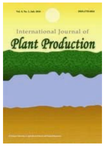

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Modification of the saffron model for growth and yield prediction under different irrigation water salinity, manure application and planting methods

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Abstract

The Saffron Yield Estimation Model (SYEM) was modified for salinity conditions, cow manure application and planting methods using two-year experiments data in Badjgah region of Iran. A split-split plot arrangement was conducted in complete randomized block design during two years with irrigation water salinity levels (0.45 (fresh water, S_1), 1.0 (S_2), 2.0 (S_3) and 3.0 (S_4) dS m^{-1}) as the main plot, cow manure levels (30 (F_1) and 60 (F_2) Mg ha^{-1}) as the sub plot and planting method (basin (P_1) and in-furrow (P_2)) as the sub-sub plot in three replications. Data of the second and first growing season were used to calibrate and validate the modified model, respectively. In the modified SYEM model, the soil salinity was estimated. Based on the NRMSE and d indices, the modified SYEM model presented a very good to fair estimation of actual evapotranspiration, evaporation, transpiration, soil water content and salinity, leaf dry matter, corm and saffron yields. The advantage of this model is its simplicity and easy calibration in other climate conditions for saffron crop. Prediction of saffron yield by this model can be used for better irrigation salinity management under different manure application levels and planting methods.

Keywords: Evapotranspiration; Manure application; Saffron modeling; Saline water; Saffron yield; Planting method.

Introduction

Accurate prediction of crops yield is necessary for better management of agricultural systems especially in arid and semi-arid regions. Modeling is one of the useful tools to achieve this goal to reduce administrative costs and to predict crops yield in different environmental conditions. Irrigation by using saline water is a common practice in arid and semi-arid areas, even though it may cause a decrease in crops yield and progressive soil salinization. Therefore, crop models have been developed in order to determine the most suitable irrigation strategy for higher yield, profitability and soil salinity management of certain crops. Furthermore, there are many variables such as soil conditions, soil nutritions, planting methods which have significant influence on yield and crops growth. However, studying the interaction effects of all variables is not possible. In this condition, models application is the best way to characterize and quantify the effects of different variables on crop growth and yield.

Different models have been developed to evaluate crops yield and their growth under different environmental conditions, management practices and considering effects of many variables on crops, all around the world. Many researchers have modeled the behavior of crops when undergoing water or salt stresses. For example, Allen et al. (1998) related actual crop evapotranspiration (ET_a) to soil water and soluble salts content in the root zone. Inputs of this model were the readily available soil water in the root zone (RAW) and the depletion factor (p). Pereira et al. (2007) developed a model which allowed balancing the values of RAW and p depending on the variable soil salinity conditions.

SALTMED model as an integrated model can simulate water and salt distribution in the soil profile, nitrogen transfer in the soil, leaching requirements, yield and crop growth by considering soil types, crops, irrigation systems and scheduling and different water qualities (Ragab, 2002). A simple model was developed to predict dry matter, seed yield and other crop parameters of rapeseed under deficit irrigation and salinity by using soil water and salt budget and other plant physiological relationships by Shabani et al. (2015). Azizian et al. (2015) modified the Maize Simulation Model (MSM) for predicting maize growth and yield under saline water application at different levels of irrigation water and N fertilizer in furrow irrigation.

The soil water budget and relationships for evapotranspiration partitioning, leaf area index and transpiration function was used to develop the simple models for growth and yield production of cowpea under soil water stress (Sepaskhah and Ilampour, 1996; Sepaskhah et al., 2006b) and for sugar beet, winter wheat and sweet maize under soil water and salt stress (Sepaskhah et al., 2006a).

Saffron (*Crocus sativus* L.) is a strategic export crop and the most expensive spice in the Islamic Republic of Iran. Because of saffron low water requirement and high income it should be considered in sustainable agriculture. Effects of planting methods and corm density (Behnia, 2009), chemical and organic fertilizers (Arslan et al., 2009; Omidi et al., 2009), corms weight and size (Nassiri-Mahallati et al., 2007) and effects of salinity, irrigation regimes, fertilizer levels and planting methods (Sepaskhah and Yarami, 2009; Yarami and Sepaskhah, 2015a; Yarami and Sepaskhah, 2015b) on yield and physiological growth of saffron and evaluation of toxic and essential ions uptake by saffron in different conditions (Yarami and Sepaskhah, 2016) have been investigated. Sepaskhah et al. (2013) developed a model for growth and yield prediction of saffron under various irrigation regimes. The effective usage of limited water resources and application of saline water for irrigation in arid and semiarid regions requires an appropriate irrigation management and management tools such as crop models. However, using simple approach to model saffron yield under salinity stress and other management conditions such as manure application levels and planting methods has not been studied yet.

Therefore, the objective of this study was to modify the model developed by Sepaskhah et al. (2013) for predicting saffron growth and yield under saline water application at different cow manure levels and planting methods by using soil water budget and other simple relationships for evapotranspiration partitioning, leaf area index determination and leaf dry matter-transpiration function, corm-transpiration function and saffron-corm function.

Materials and Methods

Field experiments

The data of this investigation were obtained from two years experiment in 2011-2012 and 2012-2013 that were conducted at Experimental Station of Agricultural College, Shiraz University located in Badjgah region at 29° 56' N, 52° 02' E and 1810 m above the mean sea level, in southwest of Iran with a semi-arid climate. Long-term average air temperature, relative humidity and precipitation of the region are 13.4 °C, 52.2% and 387 mm, respectively. A split-split plot arrangement was conducted in complete randomized block design during two years with irrigation water salinity levels (0.45 (fresh water, S_1), 1.0 (S_2), 2.0 (S_3) and 3.0 (S_4) dS m^{-1}) as the main plot, cow manure levels (30 (F_1) and 60 (F_2) Mg ha^{-1} for first growing season and 15 and 30 Mg ha^{-1} for the second growing season that were applied at the beginning of each growing seasons) as the sub plot and planting method (basin (P_1) and in-furrow (P_2)) as the sub-sub plot in three replications. Saline water was obtained by addition of NaCl and $CaCl_2$ to the fresh water, in equal equivalent proportion. Details of the experiment were described by Yarami and Sepaskhah (2015a), Yarami and Sepaskhah (2015b) and Yarami and Sepaskhah (2016).

Soil water content at 0.3, 0.6 and 0.75 m depths was measured with neutron scattering method before each irrigation event. During periods with no sufficient rain, irrigation water was applied at 24 days interval that is the best interval for saffron irrigation in the study area (Azizi-Zohan et al., 2009). Total amount of irrigation water applied was 207 and 263 mm for the first and second growing seasons, respectively. Total rainfall was also 363 and 445 mm during the growing periods in 2011-2012 and 2012-2013, respectively.

Reference evapotranspiration (ET_o) was calculated using modified Penman–FAO equation for semi-arid environments in the study area (Razzaghi and Sepaskhah, 2012). The actual crop evapotranspiration for the time intervals between measurements of soil water content was estimated by the water balance procedure as follows:

$$ET = I + P - Dp \pm \Delta S \tag{1}$$

Where I is the irrigation depth (mm), P is the precipitation (mm), Dp is the deep percolation (mm) from the bottom of root zone and ΔS is the variation of soil moisture in root depth (mm). Evaporation (E) from the soil surface was measured by using microlysimeter. During two growing seasons, soil samples of each 0.30 m increment, up to 0.9 m depth, were taken for chemical analysis, including electrical conductivity of soil saturation extract (EC_e) using the method described by the U.S. Salinity Laboratory (Richards, 1954).

During flowering periods, flowers were harvested every morning from the entire plot. Then, the style and stigmas were separated from flowers and air dried in a room shadow environment. At the end of flowering periods, total weight of style and stigmas (as saffron yield) were determined. Furthermore, at the end of each growing season, after leaf senescence, leaves were harvested from two rows in the middle of plots to determine the leaf dry matter yield. Corm samples were also collected from one row of each experimental plot in June 2012 and 2013 (Yarami and Sepaskhah, 2015a).

