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Evaluation of some Estimation methods of Evapotranspiration to determination of yield for Maize and Wheat using AquaCrop

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Abstract
AquaCrop model was developed to simulate crop response to water consumption and irrigation management. The model is easy to use, works with limited input, and has acceptable accuracy. On the other hand, there are different methods for estimating evapotranspiration, whose performance is different in various climatic conditions. The purpose of this research is to investigate the effect of different methods to estimate evapotranspiration of the reference plant in various climates of Iran on estimating the yield of maize and wheat using AquaCrop. To fulfil the experiment, 40-year meteorological data (1980-2020) of five cities of the country (Urmia, Mashhad, Rasht, Qazvin, and Yazd) were used. First, evapotranspiration was estimated using the FAO-56 and five temperature and radiation methods daily. Then, the yield value of these two plants was simulated by AquaCrop and compared with the FAO-56 by error statistical criteria determination coefficient (R^2), normal root means square error (NRMSE) and Nash-Sutcliffe index (NS). According to the results, among the two temperature methods Blaney-Criddle method with the NRMSE is in the range of 0-20%, R^2 and Nash-Sutcliffe are, close to the optimal value of one for maize and wheat in parameter simulation are acceptable. About radiation methods, the Priestley-Taylor and the Turc methods in simulation of maize yield. Also about radiation methods for wheat, the Turc and the Makkink method for simulation of yield are desirable.

Introduction

The severe reduction of water resources, climate changes and the subsequent policies to reduce the water allocated to the agricultural sector have made the management of water consumption in this sector of special importance. Water management use in agriculture is impossible without paying attention to the relationship between water, soil and plants. Because field experiments require spending time, money and energy, and also due to the limitation of these experiments to the physical conditions of the farm, the short duration of the experiment, and the limitation in the number of scenarios that are examined by the experiment, the use of models and software in water and soil relations have been developed (Russo and Bakker, 1986). The AquaCrop model is a plant model that is developed by FAO.

Also, evapotranspiration is one of the main components of the hydrological cycle. The correct estimation is more important for the design and management of irrigation systems, studies of water resources, and other similar cases. Due to the importance of evapotranspiration and its various applications in different sciences, calculating its amount, especially potential and actual evapotranspiration, are of great importance. In the field of calculating evapotranspiration and the effect that different calculation methods have on yield, biomass, and net irrigation water requirement, many studies have been conducted in the world including Iran. Based on the results of a study conducted by Safari et al. (2022) to calibrate and modify the coefficients of the equation for estimating evapotranspiration on four synoptic stations in Iran with arid, semi-arid, humid, and semi-humid climates, the Blaney-Criddle method was selected as the superior method for calculating ET at all four climates. In another study, three methods (Blaney-Criddle, Thorent-White, and Hargreaves-Samani) were compared to estimate the potential ET in Omidieh city. Standard error with the FAO-56 method was more accurate in estimating potential evapotranspiration (Asareh and Davoudi, 2014).

Abdollahzadeh et al. (2019) determined the actual evapotranspiration rate and net irrigation water requirement of wheat, barley and maize in Moghan plain by the AquaCrop model and compared the results with the CropWat and the NetWat models. Based on the results, evapotranspiration and water requirement of the AquaCrop model are lower compared to the CropWat and the results are higher than the NetWat for wheat and maize and less for barley. In a study, Meban et al. (2013) confirmed the effectiveness of the AquaCrop model on maize in Pennsylvania, they reported that the AquaCrop model overestimated for simulation of evapotranspiration of maize and the reason for this overestimation is related to errors in estimating hydraulic factors included FC and WP. Also in simulation of evapotranpiration of maize with the AquaCrop under different texture and soil fertility conditions was reported that the model had moderate efficiency in this field. The efficiency of the model in simulation of evapotranspiration of maize in loam soil was better than the two textures of silty-clay-loam and sandy-loam and the efficiency of the model decreased with the application of fertility stress (Ghorbanian Kurd Abadi et al., 2015). Also, the AquaCrop model for sunflower in Khuzestan province was studied and the results showed that this model simulates crop yield with high accuracy (Haydarinia et al., 2012). This model for maize in Qazvin region was calibrated by Rahimi Khoob et al. (2014). Based on their results, the average model error was determined to be about 10%.

In a study conducted by Jorenush et al. (2019) to simulate wheat yield and determine the date of cultivation in Fars province by the AquaCrop, the results showed that the model has high accuracy in simulation of canopy cover, biomass and grain yield of wheat. The results of a study in Delhi, India showed that the AquaCrop model has acceptable accuracy in simulation of grain yield, biomass and water use efficiency in cultivars of resistant and non-resistant wheat to salinity. In this study, it was found that the ability of the model to simulate performance is more than the other two parameters (Kumar et al., 2014).

The purpose of this research is to evaluate the AquaCrop model in the simulation of maize and wheat yield and to investigate the effect of different estimation methods of evapotranspiration in this simulation. Considering that limited studies have been conducted in this regard in the world, the evaluation of the AquaCrop model, as a plant model, in the climatic conditions of Iran is one of the innovations of this research.

Materials and Methods

In this research, Iran was classified into 4 different climates based on the Köppen climate classification (arid, humid, semi-arid and semi-humid) and the cities of Yazd, Rasht, Mashhad, Qazvin and Urmia as the representatives of this climate, respectively, selected and their meteorological data were used. The characteristics of meteorological stations are presented in Table (1).

The equations used to estimate of reference evapotranspiration in this study are from temperature groups: Hargreaves-Samani (H.S) and Blaney-Criddle (B.C) and the radiation group: Priestley-Taylor (P.T), Turc (T) and Makkink (Mak) were selected. The original form of the equations is presented in Table (2).

