRMSE and d, which were 0.92 t ha^{-1}, 12.37% and 0.98 for yield and 0.92 t ha^{-1}, 12.37% and 0.98 for biomass, respectively. The RMSE, NRMSE and d values in 2007-2008 (validation year) were obtained as 0.26 t ha^{-1}, 10.01% and 0.92 for yield and 0.84 t ha^{-1}, 14.93% and 0.92 for biomass, respectively. The result of calibration and validation for volumetric water content was acceptable. AquaCrop model estimated the evapotranspiration acceptable in the first year, while the accuracy of model to predict this parameter decreased for validation. Therefore, the model was calibrated effectively for yield and biomass; however, the results were less satisfactory when it came to the simulation of the severe stress (I_5).

Keywords: AquaCrop; Canola; Grain yield and biomass; Soil water content; Canopy cover; Rainfed and deficit irrigation.

Introduction

Globally, canola production has grown rapidly over the past 40 years, rising from the sixth largest oil crop to the second largest (USDA, 2014). Canola production in Iran has considerably increased form 76500 Mg in 2003 to 350000 Mg in 2013 (Kohansal and Akbari, 2013). Canola in Iran is mostly cultivated annually in autumn for oil production and rarely livestock feed. Annually more than 90% of edible oil of Iranian is imported and therefore increasing the cultivated area to overcome edible oil shortage is a major concern (Ahmadi and Niazi, 2006). Canola is either irrigated or rainfed in different parts of Iran (Soltani et al., 2014). This shows different cropping management required for optimum seed production.

Fars province is a major canola oilseed production in Iran (Ahmadi and Nizai, 2006). But water scarcity and drought condition are the main constraints in the semi-arid regions of Fars province (Shabani et al., 2013). Among the common practices to cope with water scarcity in canola production in the semi-arid areas is deficit irrigation that has been adopted successfully (Shabani et al., 2013). However, applying different deficit irrigation scenarios is not feasible in the field to study the responses of canola to various deficit irrigation levels. Therefore, crop growth modeling is an efficient alternative choice for avoiding trial and error in the field experiments (Ahmadi et al., 2015).

Many models of water management exist for crop production in different situations. Since crop growth models simulate the combined effect of environment and management on crop growth they can provide important information for crop water management strategies (Soltani and Hoogenboom, 2007). An advantage of the simulation models is that they provide information faster and require fewer resources than the experimental studies. In this regard, the Food and Agriculture Organization of the United Nations (FAO) developed AquaCrop model that is a conceptual generic model, which achieves a balance between simplicity, accuracy and robustness (Raes et al., 2009; Steduto et al., 2009). Compared with other models, AquaCrop is relatively simple to operate and allows for simulation of crop performance in multiple field management scenarios. It is a water-driven model and its development is primarily intended for simulating crop responses to water management and irrigation strategies (Ahmadi et al., 2015). In addition to a high level of accuracy, this robust model requires a limited set of input parameters, most of which are relatively easy to acquire (Steduto et al., 2009; Hsiao et al., 2009). It is a simple model that is mainly produced for end-users, but it is still under development to make it more easy-to use through simpler user interface and small number of explicit parameters and input data (Vanuytrecht et al., 2014). Input data consists of weather data, crop, irrigation and field management, soil and groundwater characteristics that define the environment in which the crop will develop.

AquaCrop has been successfully used for various crops in different places of the world. A brief review of its application in different field crops and under different management and practical scenarios is provided in Abi Saab et al. (2014), Abi Saab et al. (2015) and Ahmadi et al. (2015). One of the main applications of this model is its ability to simulate crops growth to limited and non-limited irrigation water. For instance it has been used for studying different irrigation water levels (Khoshravesh et al., 2013; Araya et al., 2010; Todorovic et al., 2009; Farahani et al., 2009), developing deficit irrigation strategies (Ahmadi et al., 2015; Paredes et al., 2015; Andarzian et al., 2011) and farm irrigation management (Garcia-Vila et al., 2009; Heng et al., 2009).

Among the other crops, Zeleke et al. (2011) simulated canola in Australia and reported satisfactory results is simulating canopy cover, biomass and yield; however the prediction were less satisfactory under severe water stress conditions. Similar poor simulation under severe water deficit is also reported by Ahmadi et al. (2015), Hsiao et al. (2009) and Heng et al. (2009) and it is stated as one of the shortcoming of AquaCrop to fail accurate simulation under highly stressed conditions. However AquaCrop model is a reliable and useful tool for simulating canopy cover and evapotranspiration in daily scale and simulation of biomass and yield with high accuracy at the end of the growing season.

So far, AquaCrop is not extensively used on canola and there still exist lacking valuable information about the AquaCrop performance in simulating canola under rainfed and different irrigation managements during the major growing periods in semi-arid areas. Therefore the objectives of this study are to calibrate and validate the AquaCrop model using canola experimental fields subject to imposed water stress during specific growth periods levels and rainfed conditions in order to simulate soil water content, evapotranspiration, canopy cover, grain yield and dry matter. In fact this study aims to simulate real conditions that water stress may be imposed to different growth periods of canola.

Materials and Methods

Site and experiment description

In this study, version 4.0 (2012) of the AquaCrop model (Raes et al., 2009; Steduto et al., 2009) was used to simulate canola growth, biomass and yield canola in Iran. The required datasets were obtained from the studies of Shabani (2006) and Sabet (2008), respectively, that reported separate field experiments on canola in the experimental farms of the Faculty of Agriculture, Shiraz University, Iran (52° 2′ E 29° 56′ N; 1810 m.s.l.). Both experiments had identical experimental conditions and treatments. The soil texture of the study area was silty clay loam. Soil water content (SWC) at permanent wilting point, field capacity and saturation were 17, 35 and 42% respectively. The experiments were arranged as randomized complete block design with 4 replications and five irrigation treatments in ridged experimental plots of 10 m long, 3 m wide and 0.5 m between the ridges. In both years, the canola seeds were sown with the rate of 6 kg ha^{-1} which led to 150 plants m^{-2}. The seeds were sown on September 23, 2005 and September 22, 2007 in the first and second experiments, respectively.

The irrigation treatments consisted of water stress at different stages of the plant growth. All plants were irrigated the same irrigation volumes and timings until the beginning of vegetative growth stage in late winter. All plots were 100 mm pre-irrigated one day prior to sowing. Irrigation treatments were: I_1: no water stress during whole growing period (control treatment), I_2: water stress during the vegetative growth stage, I_3: water stress during flowering and pod formation stage, I_4: water stress during grain filling stage and I_5: water stress during the whole growing period (rainfed farming system) with supplemental irrigations during planting and germination stage. Figure 1 shows the amount of total irrigation and rainfall for both experiments in different irrigation treatments. The total irrigation amount (without rainfall) in both years for different irrigation treatments are, respectively, as I_1: 582 and 545 mm, I_2: 551 and 430 mm, I_3: 529 and 420 mm, I_4: 313 and 300 mm and I_5: 162 and 125 mm. Total rainfall has been 304 and 121 mm during the growing season in both years, respectively.

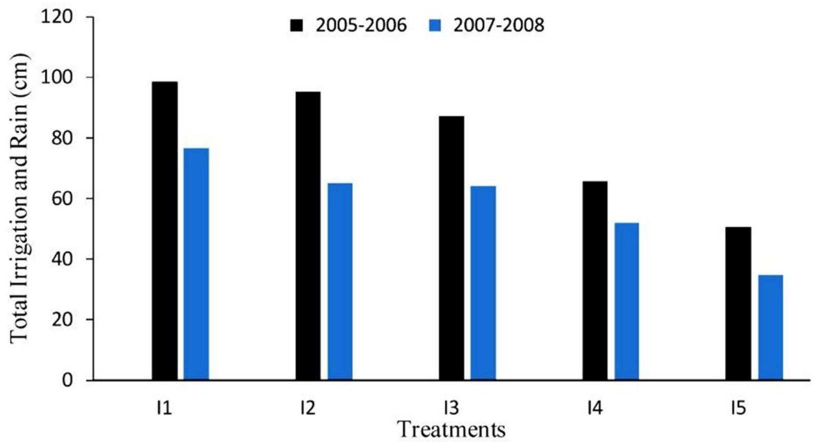

Figure 1. Total irrigation and rainfall in the growing seasons 2005-2006 and 2007-2008.

Soil water content (m) was frequently measured during the growing season one day before each irrigation event or one day after rainfall event using the neutron meter (CPN503 DR) down to 1 meter depth in 0.2 m increments. Total soil water content was calculated as the sum of the total water in the 0.2 m soil depth increments. In each irrigation event, the soil water content was raised to field capacity except those treatments subject to water stress. Direct field measurements revealed that maximum rooting depth before starting the irrigation treatments was 0.6 m which reached to 0.9 m at the end of growing season (Honar et al., 2012). Actual evapotranspiration was calculated by the soil water balance approach.