Leaf dry matter of saffron was determined in different days after first irrigation in the first and second growing seasons. To determine dry matter, the samples were taken from 0.30 m of one row of each plot and then were dried at 70 °C for 48 h and weighted. Based on dry matter measurements, saffron leaf area (LA) was calculated by the following equations (Shirmohammadi-Aliakbarkhani, 2002):

$$LA = 31.797W + 112.56 \quad (2)$$

Where LA and W are leaf area (cm^2) and leaf dry matter (g), respectively. Leaf area index (LAI) was determined by dividing of the leaf area (LA) by the ground surface area that is covered by plant (i.e. multiplication of the sampling length, 0.30 m, by the distance between two rows (0.30 m), Yarami and Sepaskhah, 2015b).

Description of SYEM model

The Saffron Yield Estimation Model (SYEM) is a dynamic growth model for simulating growth and yield prediction of saffron under various water application rates. This model was programmed in C# language and has one main body and five sub-routines that were described in details by Sepaskhah et al. (2013). Data for model development were obtained from Yarami et al. (2011), Yarami (2008), Azizi-Zohan et al. (2009) and Monfared (2005).

Reference evapotranspiration

The reference evapotranspiration (ET_o, mm d^{-1}) was calculated using the modified Penman–FAO equation for study region (Razzaghi and Sepaskhah, 2012) as follows (Doorenbos and Pruitt 1977):

$$ET_o = C\,[0.408 \times W \times R_n + 0.27\,(1-W)\,F_u\,(e_s - e_a)] \quad (3)$$

Where C is a correction coefficient, W is the temperature-related factor, R_n is the net radiation (MJ m^{-2} d^{-1}), F_u is the wind speed function and e_s-e_a is the vapor pressure deficit (kPa).

Crop evapotranspiration

Standard crop evapotranspiration of saffron (ET_c) was calculated by multiplying reference evapotranspiration (ET_o) and crop coefficient (K_c) (Allen et al., 1998) as follows:

$$ET_c = K_c \times ET_o \quad (4)$$

$$K_c = a_0 + a_1\,(DAFI)^2 + a_2\,(DAFI)^3 + a_3\,(DAFI)^4 \quad (5)$$

Where K_c is the function of the days after first irrigation ($DAFI$) and a_0, a_1, a_2 and a_3 are constants (crop coefficient that is a reported by Sepaskhah et al., 2013). K_c equation was derived from the data given in the study of Yarami et al. (2011) for the first and second years and from Shirmohammadi-Aliakbarkhani (2002) for the third year.

Actual evapotranspiration

The saffron daily actual evapotranspiration ($ET_{a,i}$) under soil water stress condition was calculated as follows (Allen et al., 1998):

$$ET_{a,i} = K_{s,i} \times ET_{c,i} \tag{6}$$

Where $K_{s,i}$ is the dimensionless daily soil water stress coefficient which varies between 0.0 and 1.0. In no stress conditions, $K_{s,i}$ should be taken as 1.0. This coefficient depends on total available water of soil (TAW_i in mm) and soil water deficit in the root zone ($D_{r,i}$ in mm) and fraction of TAW_i that a crop can extract water from root zone without suffering water stress (p_i) (Allen et al., 1998).

$$K_{s,i} = \frac{TAW_i - D_{r,i}}{(1 - p_i)TAW_i} \tag{7}$$

$$p_i = p_t + 0.04\ (5 - ET_{c,i}) \tag{8}$$

Where p_i is the daily actual coefficient of readily available water and p_t is the coefficient of soil available water at ET_c of 5 mm d^{-1} that considered as 0.29 for saffron (Sepaskhah and Yarami, 2009). Soil water deficit in the root zone (soil water depletion) at the end of each day was also determined using soil water balance as follows:

$$D_{r,i} = D_{r,i-1} - P_i - I_i + RO_i - CR_i + ET_{a,i} + Dp_i \tag{9}$$

Where $D_{r,i}$ is the depleted soil water depth from the root zone in day i (mm), $D_{r,i-1}$ is the depleted soil water depth in the root zone at the end of previous day i-1 (mm), P_i, I_i, RO_i and CR_i are the precipitation, irrigation depth, soil surface runoff and capillary rise from groundwater in day i (mm), $ET_{a,i}$ is the daily crop evapotranspiration (mm) and Dp_i is the deep percolation to below the root zone in day i (mm). The soil surface runoff and capillary rise from groundwater were considered as negligible in the study. To begin the soil water balance calculation, the initial depleted soil water depth ($D_{r,i-1}$) should be estimated using the following equation:

$$D_{r,i-1} = 1000 \times (\theta_{FC} - \theta_{i-1}) \times z_r \tag{10}$$

Where θ_{fc} is the volumetric soil water content at field capacity (cm^3 cm^{-3}), θ_{i-1} is the mean volumetric soil water content in the root zone at previous day i-1 (cm^3 cm^{-3}) and z_r is the root depth (m).

The value of Dp_i after irrigation or a heavy rain was estimated by the following equation:

$$Dp_i = P_i + I_i - ET_a - D_{r,i-1} \tag{11}$$

In above equation, it is assumed that the soil water content reaches field capacity at the wetting day; therefore, the $D_{r,i}$ in Eq. (9) becomes zero. The soil water balance in more details were described by Sepaskhah et al. (2013).

In this model root depth was divided in-to four layers with same thickness but with different water absorption as 40%, 30%, 20% and 10% of actual evapotranspiration (from top to bottom layers). Root depth in each day of growing season was estimated by the following equation (Borg and Grimes, 1986):

$$z_r = R_{d\,\min} + R_{d\,\max}(0.5 + 0.5\sin(3.03\frac{D_{ag}}{D_{tm}} - 1.47)) \tag{12}$$

Where z_r is the root depth (m), $R_{d\ min}$ is the planting depth (m) which is usually 0.2 m for saffron, $R_{d\ max}$ is the maximum root depth, 0.45 m (Sepaskhah et al., 2013) for saffron, D_{ag} is the number of days after first irrigation, D_{tm} is the number of days after first irrigation that root reaches the maximum depth, 173 d for saffron (Shirmohammadi-Aliakbarkhani, 2002). When D_{tm} is not available model consider 85% of the total growing season as D_{tm}.

Yield estimation

The following regression equation, which was derived from the data obtained from study of Yarami (2008) on saffron, was used in the model to determine daily leaf area index (LAI):

$$LAI = 0.862 \times \left\{1 - EXP\left[-\left(\frac{ET_a}{139.74}\right)^2\right]\right\} \quad for \;\; DAFI \le 150 \tag{13}$$

Where the ET_a in Eq. (13) is determined by Eq. (6). *LAI* after 150 days after first irrigation for saffron was reduced and estimated by a linear equation as follows:

$$LAI = -0.00961 \times (DAFI - 150) + LAI_{150} \quad for \;\; DAFI > 150 \tag{14}$$

Where *DAFI* is the number of days after first irrigation and LAI_{150} is the *LAI* at 150 *DAFI*.

In order to determine the soil evaporation (E, Eq. (16)) and saffron transpiration (T, Eq. (17)), the ratio of evaporation to actual evapotranspiration was determined as the exponential function of *LAI* (Yarami, 2008) as follows:

$$\frac{ET}{ET_a} = EXP(-1.15 \times LAI) \tag{15}$$

$$E = \left(\frac{E}{ET_a}\right) \times ET_a \tag{16}$$

$$T = ET_a - E \tag{17}$$

Total dry matter production was determined using transpiration and the difference of saturated vapour pressure and actual vapour pressure as follows (Tanner and Sinclair, 1983):

$$Y_t = 2.944 \times \left(\frac{T}{e_s - e_a} \right) \tag{18}$$

Where Y_t is the total dry matter production (kg ha^{-1}), T is the seasonal transpiration (mm) and e_s and e_a are the saturated and actual vapour pressure (kPa), respectively.

In the model, corm production was estimated as the function of transpiration as follows (based on the data from study of Azizi-Zohan et al., 2009; Monfared, 2005):

$$B = 57.18 \times T \tag{19}$$

Where B is the corm yield (kg ha^{-1}) and T is the seasonal transpiration (mm).

Finally, saffron yield was estimated as the function of corm yield as follows (based on the data from study of Azizi-Zohan et al., 2009; Monfared, 2005):

$$Y = 4.31 \times 10^{-2} \times B^2 \tag{20}$$

Where Y is the saffron yield (kg ha^{-1}) and B is the corm yield (kg ha^{-1}). Eqs. (19 and 20) were determined based on data obtained from stressed and non-stressed conditions.

Modification of SYEM model for salinity, manure application and planting method

Salinity conditions

Soil salinity was estimated by salt balance equation. In this order, the root depth was divided in-to four layers with same thickness. The flow chart of the modified SYEM model is shown in Figure 1. Two cases were presumed to estimate the salinity of each soil layer: In the first case, leaching was occurred from a given soil layer due to higher applied water than the soil water holding capacity. In this case, salts were leached to the next layer. To estimate the salinity in each soil layer, it is assumed that total remained salt from previous irrigation event is dissolved in the infiltrated water into the soil layer, resulting in a uniform salt solution. Hence, salinity of deep percolated water from a given layer is equal to its electrical conductivity of soil solution (EC_{ss}). The electrical conductivity of soil solution in a given layer is calculated by following equation (Azizian et al., 2015; Shabani et al., 2015):

$$EC_{ssi}^{j} = \frac{\dfrac{EC_{ssi}^{j-1} \times 640 \times D_{p_i}^{j-1} + EC_{ssi-1}^{j} \times 640 \times \theta_{i-1}^{j} \times \Delta z_i^j}{D_{p_i}^{j-1} + \theta_{i-1}^{j} \times \Delta z_i^j}}{640} \tag{21}$$

Where EC_{ssi}^{j} is the electrical conductivity of soil solution salinity of layer j in day i (dS m^{-1}), EC_{ssi}^{j-1} is the water salinity that entered into the layer from the upper layer that is equal to the soil solution salinity of the upper layer (dS m^{-1}), Dp_i^{j-1} is the depth of water entered each soil layer from upper layer ($j-1$) in day i (mm), EC_{ssi-1}^{j} is the previous soil solution salinity in the layer (dS m^{-1}), θ_{i-1}^{j} is the soil volumetric water content of layer j in previous day (m^3 m^{-3}), 640 is the conversion coefficient of the electrical conductivity of soil solution salinity (dS m^{-1}) to salt concentration (mg L^{-1}) and Δz_i^j is the thickness of layer j in day i (mm).

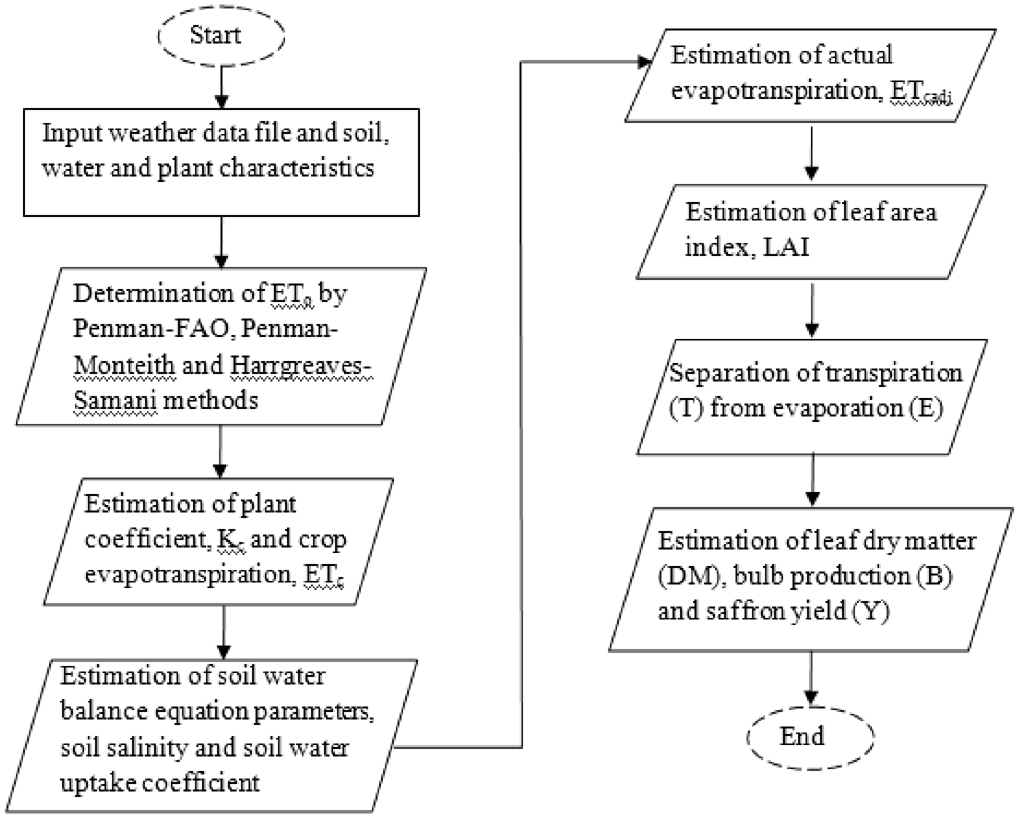

Figure 1. The flow chart of the modified Saffron Yield Estimation Model.

In the second case, water is entered to a soil layer from upper layer but leaching is not occurred from the layer. In this case, the electrical conductivity of soil salinity is calculated as follows (Azizian et al., 2015; Shabani et al., 2015):

$$EC_{ssi}^{j} = EC_{ssi-1}^{j} + \frac{\dfrac{EC_{ssi}^{j-1} \times 640 \times D_{p_i}^{j-1} \times \Delta z_i^j}{\theta_s^j \times \Delta z_i^j}}{640} \tag{22}$$

Where θ_s^j is the saturation soil water content of layer j (m^3 m^{-3}).

After estimation of the electrical conductivity of soil salinity, osmotic potential (h_o) of the soil water was estimated as follows (Richards, 1954):

$$h_0 = -360 \times ECe \tag{23}$$

Where h_o is the osmotic potential (cm) and EC_e is the electrical conductivity of soil saturation extract (dS m^{-1}) that is derived from EC_{ss} multiplying by 0.70 as the ratio of soil field capacity water content to soil saturated water content (Smedema and Rycroft, 1983) prepared in the laboratory for soil salinity measurement according to the US Salinity Laboratory Staff method (Richards, 1954).

Water flow in unsaturated soils described by Richards'equation (Richards, 1931). In this equation, the soil water extraction rate by plant roots term (S) is determined as follows:

$$S = \alpha(h, h_0) \times S_{\max} \tag{24}$$

Where S_{max} is the maximum water uptake rate (under no stress conditions) and $\alpha(h,h_o)$ is the dimensionless water uptake reduction function that is a function of soil water pressure (h) and osmotic potential (h_o). Different functions for water uptake reduction are suggested under water or salinity stress or combined stresses. Two available macroscopic reduction functions for the combined stresses are as follows:

$$\alpha(h, h_0) = \frac{h - h_4}{h_3 - h_4}\left[1 - \frac{b}{360}(h_0^* - h_0)\right] \quad \text{Maas and Hoffman (1977)} \tag{25}$$

$$\alpha(h, h_0) = \frac{h - (h_4 - h_0)}{h_3 - (h_4 - h_0)}\left[1 - \frac{b}{360}(h_0^* - h_0)\right] \quad \text{Homaee and Feddes (1999)} \tag{26}$$

Where h is the soil matric potential corresponding to the soil water content, h_3 is the soil water pressure head threshold value, h_4 is the soil water pressure head at wilting point, h^*_o is the threshold soil water osmotic potential corresponding to the threshold soil water salinity, h_o is the soil osmotic potential corresponding to the soil water salinity and b is the dry matter reduction per unit increase in saturated soil extract salinity under full irrigation conditions. Eq. (26) is valid for $h_o \leq h_o^*$ and $(h_4 - h_o) \leq h \leq h_3$ conditions. The value of 360 cm is the conversion factor of soil water salinity to osmotic pressure head. These parameters were reported by Sepaskhah and Yarami (2010) for saffron and used in this study.