Reference evapotranspiration data as model inputs are required to run the AquaCrop model. For this purpose, meteorological variables received: maximum and minimum air temperature, maximum and minimum relative humidity, sunny hours, rain and wind speed at a height of two meters above the ground from Urmia, Rasht, Qazvin, Mashhad and Yazd stations from 1980/1/1 to 2020/12/31 and reference evapotranspiration was calculated by the methods mentioned in the table above (Tables 3).

Due to the insufficiency of lysimetric data, the FAO-Penman-Monteith (FAO-56) method, due to its high accuracy in estimation of reference evapotranspiration, is used to estimate observatory data and validation.

Introducing the AquaCrop model

The basis for estimating crop performance in the AquaCrop model is the Doorenbos-Kassam relationship, which is presented in issue 33 of the Food and Drainage Journal of the Wirld Food Organization (FAO). Modifications such as the separation of actual evapotranspiration (ET) evaporate from the soil surface (Es) and transpiration (Ts), as well as yield to biomass (B) and harvest index (HI) have been inferred (Raes et al., 2012):

$$\left(1-\frac{Y}{Y_x}\right)=K_y\left(1-\frac{ET}{ET_x}\right) \quad (1)$$

Where Y_x: maximum yield, Y: actual yield, ETx: maximum evapotranspiration, ET: actual evapotranspiration, and Ky is the ratio between the relative decrease in yield and evapotranspiration. Model inputs include four categories of meteorological, plant, management, and soil information.Table (4) shows the required data for each section.

Table 1- Details of meteorological stations studies

Station	Climate	Latitude	Longitude	Elevation (m)
Urmia	semi-humid	37° 40´	45° 3´	1328
Rasht	humid	37° 19´	49° 37´	-8.6
Mashhad	semi-arid	36° 16´	59° 38´	999.2
Qazvin	semi-arid	36° 16´	50° 0´	1279.1
Yazd	arid	31° 54´	54° 17´	1237.2

Table 2- Equations used in research

Number	name of Eq.s	Equation form	Reference
1	FAO-56	$ET_O=\frac{0.408\Delta(R_n-G)+\gamma(\frac{890}{T+273})U_2(e_a-e_d)}{\Delta+\gamma(1+0.34U_2)}$	Allen et al., 1998
2	Hargreaves-Samani	$ET_O=0.0023R_a\sqrt{T_{max}-T_{min}}(T_{mean}+17.8)$	Hargreaves and Samani., 1985
3	Blaney-Criddle	$ET_O=a+b(P(0.46T_{mean}+8.13))$	Blaney and Criddle., 1950
4	Priestley-Taylor	$ET_O=1.26(\frac{\Delta}{\Delta+\gamma})(\frac{R_n-G}{\lambda})$	Priestley and Taylor., 1972
5	Makkink	$ET_O=0.61\left(\frac{\Delta}{\Delta+\gamma}\right)\left(\frac{R_s}{2.45}\right)-0.12$	Makkink, .1957
6	Turc	$ET_O=0.013\frac{(23.89R_s+50)T_{avg}}{(T_{avg}+15)}$	Turc., 1961

Table 3- Average of 40-years data climate in each stations

Station	Tmax (°C)	Tmin (°C)	Wind speed (m/s)	Rain (mm)	Umax (%)	Umin (%)	Sunny hours (hour)
Urmia	18.01	5.29	1.88	293.36	78.72	39.40	7.99
Rasht	21.05	12.51	1.25	571.67	96.13	65.75	4.70
Mashhad	22.09	8.70	2.33	148.96	70.58	33.33	8.02
Qazvin	21.45	7.09	5.93	226.11	75.02	31.49	5.78
Yazd	27.24	17.43	2.42	25.22	43.61	17.53	9.09

Table 4- AquaCrop model input data.

AquaCrop model inputs			
Soil data	Management data	Crop data	Climate data
Soil profile	Irrigation management	Fixed parameters	Precipitation
Groundwater	Field management	User specific parameters	Minimum temprature
			Maximum temprature
			Daily potential evapotranspiration (ET_P)
			Concentration of carbon dioxide in the atmosphere (CO_2)

The most important climatic data required for the model are minimum, maximum and average daily temperature, reference plant evapotranspiration (ET_o) and precipitation. The model uses maximum and minimum daily temperature data to calculate the degree of growth day to moderate biomass crop due to frost damage. Data on daily temperature, daily precipitation and all the information needed to calculate ET_o from data of 1980-2020 in Qazvin, Rasht, Urmia, Mashhad and Yazd stations and ET_o Calculated by the methods mentioned in Table (2).

Statistical evaluation criteria

In this study, the results of the scenarios with the data of the mentioned stations for two maize and wheat crops, by error statistical criteria including determination coefficient (R^2), normal root mean square error (NRMSE) and Nash-Sutcliffe index (NS) were compared.

Explanation coefficient is one of the most important criteria for evaluating the relationship between two variables x and y, which is displayed dimensionless. This coefficient is directly related to the correlation coefficient. In this way, by taking the square root of the determination coefficient, the correlation coefficient between the two series can be obtained. As with the correlation coefficient, the closer the value of the coefficient of explanation is to one, the stronger the relationship between the two variables. If the determination coefficient is multiplied by 100, the value obtained represents the variance of the variable x, described by the variable y. The Pearson coefficient classification is given in Table (5) (Joinior et al., 2017).

Excel software was used to calculate the explanation coefficient. The NRMSE index indicates the level of estimation. The NRMSE classification by Jamieson et al. (1991) is given in Table (6) (Jamieson et al., 1991).

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

Table 5- Classificatin of Pearson coefficient.

R^2	0.1>	0.1-0.2	0.2-0.5	0.5<
Estimation result	Not correlated	Weak	Moderate	Strong

Table 6- Classification of simulation results based on NRMSE

NRMSE (%)	0-10	10-20	20-30	>30
Estimation result	Excellent	Good	Moderate	Weak

The Nash-Sutcliffe coefficient is one of the most common indicators used to evaluate the performance of hydrological models (Nash and Sutcliffe, 1970). This standard state index is a function of the least-squares error:

$$NS = 1 - \frac{\sum_1^N (ET(Sim) - ET(Obs))^2}{\sum_1^N (ET(Obs) - \overline{ET(Obs)})^2} \quad (3)$$

The range of changes of this index is from -1 to +1 and the optimal value of this index is one. Based on various studies in this field, as the studies of Gassman et al. (2007), if the value of the Nash-Sutcliffe coefficient is higher than 0.5, it has a good simulation model.

Results and Discussion

In this study, yield of maize and wheat were simulated with the AquaCrop model and the effect of different methods of estimation of ET on this parameter was evaluated. In the following, the statistical study of these two parameters in wheat and maize are discussed separately.

Maize

The results of evaluating the yield of datasets with synoptic stations from 1980 to 2020 for maize are presented in Figures (1) to (5). Based on the results of the temperature methods, Blaney-Criddle method in Urmia station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99, Rasht station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99, Mashhad station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99, Yazd station with R^2 equal to 0.98, excellent NRMSE and Nash-Sutcliffe index of 0.99 and in Qazvin station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99 are the priority for simulation and evaluation of the yield of maize. About the radiation methods, the Turc method in Urmia station with R^2 equal to 0.99, excellent NRMSE (0.49) and Nash-Sutcliffe index of 0.99 and Rasht station with R^2 equal to 0.99, excellent NRMSE (0.2) and Nash-Sutcliffe index of 0.99 are the priority for simulation yield of maize. Priestley-Taylor method in Mashhad station with R^2 equal to 0.99, excellent NRMSE (1.28) and Nash-Sutcliffe index of 0.99 and in Qazvin station with R^2 equal to 0.99, excellent NRMSE (2.89) and Nash-Sutcliffe index 0.99 is the priority. Also, the Turc method in Yazd station with R^2 equal to 0.97, excellent NRMSE (2.46) and Nash-Sutcliffe index 0.99 is the priority for simulation and evaluation yield of maize.

According to a study evaluated radiation and humidity methods for estimation of reference evapotranspiration in Golestan province, showed that Makkink, Turc, Jensen-Haise and radiation methods, respectively, have a good daily estimation of ETo and humidity methods will have good results if they are corrected (Sharifian et al., 2005). As a result of the research conducted in India with the accuracy of AquaCrop, it was reported that the acceptable model simulated biomass, grain yield and water consumption efficiency of maize in different regimes of irrigation water and nitrogen fertilizer. The best prediction of the model was made in the treatment of full irrigation and consumption of 150 kg/ha of pure nitrogen (Abedinpour et al., 2012). Also, in another study in the center of Portugal, this model predicted maize evapotranspiration, soil water balance, biomass, and yield in fully irrigated and under-irrigated conditions with high accuracy (Paredes et al., 2014).

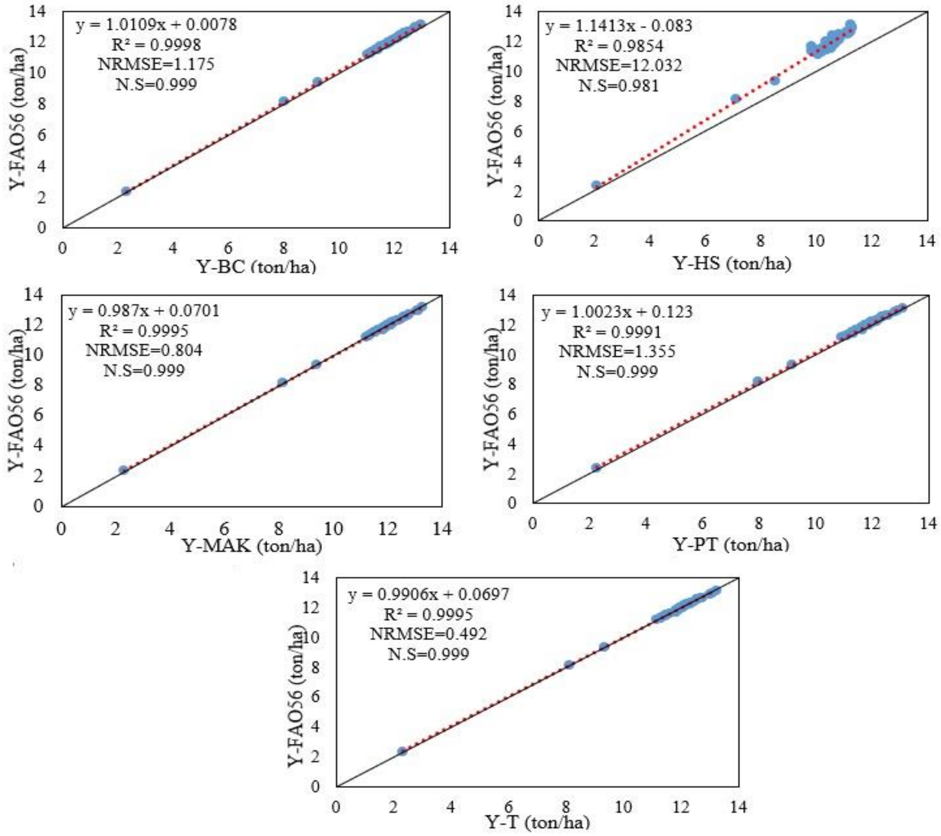

Fig. 1- Comparison of maize yield simulated by the FAO-56 method and different methods of estimation of ET in Urmia station.