Daily meteorological data such as temperature, precipitation were obtained from the synoptic station located near the experimental area at the college of Agriculture, Shiraz University. Monthly precipitation (Figure 2a), reference evapotranspiration (ET_o) based on the Penman-Monteith equation (Allen et al., 1998) (Figure 2b) and minimum and maximum temperatures (Figure 2c) during 2005-2006 and 2007-2008 growth periods are shown in Figure 2.

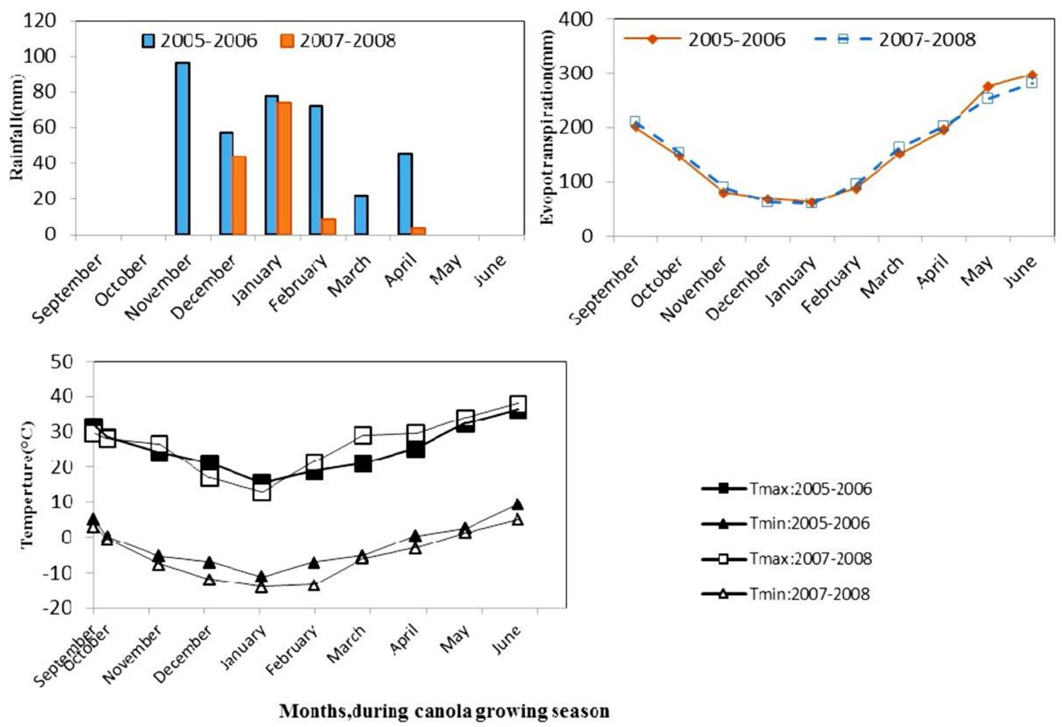

Figure 2. Monthly weather data for canola growing season in the years of 2005-2006, 2007-2008, (a) Rainfall, (b) Reference evapotranspiration, (c) Minimum and Maximum temperature.

AquaCrop model description

The detailed description of the model is presented in Steduto et al. (2009) and Raes et al. (2009). Here is brief description of the model is presented. The latest version of AquaCrop model (version 4) has been used in this study. The complexity of crop responses to water deficits led to use of empirical production functions as the most practical option to assess crop yield response to water stresses. Among the empirical function approaches, Doorenbos and Kassam (1979) represented an important equation to determine the yield response to water deficits:

$$\left(\frac{Y_x - Y_a}{Y_x}\right) = K_y \left(\frac{ET_x - ET_a}{ET_x}\right) \tag{1}$$

Where Y_x and Y_a are the maximum and actual yield, ET_x and ET_a are the maximum and actual evapotranspiration and K_y is the proportionality factor between relative yield loss and relative reduction in evapotranspiration. Equation 1 is the base of AquaCrop that separates the ET into soil evaporation (E) and crop transpiration (Tr) and separation of final yield (Y) into biomass (B) and harvest index (HI). The separation of ET into E and Tr assures neglecting the effect of non-productive part of water consumption (E) in yield production (Raes et al., 2009), which is a critical issue when ground cover is incomplete. Basically, AquaCrop engine is conceptually water-driven and water productivity is calculated as follow:

$$WP^* = \frac{B}{\Sigma\left(\frac{Tr}{ET0}\right)} \tag{2}$$

Where Tr is the crop transpiration (mm) and WP* is the normalized water productivity (kg of biomass m^{-3} mm^{-1} of cumulated water transpired over the time period in which the biomass is produced).

AquaCrop does not directly use leaf area index (LAI) rather it uses the canopy cover (CC). Since canopy cover was not measured in the field experiments the following equation was used to convert LAI to CC (Goudriaan and Van laar, 1993):

$$CC = 1 - \exp(-K \times LAI) \tag{3}$$

Where K is extinction coefficient calculated from the equation suggested by Khaledian et al. (2009):

$$K = \min(1.0, 1.43 \times LAI^{-0.5}) \tag{4}$$

Transpiration (Tr) is calculated by multiplying the reference crop evapotranspiration to basal crop coefficient (K_{cb}), which is proportional to CC.

Calibration, validation and assessment of AquaCrop model

The calibration and validation datasets were obtained from the studies of Shabani (2006) and Sabet (2008), respectively. The model parameters were calibrated using the 2005-2006 data and the parameterized model was validated with the 2007-2008 data. The calibration procedure focused on I_1 and then other four water stressed treatments were included until best-matching parameters were achieved. Due to the water-driven nature of AquaCrop, the calibrated parameters were first adjusted for soil water content and grain yield and then fine-tuned for evapotranspiration, canopy cover and biomass. The model's calibrated parameters are presented in Table 1 and divided in two groups including conservative and non-conservative parameters. The conservative parameters are those that need calibration and the non-conservatives are site- and experiment-specific.

Table 1. AquaCrop calibration parameters and their respective values for canola.

Parameter	Value
Conservative	
Base temperature (°C)	0
Upper temperature (°C)	30.0
Cover per seedling(cm^2 $plant^{-1}$)	5.00
Canopy growth coefficient CGC($\%d^{-1}$)	8.50
Canopy decline coefficient CDC ($\%d^{-1}$)	5.00
Soil water depletion factor for canopy expansion, upper limit	0.18
Soil water depletion factor for canopy expansion, lower limit	0.60
Shape factor for water stress coefficient for canopy expansion	3.40
Soil water depletion factor for stomata closure	0.58
Shape factor for water stress coefficient for stomata closure	5.00
Soil water depletion factor for early canopy senescence	0.65
Shape factor for Water stress coefficient for canopy senescence	3.00
Normalized water productivity WP*(g m^{-2})	19.0
Adjustment for yield formation (%)	100
Normalized water productivity during yield formation WP*(g m^{-2})	19.0
Basal crop coefficient (maximum)(Kcb(x))	1.1
Transpiration coefficient (Kc_{Tr})	0.25
Evaporation coefficient (Ke)	1.25
No conservative parameters	
Plant density (plants ha^{-1})	1350000
Initial canopy cover CC0 (%)	3.5
Maximum canopy cover CCx (%)	90
maximum canopy cover(GDD)	1908
to flowering(GDD)	1604
Length of the flowering stage (GDD)	791
To start of canopy senescence (GDD)	2224
to maturity (GDD)	2840
to emergence(GDD)	230
Maximum rooting depth(m)	0.9
Minimum effective rooting depth(m)	0.1
Reference harvest index HI0 (%)	30

Water stress was applied during vegetative stage in spring, flowering and grain filling stage. So the relative coefficients of the applied stress conditions were calibrated during these periods. The accuracy of the model was evaluated in terms of severe stress. Due to the high rainfall in these two years, as was the calibration of the model to estimate the product severe stress, so the Kc_{Tr} calibration 0.25 was considered and results are presented.

Various statistical indices were used for assessing the performance of the model. A common index is the coefficient of determination as Equation 5:

$$R^2 = \left[\frac{\sum(O_i-\bar{O})(P_i-\bar{P})}{\sqrt{\sum(O_i-\bar{O})^2\sum(P_i-\bar{P})^2}}\right]^2 \quad (5)$$

Where R^2 is the coefficient of determination, O_i and P_i are the observed and predicted value, respectively, $\bar{O}$ and $\bar{P}$ are the mean of observed and predicted values, respectively. Coefficient of determination ranges from 0 to 1, with values close to 1 indicating a good agreement and typically values greater than 0.5 are considered acceptable in watershed simulation (Moriasi et al., 2007).

The Root Mean Square Error (RMSE) that is defined as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(p_i-O_i)^2}{n}} \quad (6)$$

The RMSE is very sensitive to extreme values or outliers (Moriasi et al., 2007). This is in fact a weakness of all statistical indicators. RMSE is expressed in the units of the studied variable RMSE values close to 0 show better match between observed and predictions.

The normalized RMSE (NRMSE) that is expressed as percentage and gives an indication of the relative difference between model and observations.

$$NRMSE = 100 \times \sqrt{\frac{\sum_{i=1}^{n}(P_i-O_i)^2}{n\times\bar{O}^2}} \quad (7)$$

A simulation can be considered excellent if NRMSE is smaller than 10%, good if between 10 and 20%, fair if between 20 and 30% and poor if larger than 30% (Raes et al., 2012).

The index of agreement (d) was proposed by Willmott (1982) to measure the degree to which the observed data are approached by the predicted data. It ranges between 0 and 1, with 0 indicating no agreement and 1 indicating a perfect agreement between the predicted and observed data.

$$d = 1 - \frac{\sum_{i=1}^{n}(P_i-Q_i)^2}{\sum_{i=1}^{n}(|p_i-\bar{O}|+|Q_i-\bar{O}|)^2} \quad (8)$$

Results and Discussion

Calibration

Soil water content

The observed and simulated SWC in the root zone of different irrigation treatments are shown in Figure 3 and Table 2 summarizes the statistical indices. The RMSE values show that depending on the irrigation management, RMSE values ranged between 16.8 mm to 23.1 mm that correspond to 2.62 to 9% error revealing excellent SWC simulations during calibration. Robust simulation of SWC is crucial for accurate and satisfactory estimation of crop evapotranspiration and soil water balance component of AquaCrop that finally affect reliable yield simulations (Ahmadi et al., 2015; Geerts and Raes, 2010). Table 2 shows that the model was able to predict the soil moisture content well as the NRMSE for treatments were lower than 15%. The model was better in simulating the soil moisture under no stress condition (I_1) compared to the other stressed conditions as it is shown in Table 2. So AquaCrop performed well for calibration of water content. AquaCrop model simulation is good when water is available for plants, while the results are less satisfactory under increased stress.

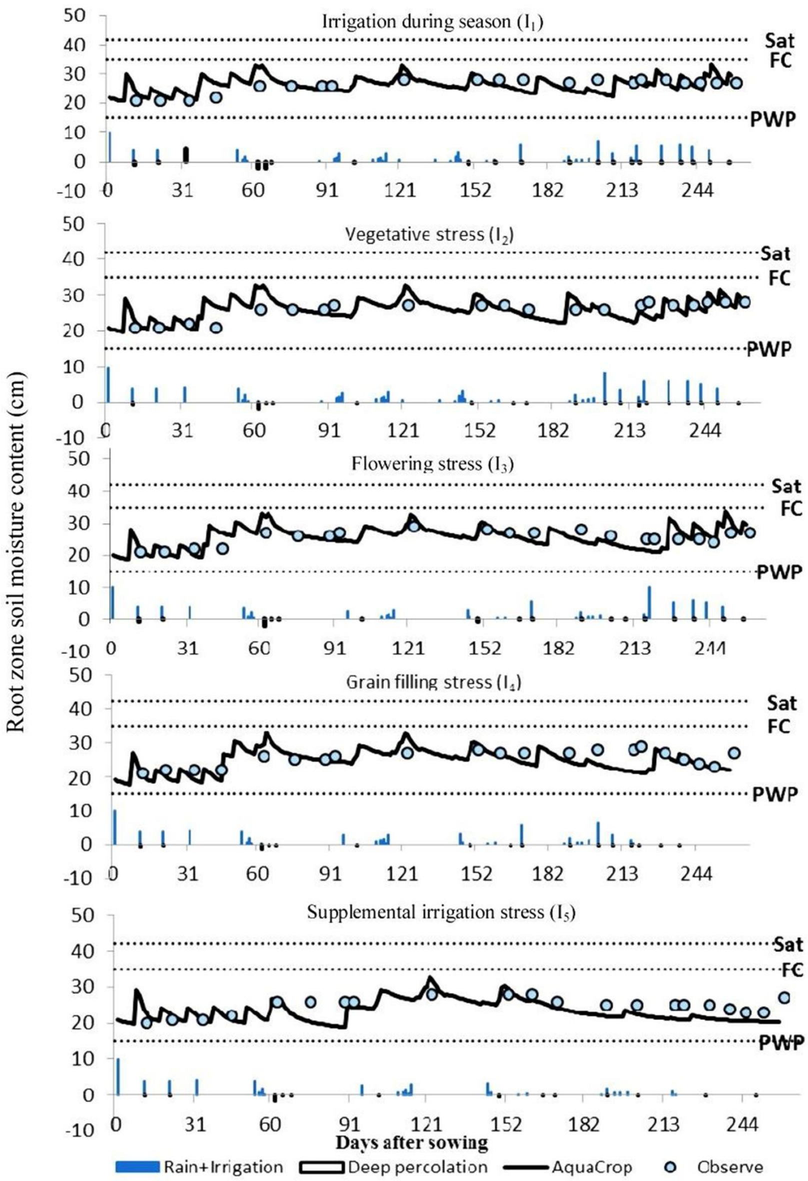

Figure 3. Amounts of irrigation + precipitation and simulation of water content in root zone in various stress treatments (irrigation during season (I_1), vegetative stress (I_2), flowering stress (I_3), grain filling stress (I_4) and supplemental irrigation (I_5) treatments) during the growth period of 2005-2006.

Evapotranspiration

The measured evapotranspiration were calculated using water balance method. Thus, the simulation was preformed cumulatively throughout the whole season (Figure 4). As it is shown in Figure 4, the model performed reasonably well for I_1 and I_4 treatments compared to other treatments, as it shown by the RMSE, NRMSE and d values were:

2.1 t ha^{-1}, 6.9% and 0.98 for I_1 and 2.3 t ha^{-1}, 6.2% and 0.99 for I_4, respectively. The simulated cumulative evapotranspiration were higher compared to measured values for irrigation during season treatments (I_1) at the beginning of growth period, while at the end of growth period the simulated and measured values got closer (Table 2). The coefficient of calibration, Kc_{Tr} and K_e are effective in accurate evapotranspiration simulation. As discussed by Pereira et al. (2015) the calibrated parameters such as $K_{c,Tr\ x}$, or the CC_x parameters, are internally changed by the model. This fact identifies a difficulty in the use of model because the user has no control on the parameterization and calibration processes. So AquaCrop model slightly overestimated evapotranspiration but it was quite satisfactory.

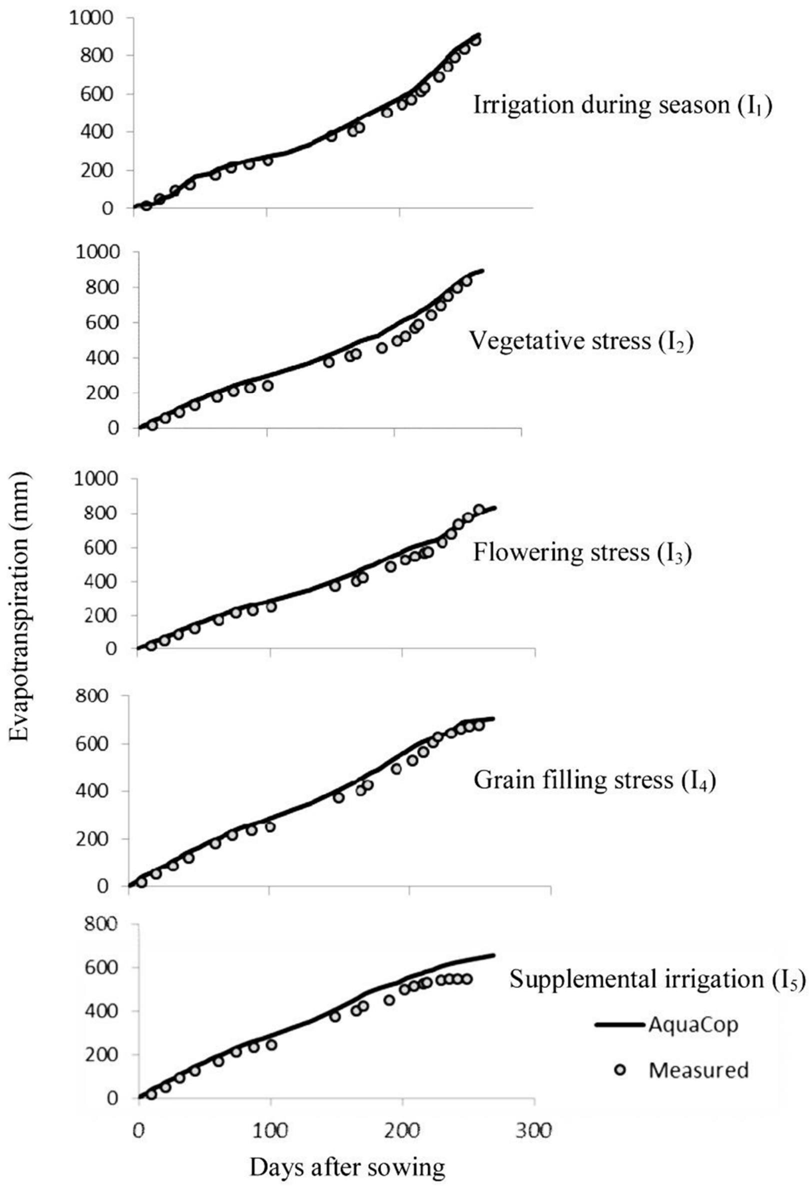

Figure 4. Variation of cumulative evapotranspiration (solid line is simulated and filled circles are measured evapotranspiration) during growth period of 2005-2006 using water balance method in irrigation during season (I_1), vegetative stress (I_2), flowering stress (I_3), grain filling stress (I_4) and supplemental irrigation (I_5) treatments.