Furthermore, another stress coefficient (K_s) under salinity and water stress conditions was given as follows (Allen et al., 1998):

$$K_s = \left[1 - \frac{b}{K_y \times 100}\left(EC_e - EC_{e-th}\right)\right] \times \left[\frac{TAW - D_r}{TAW - RAW}\right] \tag{27}$$

Where D_r is soil water deficit in the root zone or the root zone depletion (mm), TAW is the total available soil water in the root zone (mm), RAW is the readily available water (mm), K_y is the relative yield response factor to water stress that was considered to be 1.79 for saffron (Sepaskhah and Yarami, 2010), EC_e is the electrical conductivity of soil saturation extract (dS m^{-1}) and EC_{e-th} is the threshold of soil saturation extract salinity and b is the yield reduction per unit increase salinity of saturated soil extract that were considered according to Yarami and Sepaskhah (2015a) for saffron under different treatments. Eqs. (25), (26) and (27) were determined in each day and used to calculate the saffron actual evapotranspiration and transpiration. Then, dry matter production, corm and saffron yield were determined based on the Eqs. (18), (19) and (20), respectively. Furthermore, the model was modified based on Eqs. (25), (26) and (27) and results were compared to choose the one with the most accurate results.

Manure levels and planting methods

Manure application and cultivation of plant in furrow are two strategies can be used for reducing the effect of irrigation water salinity on crops growth and yield. Therefore, assessment of saffron response as a saline-sensitive crop to saline irrigation water under different cow manure application rates and planting methods is possible by using the SYEM model.

The effects of two levels of manure application (30 and 60 Mg ha^{-1}) and the basin and in-furrow planting methods were considered on coefficients of the simple relationships for evapotranspiration partitioning, leaf area index determination and leaf dry matter-transpiration function, corm-transpiration function and saffron-corm function that are used in the modified model. These coefficients that are derived based on the second year measured data and their related equations are shown in Table 1 for different treatments.

Table 1. The values of the calibration coefficients in the modified model for different treatments.

Treatments		F_1P_1*	F_1P_2	F_2P_1	F_2P_2
Equation	Calibration coefficient in the model	Value of coefficient			
$LAI = a_L \times \left\{1 - EXP\left[-\left(\frac{ET_a}{d}\right)^2\right]\right\}$	a_L	0.891	1.537	1.035	1.741
	d	231.185	265.460	243.653	269.668
$\frac{E}{ET_a} = EXP(e_L \times LAI)$	e_L	-0.536	-0.443	-0.773	-0.561
$Y_t = f \times \left(\frac{T}{e_s - e_a}\right)$	f	2.357	3.883	2.375	4.042
$B = k \times T$	k	63.894	100.360	71.360	110.350
$Y = i \times B^2$	i	1.42×10^{-8}	1.79×10^{-8}	1.63×10^{-8}	1.44×10^{-8}

* F_1= 30 Mg ha^{-1} and F_2= 60 Mg ha^{-1} application of cow manure.
P_1: Basin and P_2: In-furrow planting method.

Input and output files for modified model

This model has an input file of in.mdb with Access format and contains meteorological information including maximum and minimum daily temperature (°C), maximum and minimum relative humidity (%), wind speed (m s^{-1}), sunshine hours (hr) and amount of precipitation and irrigation depth (mm). Also, Julian date was used to show the growing period. In addition, some variables are included in the model that were region geographical parameters, initial soil water content, soil water contents at FC, PWP and saturation condition, initial electrical conductivity of soil saturation extract, information about the saffron field age and planting characteristics and some parameters for calculating stress coefficients. Also, planting method and cow manure level should be chosen by user. This input information need to be modified for different regions.

The model output file contained six tables with Access format including:

- ET_o table contained calculated daily ET_o by Hargreaves-Samani, Penman- FAO and Penman-Monteith (mm d^{-1}).

- ET_c table contained daily root depth (cm), crop coefficient (K_c) and daily crop evapotranspirtion (mm d^{-1}).
- Water and salinity balance table contained deep percolation (mm), readily available water depletion fraction, volumetric soil water content (%) and electrical conductivity of soil saturation extract (dS m^{-1}) in each quarter of root zone and mean volumetric soil water content (%) and electrical conductivity of soil saturation extract in the root zone at beginning of each day.

Also, there are three tables contained stress coefficient, daily actual evapotranspiration (mm d^{-1}), leaf area index, daily soil surface evaporation (mm d^{-1}), transpiration (mm d^{-1}), seasonal leaf dry matter (kg ha^{-1}), seasonal corm and saffron yields (kg ha^{-1}) based on Maas and Hoffman (1977), Homaee and Feddes (1999) and Allen et al. (1998) methods.

Statistical analysis

To evaluate the predicted results, Normalized Root Mean Square Error (NRMSE) and index of agreement (d) were calculated by following equations:

$$NRMSE = \frac{\sqrt{\sum_{i=1}^{n}(P_i - O_i)^2 / n}}{\overline{O}} \tag{28}$$

$$d = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}\left(\left|P_i - \overline{O}\right| + \left|O_i - \overline{O}\right|\right)^2} \tag{29}$$

Where, P_i and O_i are the predicted and measured values of each parameter, respectively, n is the number of measurements and $\overline{O}$ is the mean of measured values. The values of NRMSE and d varies between 0.0 and 1.0. When the value of NRMSE is closer to 0.0 and d is closer to 1.0, the model is more accurate. The simulation is considered excellent if a NRMSE is less than 10%, good if the NRMSE is between 10% and 20%, fair if NRMSE is between 20% and 30% and poor if the NRMSE is greater than 30% (Jamieson et al., 1991).

Results and Discussion

Data of the second and first growing season were used to calibrate and validate the modified model, respectively. The modified SYEM model was able to predict saffron growth and yield components under saline water application in different levels of cow manure application rates and planting methods.

Model modification

The original model was only able to predict the saffron yield under various water application rates and irrigation water salinity and cow manure levels and planting methods were not considered in the original model. However, the modified model is able to predict soil salinity and saffron yield components under different application rate of cow manure and planting methods.

Linear relationship between all measured and predicted parameters used for model modification and validation were analyzed by regression and the coefficients of regression, i.e., slope and intercept were analyzed statistically. If the intercepts were not significant, the regression equation was forced to pass the origin of coordinates as intercept is equal to zero and the regression equation was considered as $y=a\times x$. Then, the linear relationship between measured and predicted parameter was compared with 1:1 line by F-test. The comparison results are shown for modification and validation in Tables 2 and 3, respectively.

Furthermore, model results showed that the stress coefficient of Allen et al. (1998) [Eq. (27)] was more appropriate for prediction of actual evapotranspiration (ET_a), evaporation (E) and transpiration (T) since the NRMSE and d of the results of this equation were lower and higher than those values obtained for Maas and Hoffman (1977) and Homaee and Feddes (1999) [Eqs. (25) and (26)] methods. The same results were obtained for other traits. Therefore, Eq. (27) was selected to be used in the model for comparison between the measured and predicted different parameters.

Table 2. Relationship between the predicted and measured actual evapotranspiration (ET), evaporation (E), transpiration (T), soil water content (θ), soil salinity (EC_e), leaf area index (LAI), leaf dry matter (DM), corm yield (Y_{corm}) and saffron yield ($Y_{saffron}$) for calibration (modification) stage.

Parameter	Equation	Coefficient of determination	P_{value}	NRMSE[I]	d[II]	Slope	Intercept
						1:1 comparison	
Evapotranspiration	$ET_p = 1.02(ET_m)$[III]	0.72	8.05×10^{-24}	0.04	0.83	NS[IV]	-
Evaporation	$E_p = 2.01(E_m) - 281.65$	0.74	2.11×10^{-5}	0.09	0.78	S[V]	NS
Transpiration	$T_p = 2.38(T_m) - 343.77$	0.91	8.27×10^{-9}	0.13	0.77	S	S
Soil water content	$\theta_p = 0.46(\theta_m) + 14.75$	0.31	4.65×10^{-12}	0.11	0.69	NS	S
Soil salinity	$EC_{ep} = 0.75(EC_{em}) + 0.23$	0.65	9.08×10^{-3}	0.22	0.89	S	S
Leaf Area Index	$LAI_p = 1.20(LAI_m) - 0.22$	0.76	1.80×10^{-23}	0.29	0.90	S	S
Leaf dry matter	$DM_p = 1.06 (DM_m)$	0.85	2.98×10^{-13}	0.18	0.95	NS	-
Corm yield	$Ycorm_p = 1.08 (Ycorm_m)$	0.80	9.08×10^{-13}	0.20	0.93	NS	-
Saffron yield	$Ysaffron_p = 1.19 (Ysaffron_m)$	0.92	1.02×10^{-12}	0.30	0.95	S	-

[I] NRMSE: Normalized root mean square error.
[II] d: Index of agreement.
[III] p and m subscripts represent predicted and measured parameters, respectively.
[IV] NS: Non significant.
[V] S: Significant.