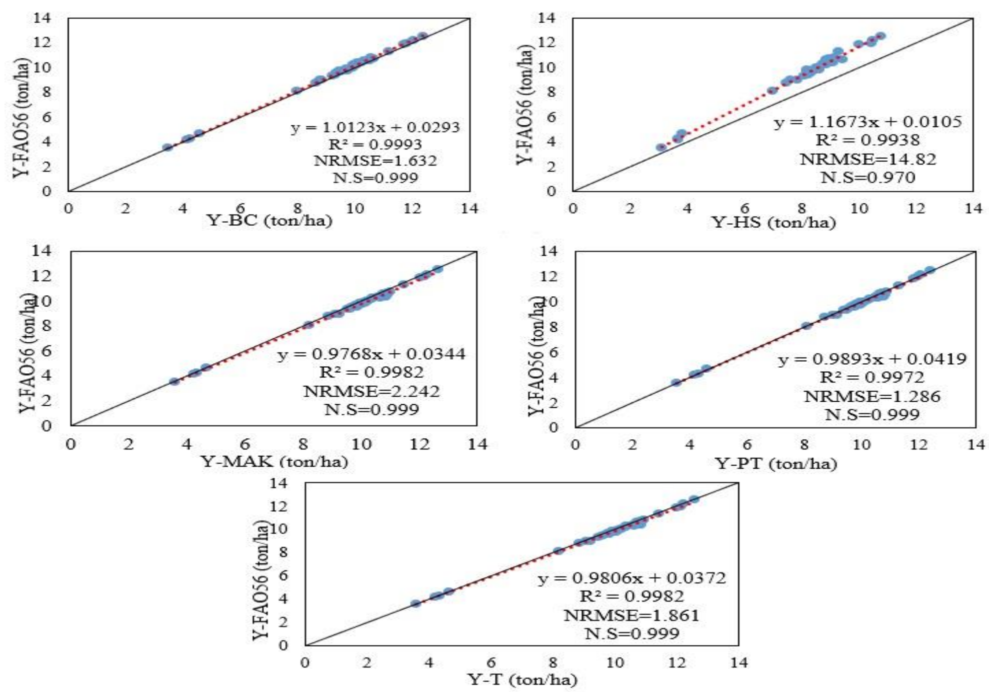

Fig. 2- Comparison of maize yield simulated by the FAO-56 method and different methods of estimation of ET in Mashhad station.

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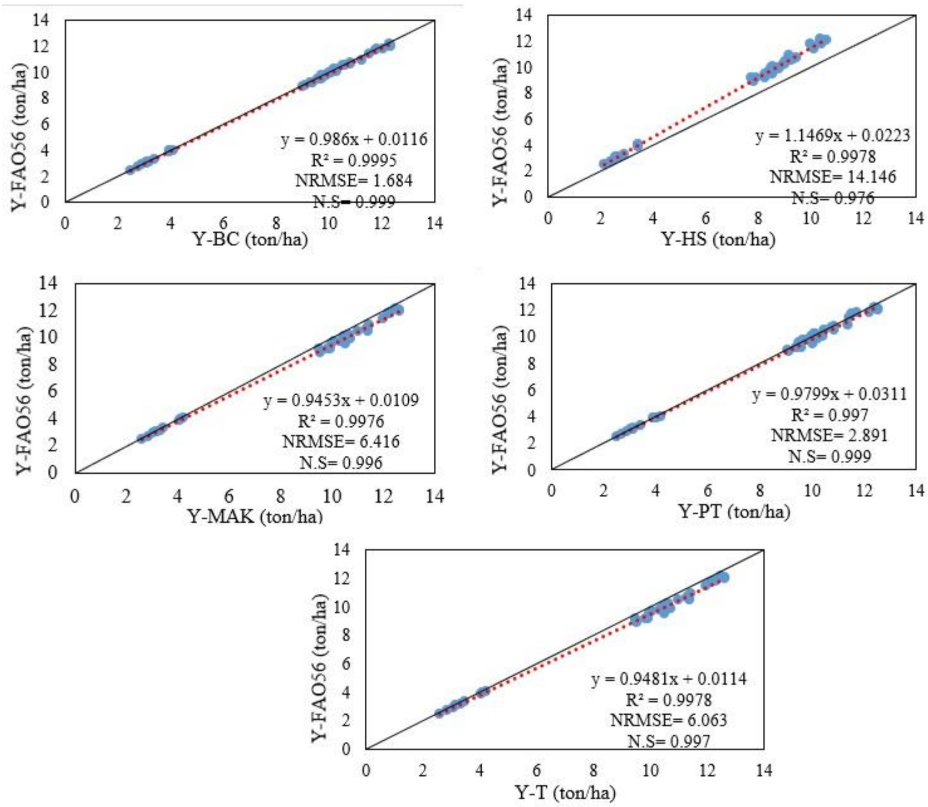
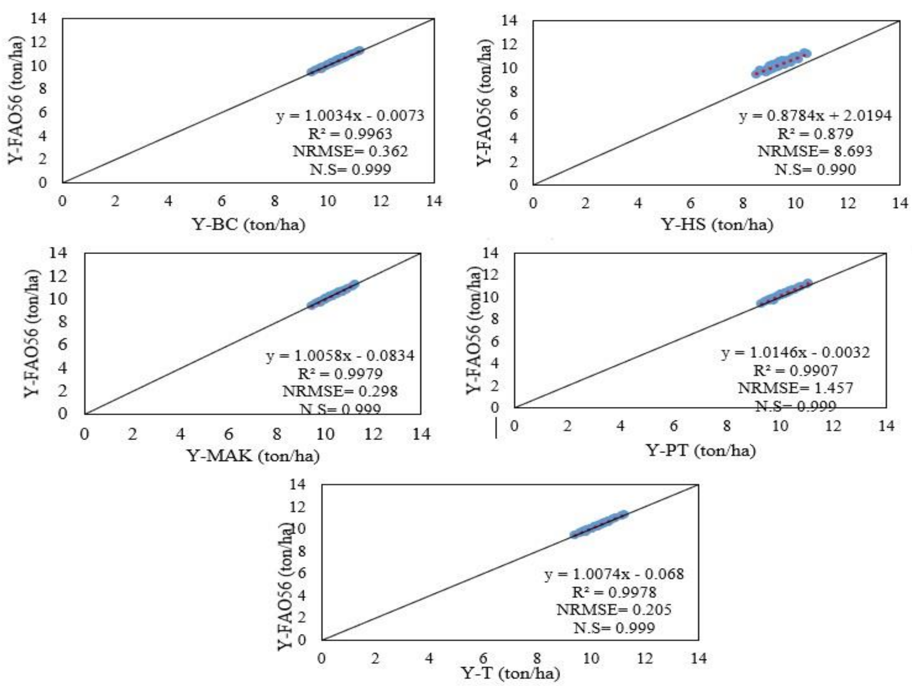


Fig. 3- Comparison of maize yield simulated by the FAO-56 method and different methods of estimation



of ET in Qazvin station.

Fig. 4- Comparison of maize yield simulated by the FAO-56 method and different methods of estimation of ET in Rasht station.

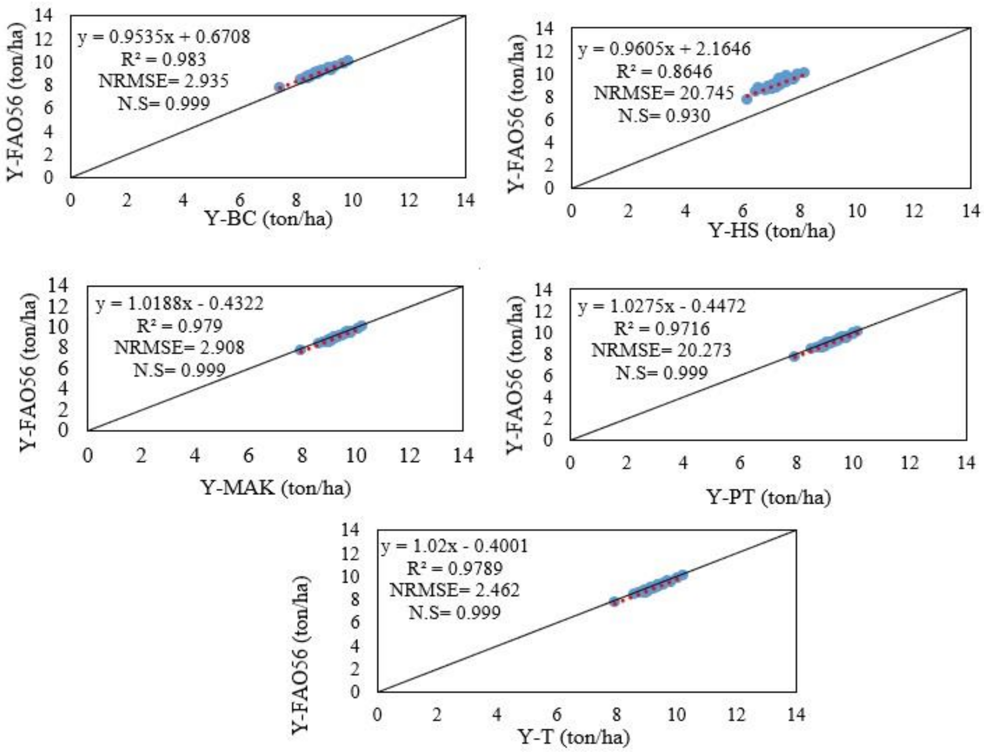


Fig. 5- Comparison of maize yield simulated by the FAO-56 method and different methods of estimation of ET in Yazd station.

Wheat

The results of evaluating the yield of datasets with synoptic stations from 1980 to 2020 for wheat are presented in Figures (6) to (10). Based on the results of the evaluation of wheat, among the temperature methods, the Blaney-Criddle method in Urmia station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99, Rasht station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99, Mashhad station with R^2 equal to 0.98, excellent NRMSE and Nash-Sutcliffe index of 0.99, Yazd station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99 and in Qazvin station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99 is the priority for simulation and evaluation of yield of wheat.

Among the radiation methods, the Turc method in Urmia station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99 and Makkink method in Rasht station with R^2 equal to 1, excellent NRMSE and Nash-Sutcliffe index of 1 is the priority for simulation of the yield of wheat. Makkink method in Mashhad station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index 0.99 and in Qazvin station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index 0.99 is the priority. Furthermore, the Turc method in Yazd station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99 is the priority for simulation and evaluation of the yield of wheat. In general, the Blaney-Criddle is a good method for the simulation of yield. Also, about radiation methods, Makkink and Turc methods are suitable for the simulation of yield of wheat in all the investigated stations.