Canopy cover

Canopy cover illustrates how crops develop during their growth period. This parameter is crucial because it shows periods where plants were under stress. Figure 5 compares measured and simulated canopy crop. The results showed that canopy cover of stressed treatments in supplemental irrigation (I_5) treatments were less satisfactory (Table 2). This has also been observed by Farahani et al. (2009) for cotton, Geerts and Raes (2010) for quinoa and Zeleke et al. (2011) for canola. It can be concluded that the AquaCrop model is most affected by irrigation and it is not successful to simulate canopy cover under severe water stress. This failure has also been shown in previous studies on Aquacrop, for instance Ahmadi et al. (2015), Heng et al. (2009). Canopy cover has more impact on biomass than other simulated parameters. In AquaCrop model, as crop approaches maturity, CC enters in a declining phase due to leaf senescence. In warm season and in addition to water stress, temperature stress influenced too. Thus in the end of season canopy cover are less satisfactory and that is why in I_5 treatment this stress problem is intensified. Similar issue is also reported by Abedinpour et al. (2012). Xiangxiang et al. (2013) reported canopy cover simulations for the full irrigation and simulations agreed very well with the experimental data for all growth stages following stem elongation but slightly less well for the earlier stages. As discussed by Andarzian et al. (2011), the simulated canopy cover was close to the observed values from sowing to flowering over 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. NRMSE indicators increases with severe water stress (Table 2). Thus although canopy cover is under the influence of water stress, it can be under the influence of severe temperature stress too. So the AquaCrop model must be well calibrated accurately for the whole stresses that may be influencing.

Biomass and the yield

By simulating water conditions that affect the crop growth, we can discuss the results of dry matter and its efficiency further. As it is shown in Table 2, the model has fairly simulated the yield and biomass in some of the treatments except for I_5 due to the cessation of irrigation. The comparison of simulated and measured values for biomass indicated that the model was acceptable, but it was less satisfactory in supplemental stress (I_5). Therefore it can be concluded that the model can simulate the yield and dry matter fairly in the end of season except for the I_5 treatment but it can't simulate for severe stress (Figures 6 and 7).

In AquaCrop model aboveground biomass is derived from the crop transpiration by means of the crop water productivity, WP* normalized for ET_0 and CO_2 (Steduto et al., 2009). The model was not successful to predict biomass during season whereas simulations at harvest were quite well. But as it is expected, the model could not predict I_5 treatment as it has been already discussed, canopy cover has great impact in biomass and its simulation was bad in I_5. In Table 2, statistical indicators in harvest time are presented.

Figure 7 shows the relationship between observed and simulated canola grain yield. The simulation of grain yield ranged from 0.98 to 3.56 t ha^{-1} while the experimental values ranged from 1.78 to 3.45 t ha^{-1}. Observed and simulated grain yield were well for I_1 to I_4 treatments but I_5 treatment was fair. The simulated grain yield showed a fair agreement with measured canola yield (Table 2; Figure 7). Xiangxiang et al. (2013) and Zeleke et al. (2011) reported that the AquaCrop model overestimated grain yield for low water treatments and underestimated for the high water ones.

Referring to Table 2, the accuracy of AquaCrop model reduced with increasing water stress level. Possibly, other environmental stresses are also effective in reality but they are not generally considered in the model. Ahmadi et al. (2015) reported that the AquaCrop structure could be modified to improve final yield and biomass simulation especially under different stages to severe water stresses during growth season.

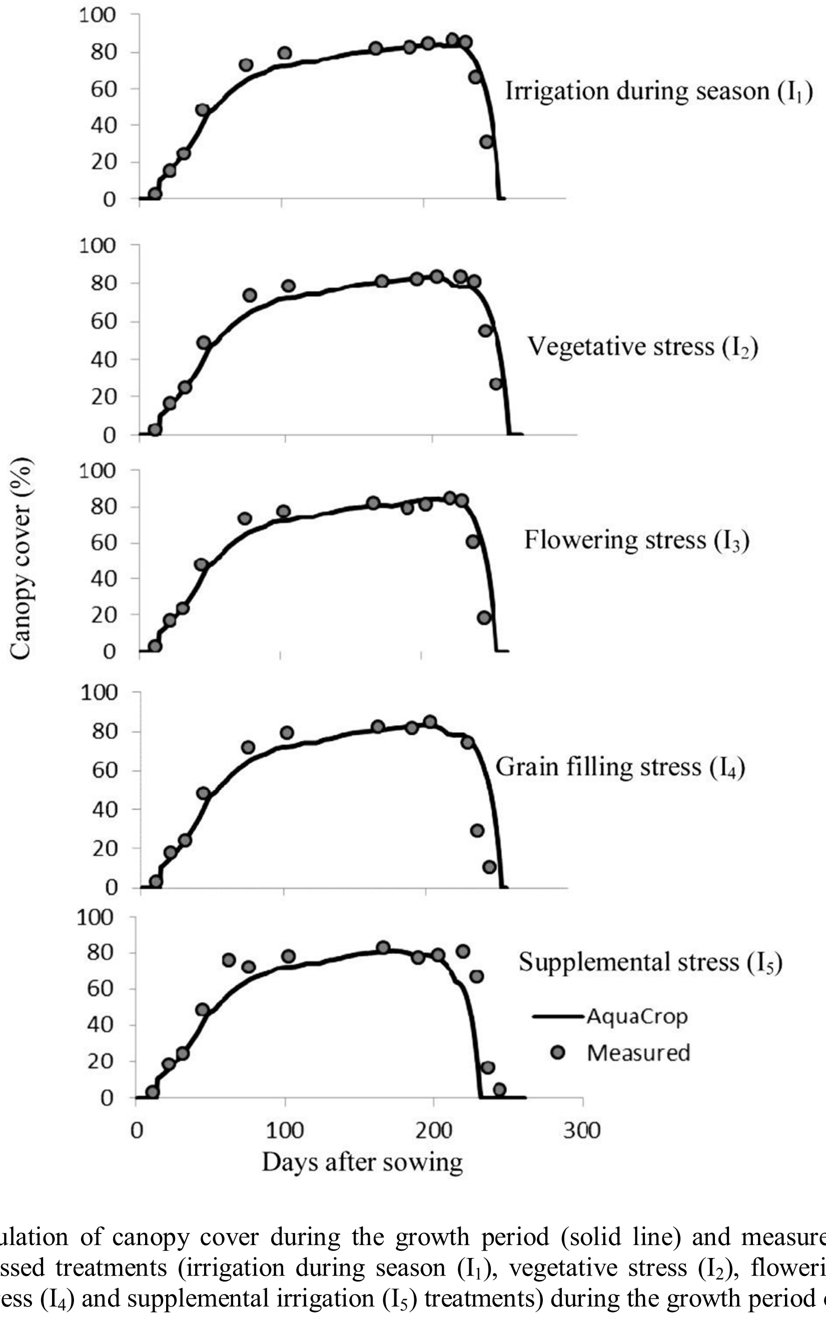

Figure 5. Simulation of canopy cover during the growth period (solid line) and measured data (filled circles) of stressed treatments (irrigation during season (I_1), vegetative stress (I_2), flowering stress (I_3), grain filling stress (I_4) and supplemental irrigation (I_5) treatments) during the growth period of 2005-2006.