Table 3. Relationship between the predicted and measured actual evapotranspiration (ET), evaporation (E), transpiration (T), soil water content (θ), soil salinity (EC_e), leaf area index (LAI), leaf dry matter (DM), corm yield (Y_{corm}) and saffron yield ($Y_{saffron}$) for validation stage.

Parameter	Equation	Coefficient of determination	P_{value}	NRMSE[I]	d[II]	slope	intercept
						1:1 comparison	
Evapotranspiration	$ET_p = 0.55(ET_m) + 198.26$ [III]	0.75	1.53×10^{-5}	0.02	0.87	S[IV]	NS[V]
Evaporation	$E_p = 1.01(E_m)$	0.37	9.84×10^{-17}	0.09	0.70	NS	-
Transpiration	$T_p = 0.998(T_m)$	0.65	4.89×10^{-16}	0.09	0.87	NS	-
Soil water content	$\theta_p = 1.00\ (\theta_m)$	0.40	5.28×10^{-18}	0.13	0.78	NS	-
Soil salinity	$EC_{ep} = 0.49(EC_{em}) + 0.43$	0.46	1.51×10^{-9}	0.28	0.77	S	S
Leaf Area Index	$LAI_p = 1.67(LAI_m) - 0.31$	0.74	1.94×10^{-16}	0.34	0.82	S	NS
Leaf dry matter	$DM_p = 1.01(DM_m)$	0.77	3.93×10^{-12}	0.19	0.92	NS	-
Corm yield	$Ycorm_p = 0.95\ (Ycorm_m)$	0.74	4.01×10^{-12}	0.18	0.90	NS	-
Saffron yield	$Ysaffron_p = 0.78\ (Ysaffron_m)$	0.95	1.30×10^{-14}	0.28	0.94	S	-

[I] NRMSE: Normalized root mean square error.
[II] d: Index of agreement.
[III] p and m subscripts represent predicted and measured parameters, respectively.
[IV] S: Significant.
[V] NS: Non significant.

Evapotranspiration, transpiration and evaporation

Relationship between the predicted and measured values of seasonal ET_a, E and T for the second year (modification stage) are presented in Figures 2a, b and c, respectively. The slopes and intercepts of the linear relationships between measured and predicted parameters were analyzed statistically. The intercept was not significant for ET_a relationship; therefore, the regression equation was forced to pass the origin of coordinates. The values of NRMSE and d showed that the modified saffron model could estimate these three parameters with high accuracy, especially in the case of ET_a. Excellent estimation of ET_a maybe due to the use of modified Penman-FAO equation (Doorenbos and Pruitt, 1977) for estimating ET_o for study region. Therefore, this equation should be calibrated for the model or other equations such as Penman–Monteith and Hargreaves–Samani equation (Hargreaves and Samani, 1985) that are inserted in the model, may be more suitable for other regions. Measured E was obtained from microlysimeters. Comparison between measured and predicted E and T indicated that the modified model is capable to predict the soil surface evaporation and transpiration of saffron with high accuracy.

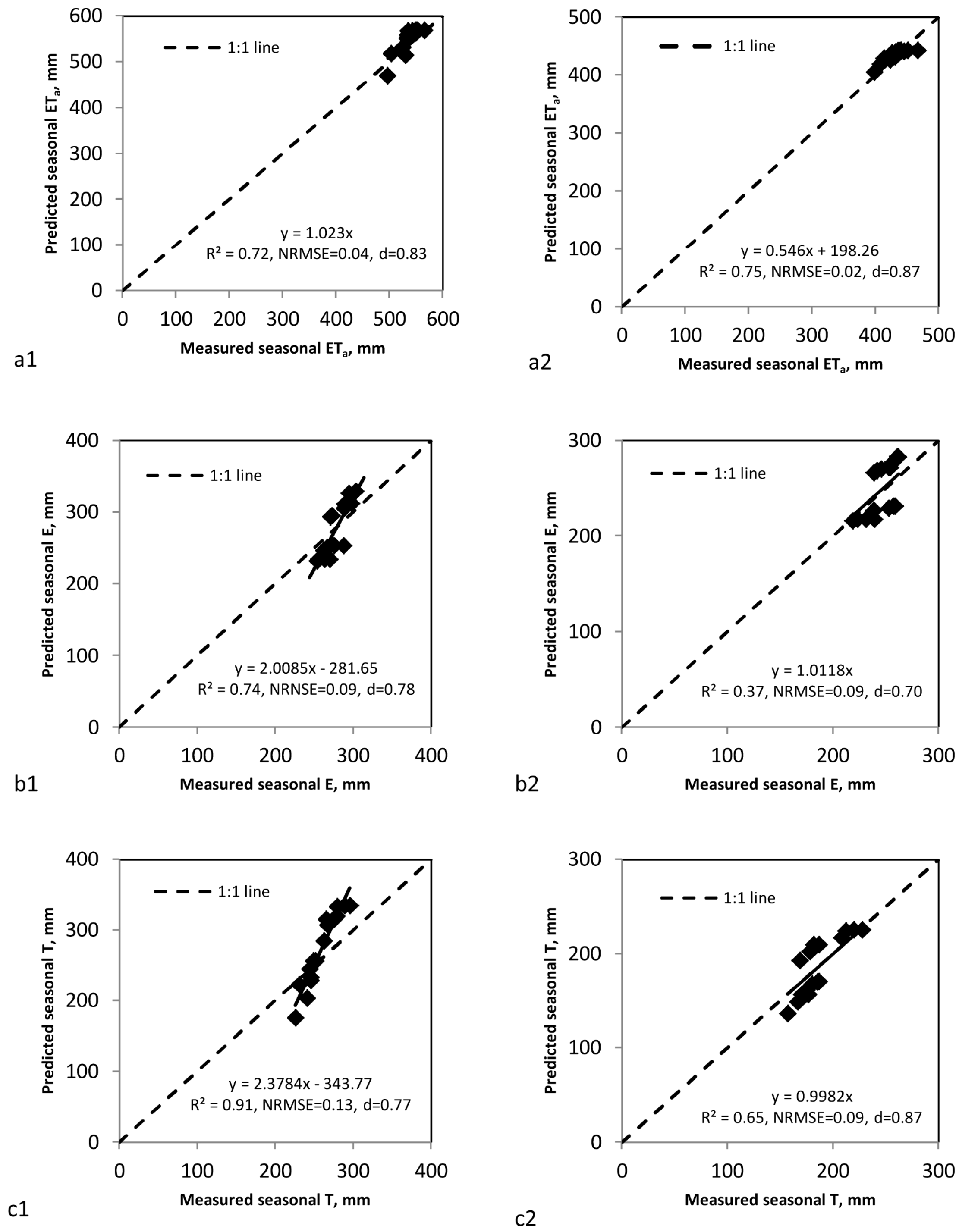

Figure 2. Relationship between the predicted and measured (a) actual evapotranspiration (ET_a), (b) evaporation (E) and (c) transpiration (T) (1: calibration and 2: validation stage).

Soil water content and salinity

Relationship between the measured and predicted soil water content at root depth in the second growing season was determined by linear regression analysis (Figure 3a). The values of NRMSE and d for this comparison were 0.11 and 0.69, respectively that indicated an acceptable estimation of soil water content by the modified model.

According to Table (2) the slope of this linear equation was not statistically different from 1 ($P<0.05$). Results show that the model almost overestimated or underestimated the soil water content in comparison with the measured values. Part of this discrepancy maybe a result of the measurement error by the neutron scattering method. Furthermore, in Figure 3a, over estimated values are almost related to the in-furrow planting method and under estimated values are related to the basin planting method.

