Agricultural Water Management 161 (2015) 136–146

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Evaluation of the AquaCrop model for barley production under deficit irrigation and rainfed condition in Iran

Ali Reza Tavakoli[a,*], Mehran Mahdavi Moghadam[b], Ali Reza Sepaskhah[c]

[a] Agricultural Research, Education and Extension Organization, Semnan Agricultural and Natural Resources Research center, Shahrood, Iran
[b] Department of Irrigation and Drainage, College of Aburaihan, Iran
[c] Department of Irrigation, College of Agriculture, Shiraz University, Iran

ARTICLE INFO

Article history:
Received 9 March 2015
Received in revised form 28 July 2015
Accepted 29 July 2015

Keywords:
AquaCrop
Deficit irrigation
Green canopy cover
Karkheh basin
Water productivity

ABSTRACT

The AquaCrop simulation model which has been developed by Food and Agricultural Organization (FAO) has the ability to assess the crop production under different irrigation water management. In this research, 2-year data of rainfed barley (2005–2007) from a research project at upstream of Karkheh river basin (Lorestan Province) were used to evaluate the accuracy of the AquaCrop model. The experimental treatments included: rainfed, one irrigation event at sowing time and one irrigation event at spring, that were performed in farmers' fields. The AquaCrop model was evaluated to predict the effect of deficit irrigation and rainfed conditions on yield, soil water content and percentage of green canopy cover. The mean normalized mean root square error for comparison between the measured and predicted values for canopy cover percentage, soil water content, and grain yield were 8.7, 12.4 and 9.2%, respectively, that showed good model accuracy. Efficiency of the model in yield estimation, soil water content and green canopy cover percentage were 0.91, 0.8 and 0.98, respectively. Agreement index for yield was close to 1.0 that showed compatibility of these predicted values with actual values. The results showed that the AquaCrop model is appropriate tool to simulate barley yield under rainfed and deficit irrigation conditions in the study area. This model is a suitable tool to determine sowing date in rainfed conditions based on first effective rain.

1. Introduction

Barley (*Hordeum vulgar* L.) is one of the important crops in irrigated and rainfed areas and it is one of the four important cereals of the world. Barley cultivated area, as the second important crop in Iran, is 1.5 million ha, 60% of which is rainfed (Ansari-Maleki, 2005). Due to its compatibility with various climatic conditions, its positive and valuable characteristics for human and animal feeds, and its importance in food industry, barley has always had a special place in agriculture throughout millenniums. Global production of barley during 2004 has been about 153.83 million tons (Anon, 2006). Referring to the 2009 report by Ministry of Jihad-e-Agriculture, in the crop year of 2008–2009, barley cultivation area in Iran was 1.6 million ha, of which 56.8% was rainfed and 43.2% was irrigated. Barley yield in Iran has been estimated as 3.45 million tons, and amount of yield per hectare in irrigated area is 3293 kg ha^{-1}, while in the rainfed conditions is 1.118 t ha^{-1} (Anon, 2009a).

The country of Islamic Republic of Iran receives approximately 413 bcm of water from precipitation per year, from which 296 bcm goes unutilized through evaporation and evapotranspiration. The climatic conditions in Iran are considered as arid and semi-arid, more than 80% of country is arid and semi-arid, extreme temperature of −20 to +50 degree Celsius is common. Its mean precipitation is about 246 mm, (with average between 50 mm and 2000 mm) which is less than the mean precipitation of the world (Anon, 2010). In addition, the annual potential evaporation in some parts is 20–40 times higher than the precipitation. Long term yield data indicate low barley yield, particularly in rainfed farms with the mean grain yield of 900–1000 kg ha^{-1} (Tahir et al., 1991). The reasons for this may be due to the fact that in cold and highland regions which include 30–40% of the rainfed barley area, mostly low yield is obtained. This low yield is due to susceptibility to frost, dryness, pests, diseases, and local cultivars with low yield potential (Anon, 2010).

The Improper distribution and low amount of precipitation are among general indices of rainfed regions; variations in these parameters cause a high risk, and make the production to change

* Corresponding author.
E-mail addresses: art.tavakoli@gmail.com (A.R. Tavakoli), mehran.mahdavi.moghadam@gmail.com (M. Mahdavi Moghadam), sepas@shirazu.ac.ir (A.R. Sepaskhah).

http://dx.doi.org/10.1016/j.agwat.2015.07.020
0378-3774/

over the different cropping years. Determination of yield variability owing to seasonal rainfall variations using conventional methods is not possible. An appropriate alternative is use of crop simulation models. By applying the crop growth simulation models, crop growth and yield could be simulated. These models could be used to evaluate farm management options and planning as well. Since the yield of rainfed agriculture and income is low and depend on the amount and distribution of precipitation; therefore, production management in rainfed agriculture and increasing the precipitation productivity is of great importance.

The AquaCrop model has been used for simulation of yields for various crops (Alizadeh et al., 2010; Andarzian et al., 2011; Farahani et al., 2009; Garcia-Vila et al., 2009; Geerts et al., 2009; Heng et al., 2009; Hsiao et al., 2009; Salemi et al., 2011; Tavakoli et al., 2010, 2014; Babazadeh and Sarai-Tabrizi, 2012).