Pashakhah et al. (2014) examined the reference evapotranspiration by the Blaney-Criddle, Hargreaves and Thorent-White methods for different climates of Iran based on the UNESCO climate in comparison with the FAO-56 standard method. Their results showed that the Blaney-Criddle method has the best estimation in arid, semi-arid and humid climates. The results of this study remarked that in the studied climates, due to the lack of access to the required data, it is not possible to estimate the reference evapotranspiration by the FAO-56 method, using the calibrated equations can be made similar estimates.

Iqbal et al. (2014) calibrated the AquaCrop version 1/3 of the winter wheat crop in the North China Plain. The results showed that the biomass yield under different irrigation conditions is estimated with appropriate accuracy by the model. The AquaCrop model has been evaluated for several products and some regions of Iran. This model provided acceptable results for predicting wheat and soybean yield in low irrigation conditions in Karaj region (Alizadeh et al., 2010; Babazadeh and Sarai Tabrizi, 2012). The results of a study conducted in Zahedan synoptic station showed that methods based on mass transfer had showed the statistically weakest performance compared to other methods with the standard method of the FAO-56; But temperature and radiation methods such as Turc, Jensen-Haise, Hargreaves and Blaney-Criddle methods can be a good alternative to the relatively complex FAO-56 hybrid method for the hot and dry climate of Zahedan (Kahkhamoghadam, 2017). Based on these studies, the results obtained in this research can be mentioned.

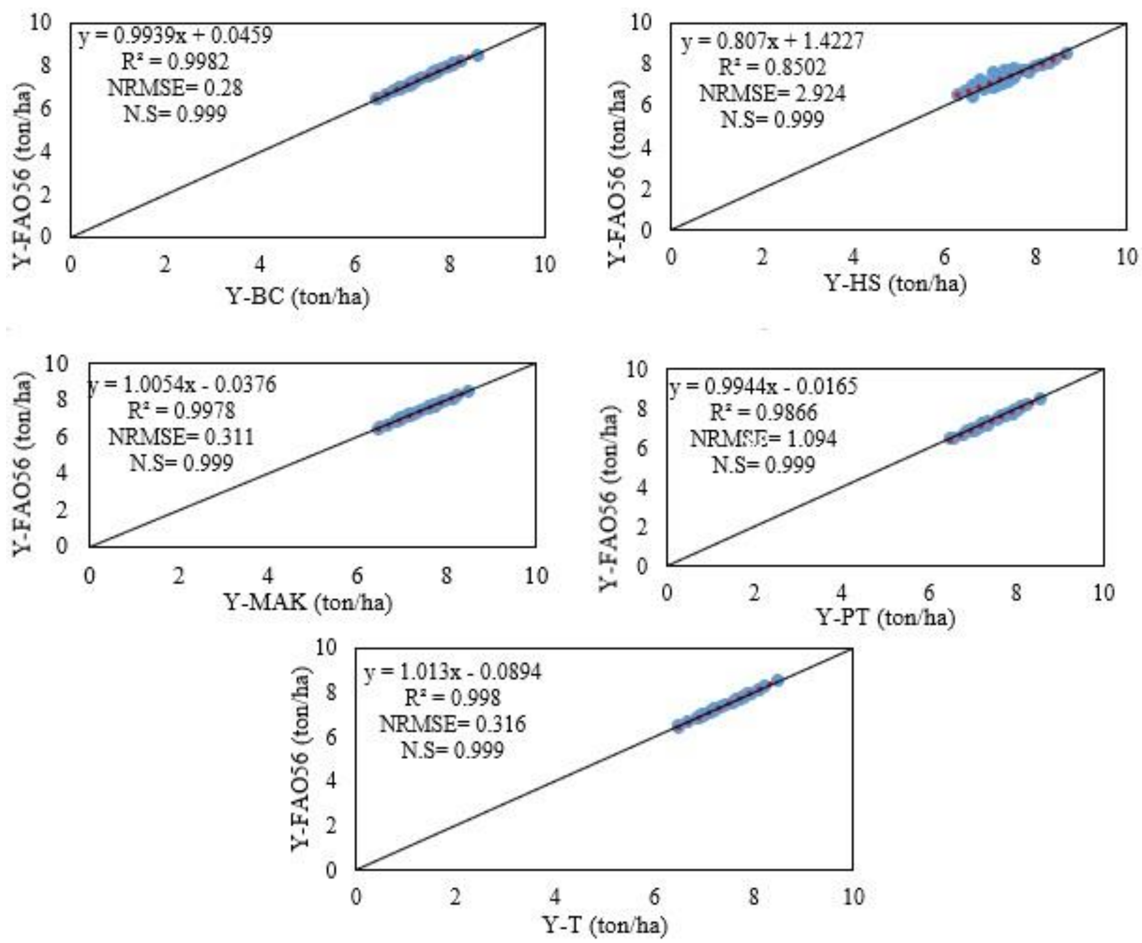


Fig. 6- Comparison of wheat yield simulated by the FAO-56 method and different methods of estimation of ET in Urmia station.