Relationship between the measured and predicted soil salinity was presented in Figure 3b. The values of NRMSE and d index were 0.22 and 0.89, respectively that showed a fair estimation of soil salinity by the modified saffron model. There are many sources of errors in process of soil sampling and soil salinity measurements. Therefore, it is recommended to provide the soil salinity measurement by suction cap in field conditions for higher accuracy. The other source of error may be the complication of the interaction between the irrigation water salinity and cow manure application rates in the soil. In the other words, the functional effect of cow manure application rates on the soil salinity was not considered; however, the model have been modified to estimate the soil salinities for two cow manure application rates based on the salt balance method.

Leaf area index

The measured and predicted LAI during the second growing season was compared in Figure 3c. The value of NRMSE was 0.29 that showed a fair estimation of LAI by the modified saffron model; however, the d value was 0.90 which indicated an accurate estimation of LAI. According to Figure 3c1, LAI at early stage of growth was not predicted accurately. This may show that Eq. (13) is not appropriate for LAI estimation at the early stage of the saffron growth. The same result is reported by Sepaskhah et al. (2013) for LAI estimation by application of the previous version of saffron model.

Yield components

The measured and predicted leaf dry matter, corm yield and saffron yield by the model based on Allen et al. (1998) equation of water uptake coefficient are compared in Figures 4a, b, c, respectively. Linear relationships were obtained between the measured and predicted values; however, the intercept was not statistically significant for three relationships. Therefore, the linear regressions were passed the origin (intercept=0). The slopes of linear regression fitted to the leaf dry matter and corm yield variables were not statistically different from 1. The NRMSE and d values for leaf dry matter prediction were 0.18 and 0.95, respectively that shows good estimation of leaf dry matter for calibration stage.

The values of NRMSE and d for corm yield were 0.20 and 0.93, respectively that are higher and lower than those obtained for leaf dry matter, respectively indicating that the errors are relatively high for corm yield prediction. The values of NRMSE and index of agreement (0.30 and 0.95, respectively) indicated that the accuracy of saffron yield prediction by the model was fair. According to NRMSE and d values, the modified model predicted the leaf dry matter and corm yield fairly well. Sepaskhah et al. (2013)

indicated that the errors were relatively low for corm and saffron yields prediction by application of the original version of SYEM model. However, in the model various environmental conditions should be considered due to the fact that the relationship between leaf dry matter and ratio of transpiration to the difference of saturated vapour pressure and actual vapour pressure may be different.

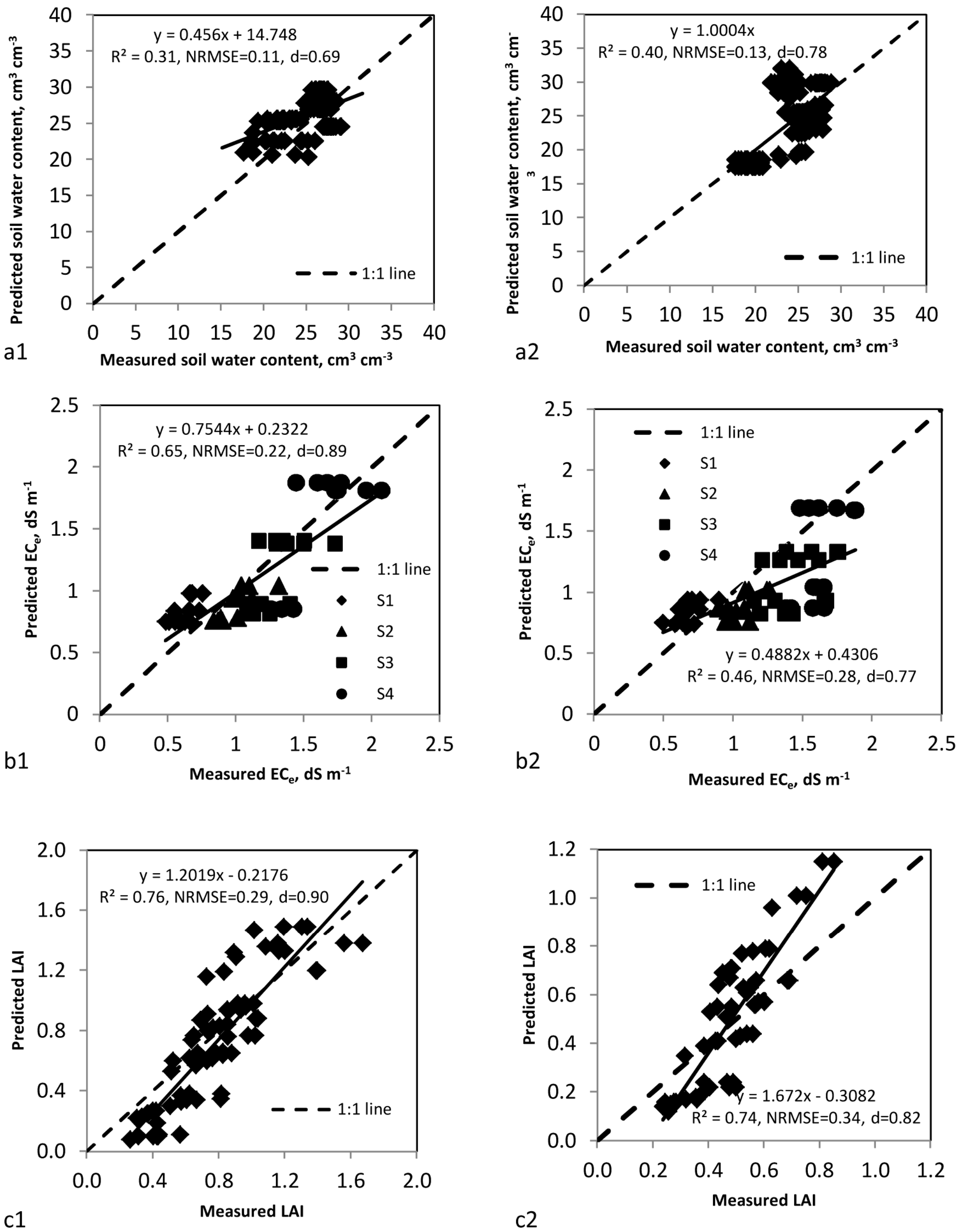

Figure 3. Relationship between the predicted and measured (a) soil water content, (b) soil saturation electrical conductivity (EC_e) and (c) leaf area index (LAI) (1: calibration and 2: validation stage).

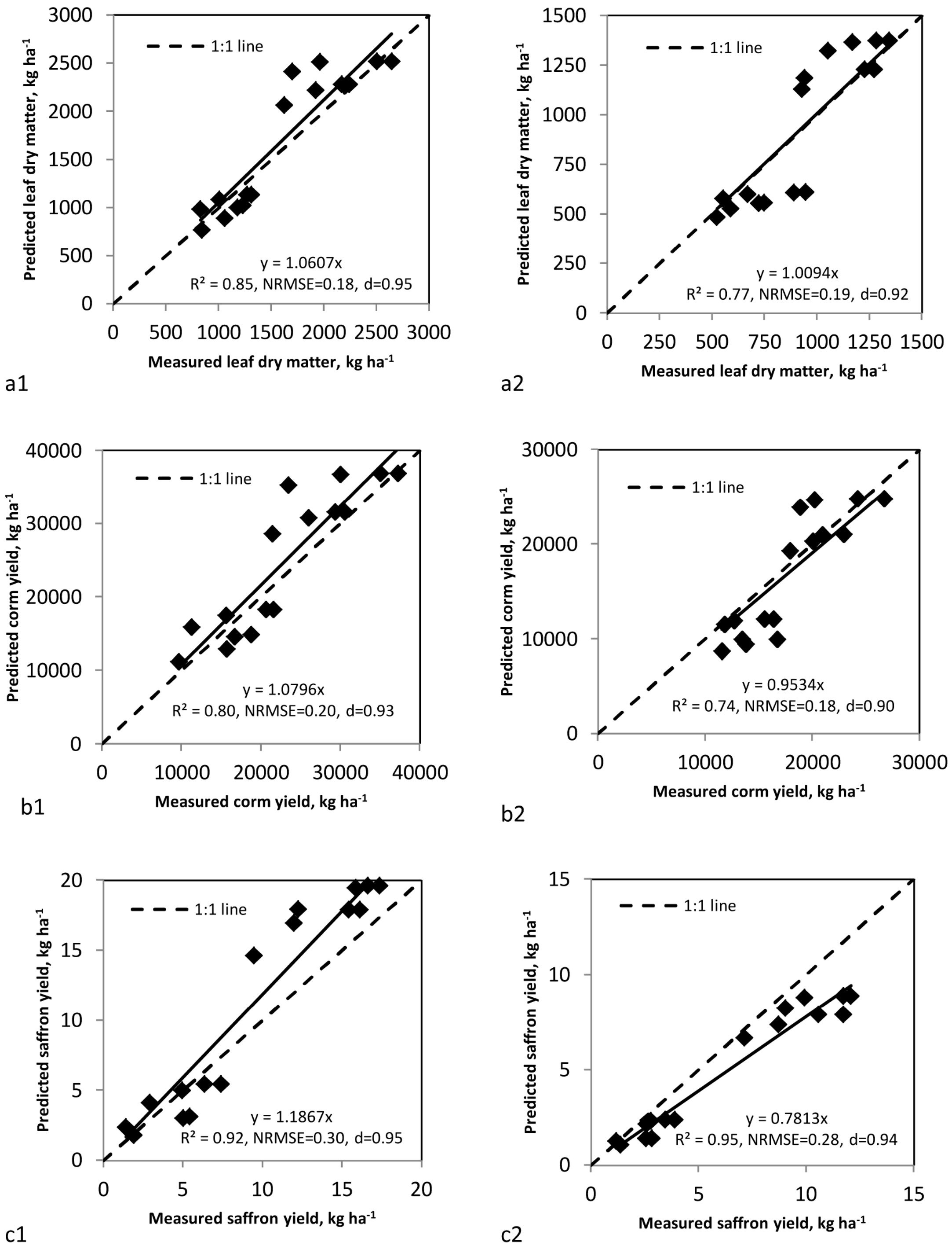

Figure 4. Relationship between the predicted and measured (a) leaf dry matter, (b) corm yield and (c) saffron yield (1: calibration and 2: validation stage).

Model validation

Evapotranspiration, transpiration and evaporation

The relationship between measured and estimated seasonal ET_a, E and T values by the modified SYEM model in validation stage are presented in Figures 2a, b and c. The value of index of agreement (d) was high (0.87) and NRMSE was lower than 10% (0.02) for ET_a prediction. These statistical parameters indicated that the accuracy of estimated actual evapotranspiration was very good and their results were statistically close to the measured values. The NRMSE values for E and T prediction were 0.09 that indicated a very good estimation of these parameters by the modified SYEM model (NRMSE<10%). Maximum values of the measured ET_a and T were 467 and 227 mm in $S_1F_2P_2$ treatment for the first growing season (validation stage). However, the corresponding predicted values were 442 and 224 mm, respectively in the same treatment that are close to each other. Minimum values of the measured ET_a and T were 399 and 157 mm respectively, in $S_4F_1P_1$ treatment that are close to minimum values of predicted ET_a and T that were 405 and 136 mm, respectively. These results indicated that the modified model is capable to predict the actual evapotranspiration and transpiration fairly well in the first growing season of saffron.

Soil water content and salinity

Relationship between the predicted and measured soil water content is presented in Figure 3a. The NRMSE and d values of these comparisons were 0.13 and 0.78 indicated that the modified SYEM model estimated the soil water content with acceptable accuracy. The intercept of the linear relationship was not statistically significant, therefore the equation was forced to origin. According to Figure 3a, measured values of soil water contents were generally higher in comparison with the predicted values. This may be as a result of water content measurement error obtained by the neutron scattering method. However, the value of index of agreement (d) was fairly high.

The relationship between measured and predicted soil salinity at root depth by the modified model was determined by linear regression analysis (Figure 3b). The value of NRMSE (0.28) was between 20% and 30%, which shows a fair estimation of soil salinity. The value of d index was 0.77. Generally, these statistical parameters indicated that the accuracy of the estimated soil salinity is fair in validation stage.

Leaf area index

Relationship between the measured and predicted leaf area index was obtained by linear regression (Figure 3c). The value of NRMSE (0.34) is high that indicated LAI prediction by model for validation stage is poor and the model overestimated the LAI at the end of the first growing season. This might be due to the occurrence of some uncertainty in equations that show the relationship between LAI and ET_a for the second growing season (calibration stage). We have tested different calibration coefficients and the results have reported based on the optimum coefficient for yield prediction. Discrepancies between the measured and predicted values of LAI are related to the in-furrow planting method that we could not have a specific functional simulation for it. By obtaining different relationships between LAI and ET_a for consecutive growing seasons or different equation to estimate the LAI (Eq. 2) that could be calibrated for different treatments, the estimation of LAI should be improved. Since, corm density of saffron increased each year compared with previous year; therefore, the saffron canopy cover and LAI increased and the soil surface evaporation decreased. However, the model almost underestimated the soil surface evaporation values (according to Figure 2b) and overestimated the LAI values during the first growing seasons. Furthermore, the relationship between LAI and ET_a may be different in different environmental conditions that should be considered in the model use. Sepaskhah et al. (2013) reported that the saffron model overestimated the LAI in the middle of the growing season considerably while the underestimation early in the season and late in the season are not as large as the overestimation. They also observed that the saffron model was not able to predict the maximum LAI very accurately especially under irrigated conditions.

In general, we have to say that there was naturally some uncertainty in the measurement of some parameters such as soil salinity, soil water content, evaporation and transpiration and also in the calibration equation. Therefore, there was probably inaccuracy in their measurement and consequently resulting in scattering of the points. However, NRMSE and d-index (index of agreement) of the comparison between the measured and predicted values have the acceptable values. Furthermore, in the modified model the effects of two levels of manure application (30 and 60 Mg ha^{-1}) and two planting methods (the basin and in-furrow) were considered on coefficients of the relationships between different parameters. This is one of the model shortcomings especially for the parameters prediction of the in-furrow planting method that have been provided a suitable condition for growth of corms in the field.

Yield components

Relationship between the measured and predicted leaf dry matter, corm and saffron yields were obtained by linear regression (Figures 4a, b and c). The NRMSE and d values of the comparison for leaf dry matter were 0.19 and 0.92 indicated a good estimation of saffron dry matter by the modified model under salinity conditions in validation stage. The values of NRMSE and d were 0.18 and 0.90 for corm yield, which indicated that the accuracy of corm yield prediction was good. Therefore, the modified saffron model could be applied for leaf dry matter and corm yield prediction under application of saline water, different application rates of cow manure and planting methods.

The value of NRMSE (0.28) and index of agreement (0.94) for saffron yield prediction indicated that the accuracy of saffron yield predictions by the model was fair in validation stage. Generally, this model was applicable to determine saffron yield components and it could be a valuable tool for farm management under different levels of irrigation water salinity, manure application rates and different planting methods.

Conclusions

In this investigation, the SYEM model was modified to predict the actual evapotranspiration, evaporation, transpiration, soil water content and salinity, leaf area index, leaf dry matter, corm and saffron yields of saffron crop under different irrigation water salinities and manure application rates and planting methods by using two field experiments data based on the soil water and salt budget and other simple plant physiological relationships. Results of the modified SYEM model showed that water stress coefficient of Allen et al. (1998) led to a more accurate estimation of different parameters in the calibration and validation stages.

According to the NRMSE index, results showed that the modified SYEM model presented excellent estimation of ET_a and E; good estimation of T, θ, leaf DM and Y_{corm} and fair estimation of EC_e, LAI and $Y_{saffron}$ in calibration stage and excellent estimation of ET_a, E and T; good estimation of θ, leaf DM and Y_{corm}; fair estimation of EC_e and $Y_{saffron}$ and poor estimation of LAI in validation stage. The prediction of leaf area index was not accurate in model validation. These might have been due to the use of less accurate relationship between LAI and ET_a for the validation stage. In general, model was able to estimate leaf dry matter, corm and saffron yields properly. In the modified model the effects of two levels of manure application (30 and 60 Mg ha^{-1}) and two planting methods (the basin and in-furrow) were considered on coefficients of the relationships between different parameters. This is one of the model shortcoming especially for the parameters prediction of the in-furrow planting method that have provided a suitable condition for growth of corms in the field. Furthermore, the functional effect of cow manure application rates on soil salinity it was not considered; however, the model have been used to estimate the soil salinities for two cow manure application rates based on the salt balance method. However, prediction of saffron yield by this model is simple and can be used for better irrigation water salinity management under different manure application rates and planting methods. Furthermore, this model can be used for saffron growth and yield prediction in other areas and climate conditions by changing calibration coefficients in the model.

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References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. Irrigation and Drainage Papers, FAO, Rome, Italy. No. 56. 300p.

Arslan, N., Ozer, A.S., Akdemir, R., 2009. Cultivation of saffron (*Crocus sativus* L.) and effects of organic fertilizers to the flower yield. Acta Hort. 826, 237-240.

Azizian, A., Sepaskhah, A.R., Zand-Parsa, Sh., 2015. Modification of a maize simulation model under different water, nitrogen and salinity levels. Int. J. Plant Prod. 9. (Pending for publication)

Azizi-Zohan, A.A., Kamgar-Haghighi, A.A., Sepaskhah, A.R., 2009. Saffron (*Crocus sativus* L.) production as influenced by rainfall, irrigation method and intervals. Arch. Agron. Soil Sci. 55 (5), 547-555.

Behnia, M.R., 2009. Effect of planting methods and corm density in saffron (*Crocus sativus* L.) yield in Damavand region. Pajou. and Sazan. 79, 101-108. (Text in Persian with English Abstract)

Borg, H., Grimes, D.W., 1986. Depth development of roots with time: An empirical description. Trans. ASAE. 29, 194-197.

Doorenbos, J., Pruitt, W.O., 1977. Guidelines for predicting crop water requirements. Irrigation and Drainage papers. FAO, Rome, Italy. No. 24. 156p.

Hargreaves, G.H., Samani, Z.A., 1985. Reference crop evapotranspiration from temperature. Appl. Eng. Agric. 1, 96-99.

Homaee, M., Feddes, R.A., 1999. Water uptake under nonuniform transient salinity and water stress. In: Feyen, J., Wiyo, K., (Eds.), Modeling of transport processes in soil at various scales in time and space. Wageningen, Wageningen Press. pp. 416-427.

Jamieson, P.D., Porter, J.R., Wilson, D.R., 1991. A test of the computer simulation model ARCWHEAT1 on wheat crops grown in New Zealand. Field Crops Res. 27, 337-350.

Maas, E.V., Hoffman, G.J., 1977. Crop salt tolerance-current assessment. J. Irrig. Drain. Div. ASCE. 103, 115-134.

Monfared, M., 2005. Effect of water deficit on physiologic parameters of saffron. Dissertation for M.Sc. degree in Irrigation and Drainage. Irrigation Department, Shiraz University. 173p. (Text in Persian with English Abstract)

Nassiri-Mahallati, M., Koocheki, A., Boroumand-Rezazadeh, Z., Tabrizi, L., 2007. Effects of corm size and storage period on allocation of assimilates in different parts of saffron plant (*Crocus sativus* L.). Iranian J. Field Crops Res. 5, 155-166. (In Persian)

Omidi, H., Naghdibadi, H.A., Golzad, A., Torabi, H., Fotoukian, M.H., 2009. The effect of chemical and bio-fertilizer source of nitrogen on qualitative and quantitative yield of saffron (*Crocus sativus* L.). J. Medic. Plant. 8, 98-109. (Text in Persian with English Abstract)

Pereira, L.S., Goncalves, J.M., Dong, B., Mao, Z., Fang, S.X., 2007. Assessing basin irrigation and scheduling strategies for saving irrigation water and controlling salinity in the upper Yellow river basin, China. Agric. Water Manage. 93, 109-122.

Ragab, R., 2002. A Holistic Generic Integrated Approach for Irrigation, Crop and Field Management: The SALTMED Model. Enviro. Model. Softw. 17, 345-361.

Razzaghi, F., Sepaskhah, A.R., 2012. Calibration and validation of four common ET_0 estimation equations by lysimeter data in a semi-arid environment. Arch. Agron. Soil Sci. 58, 303-319.

Richards, L.A., 1954. Diagnosis and improvement of saline and alkali soils. Handbook 60. U.S. Salinity Laboratory, U.S.D.A.

Richards, L.A., 1931. Capillary conduction of liquids through porous mediums. Physics. 1, 318-333.

Sepaskhah, A.R., Amini-Nejad, M., Kamgar-Haghighi, A.A., 2013. Developing a dynamic yield and growth model for saffron under different irrigation regimes. Int. J. Plant Prod. 7 (3), 473-504.

Sepaskhah, A.R., Bazrafshan-Jahromi, A.R., Shirmohammadi-Aliakbarkhani, Z., 2006a. Development and evaluation of a model for yield prediction of wheat, maize, sugar beet under water and salt stress. Biosyst. Eng. 93, 139-152.

Sepaskhah, A.R., Ilampour, S., 1996. Relationships between yields, crop water stress index (CWSI) and transpiration of cowpea (*Vigna sinensis* L.). Agronomie. 16, 269-279.

Sepaskhah, A.R., Rezaee-pour, Sh., Kamgar-Haghighi, A.A., 2006b. Water budget approach to quantify cowpea yield using crop characteristic equations. Biosyst. Eng. 95, 583-596.

Sepaskhah, A.R., Yarami, N., 2009. Interaction effects of irrigation regime and salinity on flower yield and growth of saffron. J. Hort. Sci. Biotech. 84 (2), 216-222.

Sepaskhah, A.R., Yarami, N., 2010. Evaluation of macroscopic water extraction model for salinity and water stress in saffron yield production. Int. J. Plant Prod. 4, 175-186.

Shabani, A., Sepaskhah, A.R., Kamkar-Haghighi, A.A., 2015. A model to predict the dry matter and yield of rapeseed under salinity and deficit irrigation. Arch. Agron. Soil Sci. 61 (4), 525-542.

Shirmohammadi-Aliakbarkhani, Z., 2002. Using crop water stress index to determine crop water stress and irrigation scheduling of saffron. Dissertation for M.Sc. degree in Irrigation and Drainage. Irrigation Department, Shiraz University. 168p. (Text in Persian with English Abstract)

Smedema, L.K., Rycroft, D.W., 1983. Land Drainage. Cornell University Press, Ithaca, New York. 376p.

Tanner, C.B., Sinclair, T.R., 1983. Efficient water use in crop production; research or re-search. In: Taylor, H.M., Jordan, W.R., Sinclair, T.R., (Eds.), Limitations to efficient water use in crop production. Madison (WI), American Society of Agronomy-Crop Society of America-Soil Science Society of America, pp. 1-27.

Yarami, N., 2008. Determination of crop evapotranspiration and crop coefficient of saffron using water-balance lysimeter. Dissertation for M.Sc. degree in Irrigation and Drainage. Irrigation Department, Shiraz University. 161p. (Text in Persian with English Abstract)

Yarami, N., Kamgar-Haghighi, A.A., Sepaskhah, A.R., Zand-Parsa, Sh., 2011. Determination of the potential evapotranspiration and crop coefficient for saffron using a water-balance lysimeter. Arch. Agron. Soil Sci. 57 (7), 727-740.

Yarami, N., Sepaskhah, A.R., 2015a. Saffron response to irrigation water salinity, cow manure and planting method. Agric. Water Manage. 150, 57-66.

Yarami, N., Sepaskhah, A.R., 2015b. Physiological growth and gas exchange response of saffron (*Crocus sativus* L.) to irrigation water salinity, manure application and planting method. Agric. Water Manage. 154, 43-51.

Yarami, N., Sepaskhah, A.R., 2016. Effect of irrigation water salinity, manure application and planting method on soil ions variation and ions uptake by saffron plant (*Crocus sativus* L.). Int. J. Plant Prod. 10 (2), 197-220.