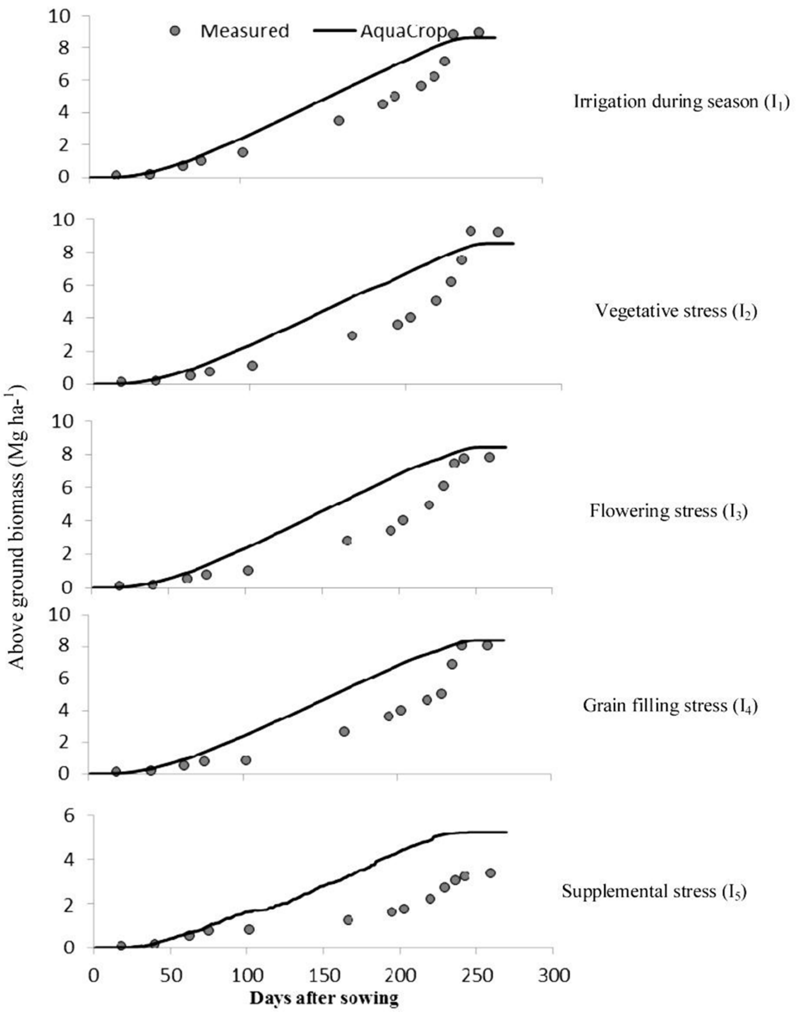

Figure 6. Simulation of aboveground biomass during the growth period (solid line) and measured data (filled circles) of stressed treatments (irrigation during season (I_1), vegetative stress (I_2), flowering stress (I_3), grain filling stress (I_4) and supplemental irrigation (I_5) treatments) during the growth period of 2005-2006.

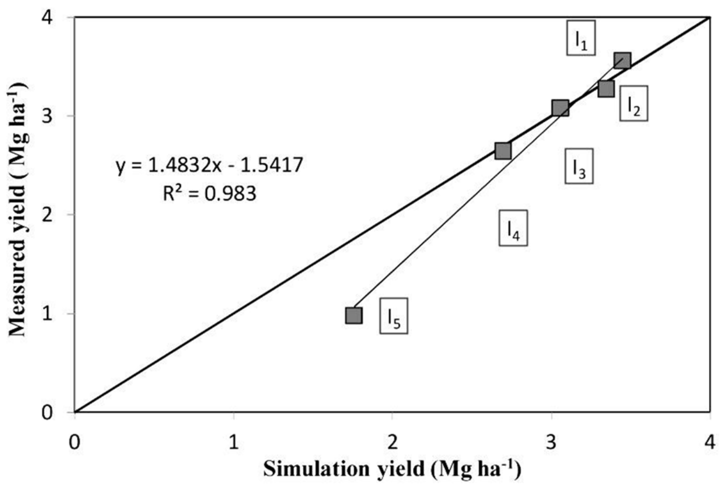

Figure 7. Regression relationship between simulated and measured yield and 1:1 line(irrigation during season (I_1), vegetative stress (I_2), flowering stress (I_3), grain filling stress (I_4) and supplemental irrigation (I_5) treatments) during the growth period of 2005-2006.

Table 2. The statistical results for root zone soil moisture, evapotranspiration, canopy cover, yield and biomass for growth period of 2005-2006.

treatment	Root Zone Soil Moisture				
	I_1	I_2	I_3	I_4	I_5
RMSE (t ha^{-1})	1.78	2.31	2.18	1.68	2.07
NRMSE (%)	6.75	9.00	8.58	2.62	8.40
d	0.98	0.98	0.98	0.99	0.98
treatment	Root Zone Soil Moisture after Applying Stress				
	I_1	I_2	I_3	I_4	I_5
RMSE(t ha^{-1})	1.95	2.6	2.9	3.5	3.6
NRMSE (%)	9.5	7.8	12.1	15	14.7
d	0.99	0.99	0.98	0.98	0.98
treatment	Evapotranspiration (mm)				
	I_1	I_2	I_3	I_4	I_5
RMSE(t ha^{-1})	2.1	2.7	2.9	2.3	3.0
NRMSE (%)	6.9	8.0	8.7	6.2	10.9
d	0.98	0.98	0.99	0.99	0.98
treatment	Canopy Cover				
	I_1	I_2	I_3	I_4	I_5
RMSE(t ha^{-1})	7.05	9.46	8.05	12.95	14.05
NRMSE (%)	9.61	12.49	14.78	18.19	28.87
d	0.98	0.98	0.97	0.96	0.95
treatment	Yield				
	I_1	I_2	I_3	I_4	I_5
Measured (Mg ha^{-1})	3.56	3.27	3.08	2.64	0.98
Simulated (Mg ha^{-1})	3.45	3.35	3.06	2.70	1.76
RMSE(t ha^{-1})			0.35		
NRMSE (%)			13.12		
d			0.98		
treatment	Biomass				
	I_1	I_2	I_3	I_4	I_5
Measured (Mg ha^{-1})	8.92	9.19	7.8	8.02	3.38
Simulated (Mg ha^{-1})	8.61	8.82	7.90	8.40	5.35
RMSE(t ha^{-1})			0.92		
NRMSE (%)			12.37		
d			0.98		

Validation

The amount of water in the root zone, evapotranspiration, canopy cover and the yield were validated using independent data from 2007-2008 (Sabet, 2009). The results indicated that the simulation of water content in root zone had performed well (Figure

8). The amount of NRMSE after applying stress for I_1, I_2, I_3, I_4 and I_5 were 14.1, 11.9, 7.1, 11.6 and 7.3 t ha^{-1}, respectively which showed that AquaCrop was able to predict the soil water content with suitable accuracy. As Araya et al. (2010) reported, in this study there was a perfect match between the simulated observed soil water. Mild water stress occurred from the time of senescence to maturity during which slight mismatches were observed. Similarly, Xiangxiang et al. (2013) reported that the water dynamics around the root zone were adequately simulated by the model. Both Farahani et al. (2009) and Hussein et al. (2011) reported that AquaCrop predicted well the wetting and drying cycles due to irrigation events; however, it tended to overestimate the total soil moisture content, particularly in the deficit irrigation managements. Thus according to the simulation, AquaCrop was satisfactory in simulating soil water content for the both season 2005-2006 and 2007-2008. Parameters calibrated in the section soil water was acceptable, because statistical indicators in results validation was good (Table 3).

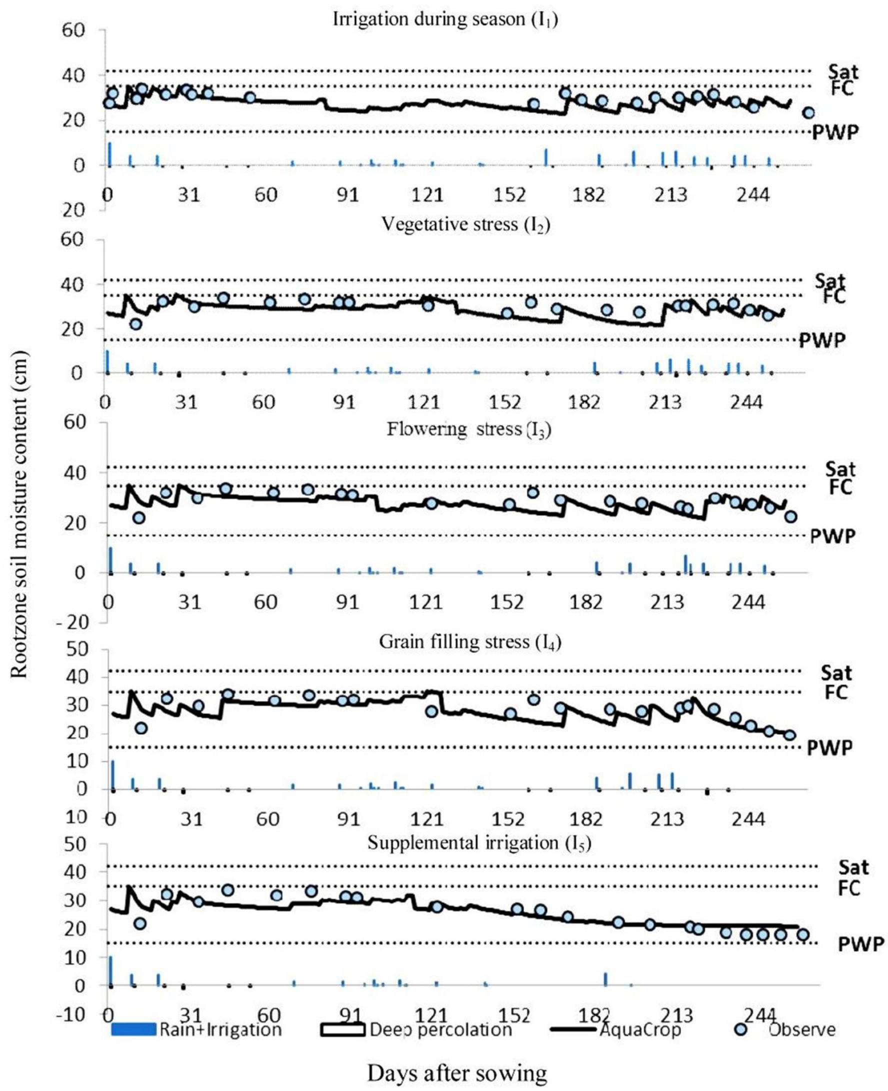

Figure 8. The amount of irrigation+ precipitation and simulation of water content in root zone in various stress treatments (irrigation during season (I_1), vegetative stress (I_2), flowering stress (I_3), grain filling stress (I_4) and supplemental irrigation (I_5) treatments) during the growth period of 2007-2008.

The statistical analysis showed that AquaCrop model could not simulate the evapotranspiration in severely water stress condition as well as other irrigation managements as the NRMSE was higher than 17% for I_5 treatment (Table 3). The amount of simulated evapotranspiration for other irrigation managements was satisfactory by the model (Figure 9). In the I_5 poor evapotranspiration simulation may be due to the poor CC simulation since evapotranspiration simulation is very much dependent on CC. Of course, soil evaporation when canopy cover is complete or is near completion are too much dependent on CC and little effect can be seen on the soil evaporative characteristics. Thus refer to canopy cover in I_5 treatment, it is seen that NRMSE is fair because evapotranspiration simulation was not as good as other irrigations. A part of the reason is the fact that AquaCrop already accounts for the effect of Tr on plant water status in a limited way by adjusting the stress threshold p value according ET_o (Steduto et al., 2009). The fact that the model, so far, has proven relatively robust and applicable to many of the water conditions tested in this study and other studies (Heng et al., 2009; Farahani et al., 2009; Geerts and Raes, 2010) puts credence to the chosen approach.

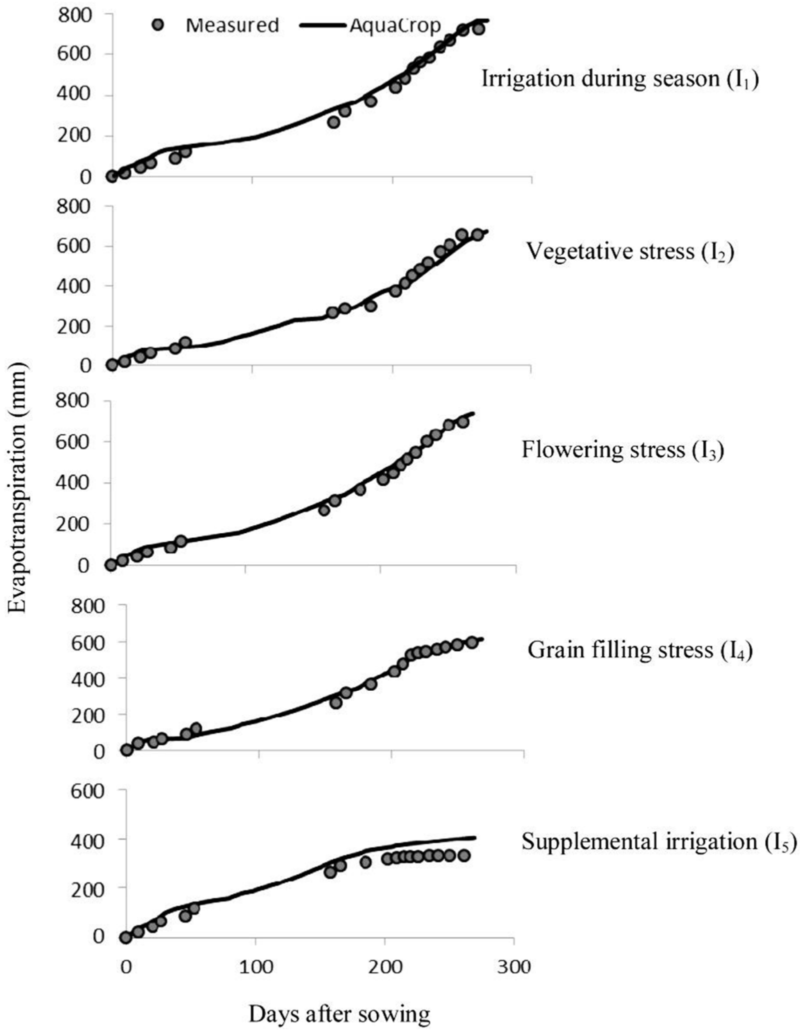

Figure 9. Variation of cumulative evapotranspiration (solid line is simulated and filled circles are measured evapotranspiration) during growth period of 2007-2008 using water balance method in irrigation during season (I_1), vegetative stress (I_2), flowering stress (I_3), grain filling stress (I_4) and supplemental irrigation (I_5) treatments.

The validation of simulated canopy cover had fine results except for I_5 (supplementary irrigation in the whole period of growth) (Table 3). The results of yield simulation were acceptable in spite of the fact that the model could not give any good results for the stressed treatment during the whole period of growth with supplementary irrigation, however the model prediction for biomass was also not acceptable (Table 3). As mentioned in the calibration, it can be said that in addition to water stress, temperature stress will be too influential (Andarzian et al., 2011). Figure 10 showed that canopy cover started with slight mismatch in sowing to flowering time. As discussed by Hsiao et al. (2009), RMSE ranged in 5.85 to 13.59 t ha^{-1} for water stress treatments. Therefore, this aspect of AquaCrop appears to require further development for severe water stress.

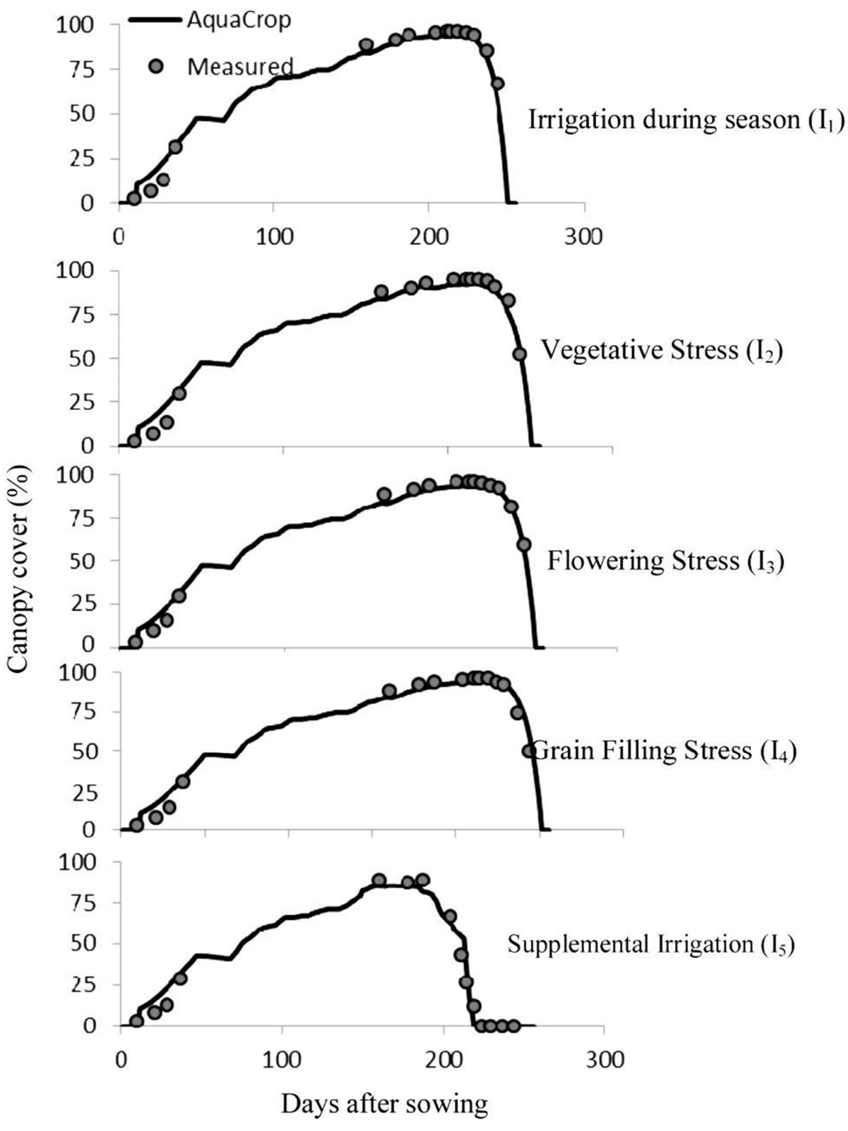

Figure 10. Simulation of canopy cover during the growth period (solid line) and measured data (filled circles) of stressed treatments (irrigation during season (I_1), vegetative stress (I_2), flowering stress (I_3), grain filling stress (I_4) and supplemental irrigation (I_5) treatments) during the growth period of 2007-2008.

Above ground biomass in validation showed that the AquaCrop model cannot simulate precisely during growth season and the model needs improvement to simulate grain yield with better accuracy (Figure 11). This statement is also reported by Heng et al. (2009) and Jin et al. (2014) reported that biomass was more relative with transpiration. Therefore we calculated RMSE, NRMSE and d in harvest time. However, it is important to simulate the growth period but the final biomass in the end of season is more important. The final above ground biomass had NRMSE as 14.9% and RMSE as 0.84 t ha^{-1} (Table 3) although other researchers reported almost similar simulations as Hanson et al. (1999), Wei et al. (2015) and Paredes et al. (2015).

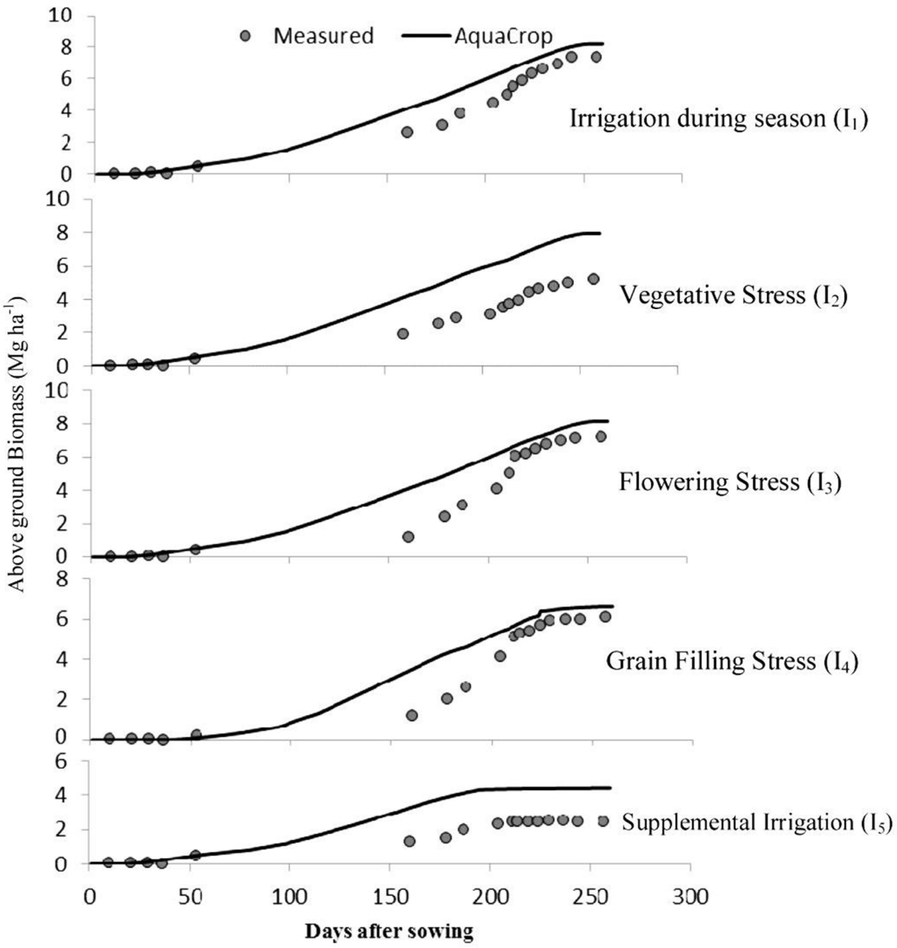

Figure 11. Simulation above ground biomass during the growth period (solid line) and measured data (filled circles) of stressed treatments (irrigation during season (I_1), vegetative stress (I_2), flowering stress (I_3), grain filling stress (I_4) and supplemental irrigation (I_5) treatments) during the growth period of 2007-2008.

In this study, simulation of yield for data 2007-2008 were 3.28 and 0.32 t ha^{-1} for without irrigation (I_1) and deficit irrigation (I_5) respectively (Table 3; Figure 12). For improved biomass and yield in severe water stress conditions, it is suggested considering strategy of ET that in severe stress condition reduces biomass and yield. In another way Jin et al. (2014) considered different planting dates. However, AquaCrop modeling is a good predictor when irrigation is adequate and this was corroborated by Heng et al. (2009).

Table 3. The statistical results for root zone soil moisture, evapotranspiration, canopy cover, yield and biomass for growth period of 2007-2008.

treatment	Root Zone Soil Moisture				
	I_1	I_2	I_3	I_4	I_5
RMSE(t ha^{-1})	1.79	1.91	2.15	3.22	2.77
NRMSE (%)	5.93	6.39	7.42	11.22	10.87
d	0.98	0.98	0.98	0.97	0.97
treatment	Root Zone Soil Moisture after applying stress				
	I_1	I_2	I_3	I_4	I_5
RMSE(t ha^{-1})	2.1	2.2	1.9	2.0	1.9
NRMSE (%)	14.1	11.9	7.1	11.6	7.3
d	0.98	0.98	0.98	0.98	0.98
treatment	Evapotranspiration (mm)				
	I_1	I_2	I_3	I_4	I_5
RMSE(t ha^{-1})	2.1	2.0	1.8	1.7	2.4
NRMSE (%)	8.02	8.28	6.70	4.9	19.32
d	0.99	0.99	0.99	0.99	0.97
treatment	Canopy Cover				
	I_1	I_2	I_3	I_4	I_5
RMSE(t ha^{-1})	7.5	9.46	8.5	12.95	14.25
NRMSE (%)	9.30	10.80	10.90	11.70	16.20
d	0.97	0.98	0.98	0.97	0.96
treatment	Yield				
	I_1	I_2	I_3	I_4	I_5
Measured(Mg ha^{-1})	3.58	2.66	2.98	3.50	0.75
Simulated(Mg ha^{-1})	3.28	2.87	3.10	3.13	0.32
RMSE(t ha^{-1})			0.26		
NRMSE (%)			10.01		
d			0.98		
treatment	Biomass				
	I_1	I_2	I_3	I_4	I_5
Measured(Mg ha^{-1})	7.35	5.21	7.22	5.98	2.45
Simulated(Mg ha^{-1})	7.45	5.50	7.10	6.10	4.30
RMSE(t ha^{-1})			0.84		
NRMSE (%)			14.93		
d			0.92		

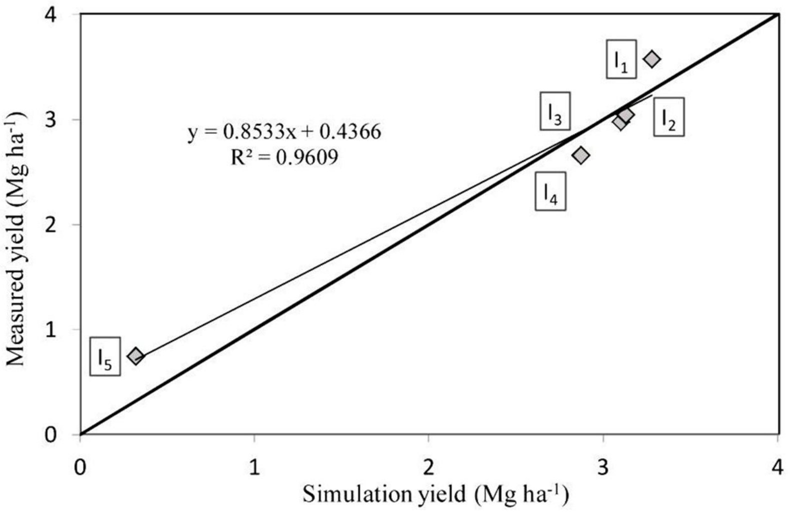

Figure 12. Regression relationship between simulated and measured yield to regression and 1:1 line (irrigation during season (I_1), vegetative stress (I_2), flowering stress (I_3), grain filling stress (I_4) and supplemental irrigation (I_5) treatments) during the growth period of 2007-2008.

Conclusions

The AquaCrop model was parameterized using two years of field observation of a canola crop in Iran. The model was calibrated and compared with the observed soil water content, evapotranspiration, canopy cover and final biomass and yield.

Regarding total soil water content, comparison of simulated and observed values for all treatments in different growth stages showed close agreement to observation. As for evapotranspiration, we should be more careful because it will have a large impact on canopy cover and final biomass and yield. The result was good in all treatment but less satisfactory in severe stress (I_5) in particular second year. Canopy cover it is too important. If soil water and evapotranspiration are in good agreement, the canopy cover simulation is nearly close to observation. Because of this dependency, severe stress treatment had poor results. About final yield and biomass, the model shows clearly very accurate prediction except rainfed treatment. Finally it is concluded that the AquaCrop model cannot provide satisfactory results under severe water stress conditions. The model tended to overestimate attainable final biomass and final grain yield. We can conclude from this study that the AquaCrop model can be used with a reliable degree of accuracy under mild water stress.

References

Abi Saab, M.T., Albrizio, R., Nangia, V., Karam, F., Rouphael, Y., 2014. Developing scenarios to assess sunflower and soybean yield under different sowing dates and water regimes in the Bekaa valley (Lebanon): Simulations with Aquacrop. Int. J. Plant Prod. pp. 457-482.

Abi Saab, M.T., Todorovic, M., Albrizio, R., 2015. Comparing AquaCrop and CropSyst models in simulating barley growth and yield under different water and nitrogen regimes. Does calibration year influence the performance of crop growth models. Agr. Water Manage. 147, 21-33.

Abedinpour, M., Sarangi, A., Rajput, T.B.S., Singh, M., Pathak, H., Ahmad, T., 2012. Performance evaluation of AquaCrop model for maize crop in a semi-arid environment. Agr. Water Manage. 110, 55-66.

Ahmadi, S.H., Mosallaeepour, E., Kamgar-Haghighi, A.K., Sepaskhah, A.R., 2015. Modeling maize yield and soil water content with AquaCrop under full and deficit irrigation managements. Water Resour. Manag. 29, 2837-2853.

Ahmadi, S.H., Niazi Ardekani, J., 2006. The effect of water salinity on growth and physiological stages of eight canola (*Brassica napus*) cultivars. Irrig. Sci. 25, 11-20.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration: guidelines for computing crop water requirements. Irrigation and drainage Paper n. 56. FAO, Rom, Italy, 300p.

Andarzian, B., Bannayan, M., Steduto, P., Mazraeh, H., Barati, M.E., Rahnama, A., 2011. Validation and testing of the AquaCrop model under full and deficit irrigated wheat production in Iran. Agr. Water Manage. 100, 1-8.

Araya, A., Solomon, H., Kiros, M.H., Afewerk, K., Taddese, D., 2010. Test of AquaCrop model in simulating biomass and yield of water deficient and irrigated barley (*Hordeum vulgare*). Agr. Water Manage. 97, 1838-1846.

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

Farahani, H.J., Izzi, G., Oweis, T.Y., 2009. Parameterization and evaluation of the AquaCrop model for full and defi cit irrigated cotton. Agron. J. 101, 469-476.

Garcia-Vila, M., Fereres, E., Mateos, L., Orgaz, F., Steduto, P., 2009. Deficit Irrigation Optimization of Cotton with AquaCrop. Agron. J. 101, 477-487.

Geerts, S., Raes, D., 2010. Using AquaCrop to derive deficit irrigation schedules. Agr. Water Manage. 98, 213-216.

Goudriaan, J., Van Laar, H.H., 1993. Modelling Potential Crop Growth Processes. Kluwer Academic Press.

Hanson, J.D., L., Rojas, K., Hanson, J., Shaffer, M., 1999. Modeling Management Effects on Water Quality and Crop Production. Water Resources Publications, LLC, CO, USA, pp. 81-118.

Heng, L.K., Hsiao, T.C., Evett, S., Howell, T., Stedute, P., 2009. Validating the FAO AquaCrop Model for Irrigated and Water Deficient Field Maize. Agron. J. 101, 488-498.

Honar, T., Sabet-Sarvestani, A.A., Sepaskhah, A.R., Kamgar-Haghighi, A.A., Shams, Sh., 2012. Simulation of Soil Water Content and Yield of Canola Using CRPSM. J. Sci. Technol. Water Soil Sci., Isfahan, Iran. 16 (59), 45-57. (Text in Persian with English abstract)

Hsiao, T.C., Heng, L., Steduto, P., Rojas-Lara, B., Raes, D., Fereres, E., 2009. AquaCrop-The FAO crop model to simulate yield response to water: III. Parameterization and testing for maize. Agron. J. 101 (3), 448-459.

Hussein, F., Janat, M., Yakoub, A., 2011. Simulating cotton yield response to deficit irrigation with the FAO AquaCrop model. Spanish. J. Agr. Sci. 9, 1319-1330.

Jin, X.L., Hai-Kuan, F., Xin-Kia, Zh., Zhen-Hai, L., Sen-Nan, S., Xiao-Yu, S., Gui-Jun, Y., Xin-Gang, X., Wen-Shan, G., 2014. Assessment of the AquaCrop Model for Use in Simulation of Irrigated Winter Wheat Canopy Cover, Biomass and Grain Yield in the North China Plain. PloS ONE. 9 (1).

Khaledian, M.R., Mailhol, J.C., Ruelle, P., Rosique, P., 2009. Adapting PILOTE model for water and yield management under direct seeding system: the case of corn and durum wheat in a Mediterranean context. Agr. Water Manage. 96 (5), 757-770.

Khoshravesh, M., Mostafazadeh-Fard, B., Heidarpour, M., Kiani, A.R., 2013. AquaCrop model simulation under different irrigation water and nitrogen strategies. Water Sci. Technol. 67, 232-238.

Kohansal, M.R., Akbari, M.R., 2013. Grain Marketing Margins Evaluation in Iran A Case Study: Bean. Int. J. Agri. Crop Sci. 6 (15), 1088-1091.

Moriasi, D.N., Arnold, J.G., Liew, M.W.V., Bingner, R.L., Harmel, R.D., Veith, T.L., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE. 50, 885-900.

Paredes, P., Wei, Z., Liu, Y., Xu, D., Xin, Y., Zhang, B., Pereira, L.S., 2015. Performance assessment of the FAO AquaCrop model for soil water, soil evaporation, biomass and yield of soybeans in North China Plain. Agr. Water Manage. 152, 57-71.

Pereira, L.S., Paredes, P., Rodrigues, G.C., Neves, M., 2015. Modeling barley water use and evapotranspiration partitioning in two contrasting rainfall years. Assessing SIMDualKc and AquaCrop models. Agr Water Manage. 159, 239-254.

Raes, D., Steduto, P., Hsiao, T.C., Fereres, E., 2009. AquaCrop-The FAO crop model to simulate yield response to water: II. Main algorithms and software description. Agron. J. 101 (3), 438-447.

Raes, D., Steduto, P., Hsiao, T.C., Fereres, E., with contributions of the AquaCrop Network. 2012, reference manual chapter 2 of version 4.0, Rome, FAO.

Sabet, A.A., 2008. Simulation of plant growth and yield of rapeseed by plant models CRPSM and CropSyst under water stress treatments at different growth stages. MSc. Thesis in Irrigation and Drainage engineering, Agriculture Faculty, Shiraz University. 198p. (Text in Persian with English abstract)

Shabani, A., 2006. Effect of water stress on different growth stages of oilseed rape (Brassica napus). MSc. Thesis in Irrigation and Drainage engineering, Agriculture Faculty, Shiraz University. 213p. (Text in Persian with English abstract)

Shabani, A., Sepaskhah, A.R., Kamgar-Haghighi, A.A., 2013, Growth and physiologic response of rapeseed (*Brassica napus* L.) to deficit irrigation, water salinity and planting method. Int. J. Plant Prod. 7 (3), 569-596.

Soltani, A., Hoogenboom, G., 2007. Assessing crop management options with crop simulation models based on generated weather data. Field Crop Res. 103, 198-207.

Soltani, M., Maleki, M.H.M., Zeinali, E., 2014. Optimal crop management can reduce energy use and greenhouse gases emissions in rainfed canola production. Int. J. Plant Prod. 8, 587-604.

Steduto, P., Hsiao, T.C., Raes, D., Fereres, E., 2009. AquaCrop-The FAO crop model to simulate yield response to water: I. Concepts and underlying principles. Agron. J. 101 (3), 426-437.

Todorovic, M., Albrizio, R., Zivotic, L., Abi Saab, M., Stoekle, C., Steduto, P., 2009. Assessment of AquaCrop, CropSyst and WOFOST Models in the Simulation of Sunflower Growth under Different Water Regimes. Agron. J. 101, 509-521.

USDA. 2014. United States Department of Agriculture. Resourse site available at http://www.ers.usda.gov/topics/crops/soybeans-oil-crops/canola.aspx .(verified 14 April 2014).

Vanuytrecht, E., Raes, D., Willems, P., 2014. Global sensitivity analysis of yield output from the water productivity model. Environ Model Softw. 51, 232-332.

Wei, Z., Paredes, P., Liu, Y., Chi, W.W., Pereira, L.S., 2015. Modelling transpiration, soil evaporation and yield prediction of soybean in North China Plain. Agr. Water Manage. 147, 43-53.

Willmott, C.J. 1982. Some Comments on the Evaluation of Model Performance. B Am Meteorol Soc. 63, 1309-1313.

Xiangxiang, W., Quanjiu, W., Jun, F., Qiuping, F., 2013. Evaluation of the AquaCrop model for simulating the impact of water deficits and different irrigation regimes on the biomass and yield of winter wheat grown on China's Loess Platea. Agr. Water Manage. 129, 95-104.

Zeleke, K., Luckett, D., Cowley, R., 2011. Calibration and Testing of the FAO AquaCrop Model for Canola. Agron. J. 103, 1610-1618.