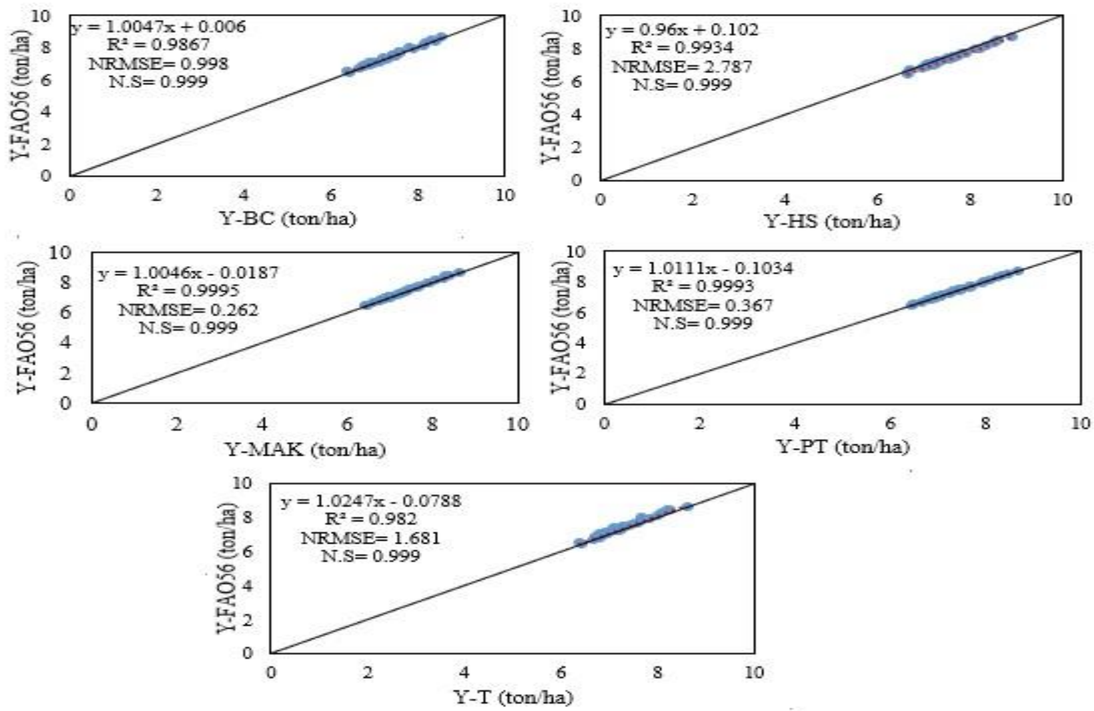


Fig. 7- Comparison of wheat yield simulated by the FAO-56 method and different methods of estimation of ET in Mashhad station

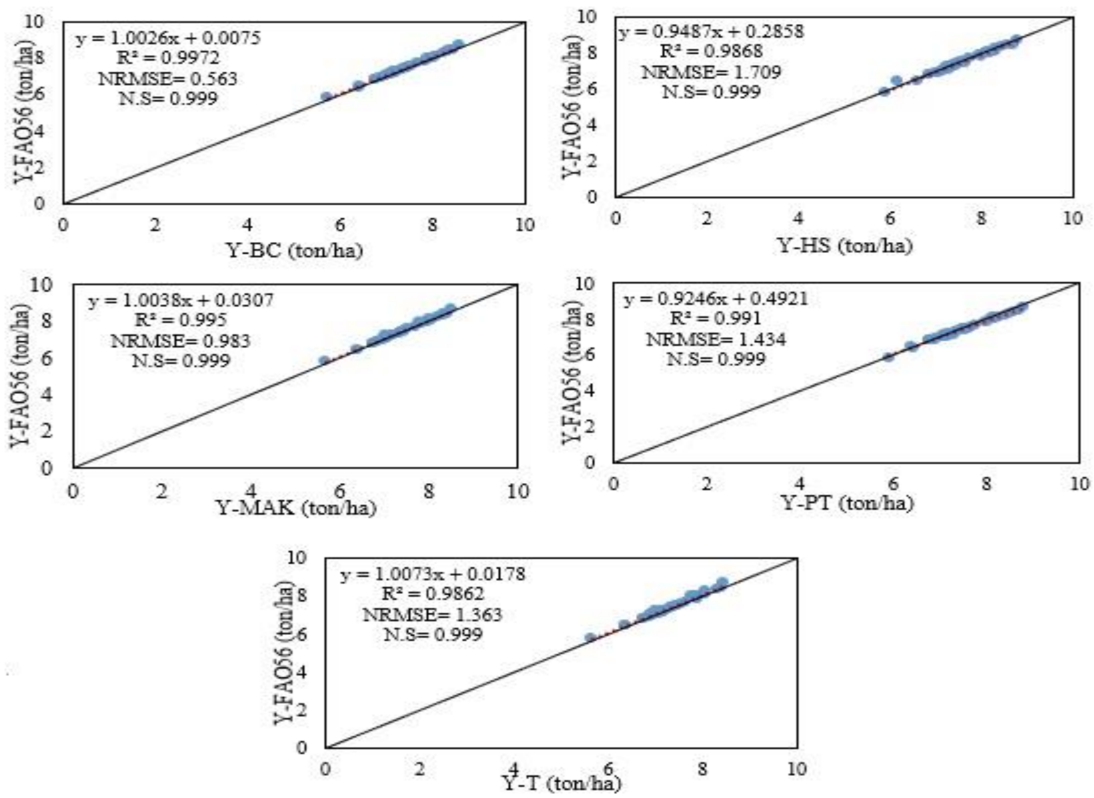


Fig. 8- Comparison of wheat yield simulated by the FAO-56 method and different methods of estimation of ET in Qazvin station.

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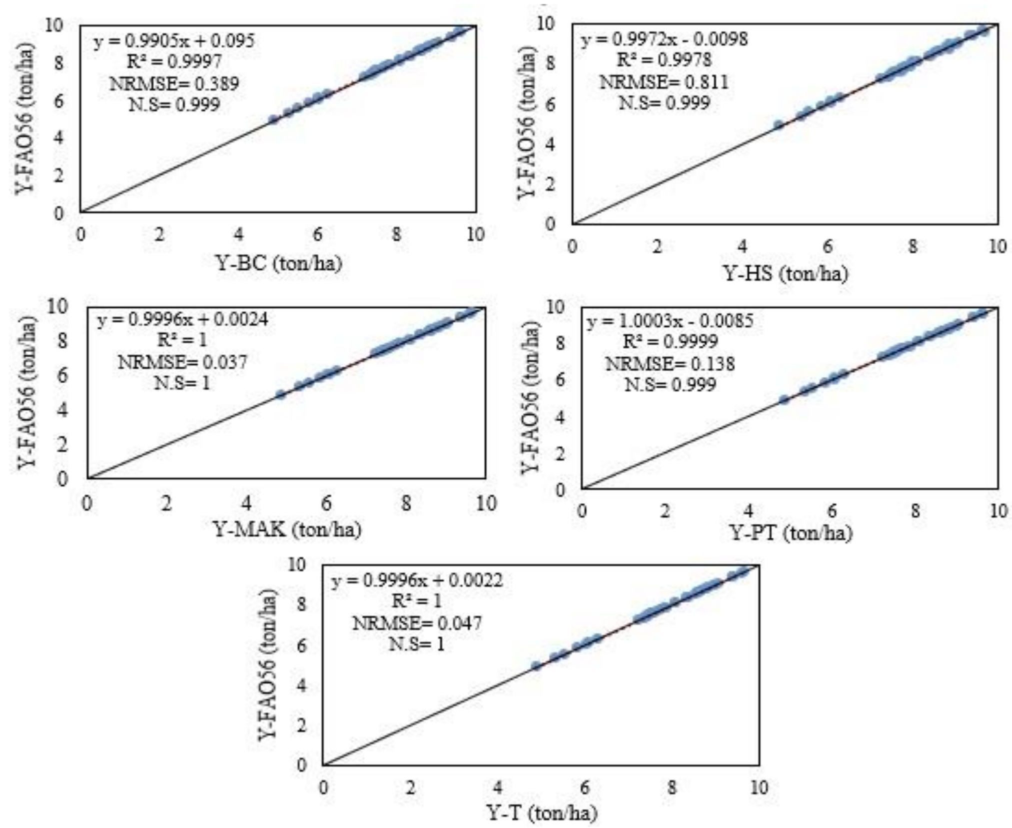

Fig. 9- Comparison of wheat yield simulated by the FAO-56 method and different methods of estimation of ET in Rasht station.

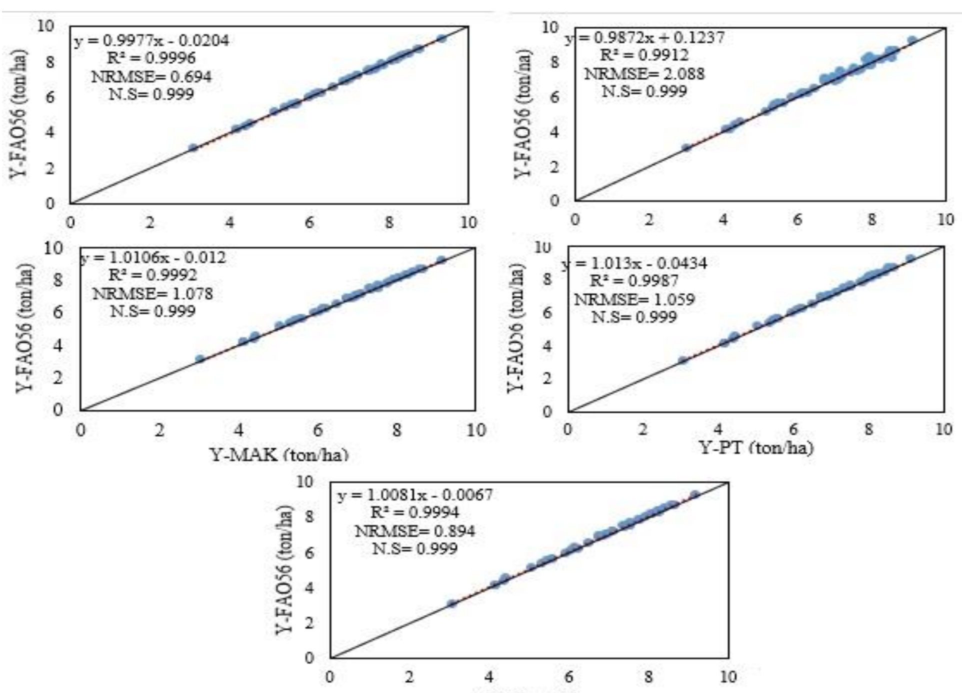

Fig. 10- Comparison of wheat yield simulated by the FAO-56 method and different methods of estimation of ET in Yazd station.

Conclusion

Evaluation of the AquaCrop model for common plants in a region plays an important role in comparing crop yield in different conditions. Wheat and maize are important crops in Iran. In this research, the ability of the AquaCrop model to simulate wheat and maize yields and the effect of different methods of evapotranspiration estimation in five cities of Iran were investigated. Based on the results of model accuracy to simulation, between the two temperature methods Blaney-Criddle method with the NRMSE is in the range of 0-20%, R^2 and Nash-Sutcliffe are close to the optimal value of one for maize and wheat in parameter simulation are acceptable. About radiation methods, the Priestley-Taylor and the Turc methods in simulation of maize yield. Also about radiation methods for wheat, the Turc and the Makkink methods for simulation of yield are desirable.

In general, among the investigated methods, the Blaney-Criddle method as a temperature method and the Turc method as a radiation method are suitable for simulating yield in these areas and provide acceptable results.

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