Compared to other cereals, barley is usually more tolerant to moisture stress; however, in stem elongation and seed formation stages during its growth and development period, this crop is susceptible to water shortage, and moisture stress that would lead to decrease yield (Tavakoli, 2014). The most important method for determining the moisture stress tolerance in cereal breeding programs is evaluation of grain yield and its components in irrigated and stress conditions (Winter et al., 1988).

Salemi et al. (2011) during their research showed that by applying the AquaCrop model, water productivity for winter wheat was 0.91–1.49 kg m^{-3} that suggests a suitable compatibility. By a research in Karaj, Alizadeh et al. (2010) also showed that this model is able to simulate wheat evapotranspiration with relatively good accuracy with root mean square error of 9.4% and maximum error of 8.21%. After a research on soybean in Karaj, Babazadeh and Sarai-Tabrizi (2012) showed that this model has an acceptable performance in simulating crop yield, evapotranspiration and water productivity, and it can simulate the amount of evapotranspiration of the crop with an error less than 4%.

Moisture variations of the soil, evapotranspiration and other plant growth parameters are estimated by some models; therefore, the AquaCrop model is used for predicting the crop yield under rainfed and single-irrigation (in sowing time and spring) conditions, and based on these results crop management modification could be possible. The effect of different irrigation scheduling (time and amount) on the crop yield is predicted by this model. Although this model has been developed based on plant-physical process (Steduto et al., 2009), it requires a rather few simple and accessible parameters as input variables.

The aim of this study was to evaluate and test the AquaCrop model in conditions of rainfed, single-irrigation at sowing time, and spring single-irrigation for simulating rainfed barley yield with deficit irrigation in Selseleh area in Lorestan province, Iran.

2. Materials and methods

2.1. Theory of model

The AquaCrop model, like the CROPWAT program, is based on relationships between relative yield and relative evapotranspiration (Doorenbos and Kassam, 1979), as follows:

$$\left(\frac{Y_x - Y_a}{Y_x}\right) = K_y\left(\frac{\mathrm{ET}_x - \mathrm{ET}_a}{\mathrm{ET}_x}\right) \quad (1)$$

where, Y_x is the maximum yield, Y_a is the actual yield, ET_x is the maximum evapotranspiration, ET_a is the actual evapotranspiration and K_y is the yield response factor between relative yield decrease and relative evapotranspiration decrease.

The AquaCrop model simulates the soil water content in the root zone based on the water inflow and outflow, and it is a tool for understanding different application of irrigation management and efficient water use. The AquaCrop model (Raes et al., 2009) has continuous structure of soil, plant and atmosphere, and deals with four major components: soil, crop (growth, development, and yield), atmosphere (temperature regime, precipitation, evaporation requirement, and CO_2 density) and intersection relationships of environmental conditions, stresses and plant response (Raes et al., 2009) and field management (mulch, irrigation, fertilization, water salinity).

Conceptual and basic aspects of the model have been described by Steduto et al. (2009), and algorithm and how-to-use of the model has been explained by Raes et al. (2006) and Anon (2014). Measuring some agricultural parameters, i.e., the growth parameters of crop (biomass and grain) and the actual evapotranspiration at farm level is difficult; however, these can be predicted by using simulation models. Based on the required data as input, the model is calibrated by part of the data, and the remaining data is used for validation.

In this model, the Canopy Cover (CC) that covers the ground surface is used instead of Leaf Area Index (LAI), and the productivity index is used instead of the relative decrease of crop yield, and the Growing Degree Day Index is of particular importance (Steduto et al., 2009) in crop development.

The AquaCrop model was developed through differentiation of transpiration from evapotranspiration, expanding the growth model from initial growth to senescence, green canopy cover, estimation and prediction of yield as a function of the final biomass (B) and harvest index (HI), and eventually differentiation of the effects of water stress in four stages of the plant growth. Estimating the plant's transpiration would lead to differentiation of efficient and inefficient uses. Daily transpiration (Tr), through daily potential evapotranspiration (ETo) and normalized water productivity (WP*), is converted into plant biomass or aerial part of the plant as follows:

$$\mathrm{B}_i = \mathrm{WP}^* \left(\frac{\mathrm{T}_{ri}}{\mathrm{ETo}_i}\right) \quad (2)$$

where WP* is the normalized water productivity, and its value for a specific plant in similar climatic conditions is fixed (Hanks, 1983; Tanner and Sinclair, 1983), and after normalizing water productivity for different climatic conditions, its value would be turned into a fixed parameter (Steduto et al., 2007). The advantage of the Eq. (2) used in AquaCrop model is that simulation of plant growth procedures in this model is done through daily time-steps, while in Eq. (1) simulation is done based on monthly or seasonal time step and K_y coefficient. In the whole period of plant growing season, the amount of water stored in the root zone is simulated through balancing the inflow (the irrigation and precipitation water) and outflow waters (surface runoff, deep infiltration, and efficient and inefficient evapotranspiration) within the root zone development. Values of soil water stress coefficient (K_s) effective on expansion and development of chlorophyll content of the plant leaf, stomata conductance of transpiration (transpiration intensity in cc unit), senescence and canopy cover reduction, and harvest index are determined by deducting the water depletion in root zone. In addition, some managerial aspects and final yield of the crop are expressed according to irrigation management (timing, amount and method of irrigation) and limitations of soil fertility through their effect on the plant growth, water productivity and plant's adaptation to stresses.

2.2. Input and output of the model

The AquaCrop model was established based on complex biophysical processes (Steduto et al., 2009), but the input data of this model are relatively simple and accessible and include the following: