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Evaluation of the Efficiency of CROPWAT Model for Determining Plant Water Requirement in Arid Regions

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Abstract

Shortage of water resources and increasing demand to consumption of this scarce resource, leads to some noticeable limitations. On the other hand, population growth and consequently, increasing demand for water in arid and semi arid regions , needs production in exchange of little amount of water consumption. To approach this objective, an experiment in the complete randomized blocks carried out in four replications for cumin plant growing in Zabol, southeastern Iran. Experimental treatments included irrigation periods at three levels. Then using CROPWAT model, the water requirement of the plant is met. Analyzing the data resulted from production gathered in different times of irrigation and consumption of water in the three times irrigation case with sound efficiency (1750 m^3/ha), is more little than the water amount which is simulated by the CROPWAT model in 2003 (6070 m^3/ha) and (5363 m^3/ha) in 2004. It then showed that this model is not effective in determining the water requirement of cumin at this region.

Keywords: Water requirement; Cumin; CROPWAT model; Efficiency; Zabol; Simulation

1. Introduction

Reaching to higher irrigation efficiencies proportional to best yield, is one of the major challenges at near future which is impossible without using the techniques and approaches in which the consumption of water is reduced. In this respect, minimum irrigation plays an important role in increasing of water use efficiency (WUE). The most important aim of minimum irrigation is reduction of water consumption by plant, so that the water deficiency stress can have the minimum effect on its yield.

Nowadays, there are different types of models to simulate plant growth and water flow at the rooting region. These models are useful and in some cases powerful tools for generalizing the research results to the actual circumstances that are not experimented yet. The CROPWAT model is used in this study to evaluate the minimum irrigation under the different circumstances from water, soil and plant resources. In addition, the model is important from this point which can facilitate and organize the research processes and is also capable of providing more meaningful comparison between research findings which are conducted at different places and circumstances. The CROPWAT model developed by FAO (1992) is a relatively simple computer- based model of water balance for management and planning of irrigation which is able to simulate the water stress condition of plant and evaluate its effect on the yield reduction. This task is based on the evapotranspiration of the reference plant and the reaction of plant to water shortage (10, 11).

The main feature of this model includes: computing the evapotranspiration of the reference plant (ETO), the irrigation demand of

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the plant and irrigation and cultivation pattern. Using the daily water balance, user can simulate different conditions of the way of supplying water and consequently evaluate the reduction of yield and efficiency of irrigation and rainfall. Computation of evapotranspiration is based on Penman- Monteith method (9). The input data are minimum and maximum temperature degrees in the form of ten days or monthly, relative humidity, sunshine hours and wind speed.

The plant parameters used in the model include plant coefficient (K_c), duration of growth season, the amount of critical evacuation and index of yield reaction (K_y). The cumin (*Cuminum cyminum)* is an annual plant from *Umbelliferae* family and one of the most important and economic pharmaceutical plants which can be very important in arid and semi arid regions of Iran in the case of water shortage and less fertility of soil. Form of leaves, length of bushes, which is short, and color covering of surface of plant's organ, all are indicators of compatibility of the plant to dry conditions (1). Moreover, it is resistant to salinity and needs to not fertile soil (1, 3). The conducted investigation on water requirement and fertilizing of cumin to achieve maximum production yield, suggests that mainly the irrigation and fertilizing demand of this plant is very limited and is less than other agricultural plant(1). Anac et al. (1999) made efforts to design a minimum irrigation conditions program for cotton plant. They used CROPWAT model and calibrated it with conditions of the Netherlands and concluded some positive results for cotton cultivation in this country (3).

Meanwhile, Tavoosi (2000), by studying the effect of different methods of irrigation on cumin yield , reported that water potential of this plant at the end of growth period reached to - 30 Bar but any effect of wilting in the plant was not reported . It means that the plant was able to absorb the required water from the soil. At the mentioned study, there was no difference in yield of seed, number of umbel in bush and number of seed in umbel in irrigation treatments, but by complete irrigation treatment, maximum amount of biomass and minimum weight of 1000 grain and harvest index is obtained (12).

Tatary (2004) has reported that increasing of times of irrigation, causes increasing of biologic yield but will cause little decrease in seed yield, weight of 1000 grain and harvest index. The best treatment was then two times irrigation with fresh water and two times in the form of fresh and brackish water mixture (11). Balandary (2003) has reported that the heat and dryness, causes increasing while moderate and wet weather causes decreasing of the amount of extract of the cumin (4). Because of the importance of the recognizing the stages of irrigation in cumin, and also enormous effects of environmental conditions, specially dryness stress, the quality and yield of the mentioned plant, the effect of irrigation timing was investigated.

2. Materials and methods

The experiment was conducted during 2003-2004 cultivation year in Zabol located at southeast of Iran. The climate of this area is hot and dry with a dry summer season. Elevation is about 485 m a.s.l. and the range of annual evapotranspiration is 4500 to 5000 mm. The soil texture of the given field was silty loam and after irrigation, its EC reduced from 9.82 ms/cm to 4.15 ms/cm and the field had been cultivated with wheat in the previous year.

Table 1. The results of soil chemical properties in the study area

Parameter	pH	-EC (meq/lit)	Ca + Mg (meq/lit)	Na (meq/lit)	HCO3 (meq/lit)	Cl (meq/lit)	SO4 (meq/lit)	Sum of Anions (meq/lit)	Saturated extract (%)
Value	7.82	9.28	43.75	56.58	6.42	48.80	84.13	74.1	29.13
Parameter	Sum of Cations (meq/lit)	SAR	ESP%	%Lime	OC%	OM%	N%	P%	K%
Value	32.1	12.12	20.14	19	84	1.43	7	30.03	18.78

The experimental design was developed as complete randomized blocks with four replications. Experimental treatments including times of irrigation at three levels (two times irrigation synchronous with sowing and after complete establishment (I_1), three times irrigation: synchronous with sowing, after complete establishment and the early flowering phase (I_2), four times irrigation: synchronous with sowing, after complete establishment and start of the flowering phase and the relatively ripen seeds (I_3).

The sowing of cumin was done in 2003 with raw distance of 20 cm and depth of sow about 1.5 cm, at the plot in 2.4 by 2.2 m dimensions and distance between two plots of 1.2 m.

The irrigation is done in such a way that at least up to 15 cm depth, soil reaches to the limits of field capacity. Amount of the consumed water by two times irrigation and its effect on the yield of cumin evaluated for unit area (ha) is equal to 1200 m^3, which does not result suitable yield. The consumed water by three times irrigation is estimated about 1750 m^3/ha , which was a suitable yield when the times of irrigation is added to four times and consumption water reached to 2350 m^3/ha, no meaningful differences in the yield was recorded.

Before the final harvest, in order to determine and compute the yield including number of umbel in a bush, number of seed in a umbel, height of stem and weight of seeds, ten bushes from each plot were selected and picked up .For computing seed and biologic yield as well as harvest index, two square meters of each plot was selected and in the field conditions, during 72 hours was dried. The results were compared .interpreted using analysis of variance by the Duncan's test with 5% confidence limit using MSTATC.

Then by using CROPWAT model, plant water requirement, which contributes in designing and management of irrigation schedule, was estimated. The outlines of the method are as follow: input data such as monthly "ETo", plant's data, pattern of cultivation as well as monthly rainfall data were entered into the model. In addition to the mentioned data at the next stage for computing irrigation schedule, soil data were entered and indices of irrigation program arranged. Meteorological data of Zabol station for two continued years of 2003 on which the cultivation was done, added to the model.

Because the water requirement of plant generally is evaluated during the growth season by crop coefficients of the same plant , then the plant coefficient (Kc)and index of yield coefficient (Ky)for cumin in Zabol, was calibrated. By having (Kc) and evapotranspiration of the reference plant (ETo) in each period, we can compute the evapotranspiration of the mentioned plant (ETc) by the following equation (12).

$$ETc=Kc*ETo$$

In order to take the ETc values for each growth period, we must compute the changes of plant coefficients during the growth period from the time of budding until harvest. Since the plant coefficients is not a fixed value, and is changed in the growth period of plant, then according to the FAO guidelines we divided the growth period into four stages including: initial stage, development stage, mid-season and end-season. For cumin it is as shown in Table 2.

It's necessary to note that, because of the differentiation of humidity conditions and wind speed, the values of plant coefficient in the mid-season and end-season by using the following equations, were calibrated:

$$Kc\text{-}mid=Kc\text{-}mid\text{-}table+[0.04(U_2-2)-0.004(RH_{min}-45)][h/3]^{0.3}$$
$$Kc\text{-}end=Kc\text{-}end\text{-}table+[0.04(U_2-2)-0.004(RH_{min}-45)][h/3]^{0.3}$$

Where:

Kc –mid, is the improved coefficient of plant in the mid season growth.

Kc-mid-table is the plant coefficient inserted in the table of FAO's irrigation manual 56.

U_2, is the wind speed above the land (m/s)

RH, is the least relative humidity in the given period (%)

H, is the height of plant .In this case it is assumed as 0.3.

Kc-end is the plant coefficient according to the FAO manual.

Table 2. Duration of growth and plant coefficient in cumin

Kc	Growth duration(day)	Growth stage
0.34	75	Initial
0.52	30	Development
0.74	30	Mid-season
0.43	25	End-season

Conditions of stress at the development region of root, is defined as critical water soil content which indicates the part of whole the existed water in soil between field capacity (Fc) and wilting (Wp) points which is used for plant transpiration. This is different for plants and growth phases and is affected by properties of plant root density, speed of evaporation and soil type. Figure 1 shows the speed of decreasing evapotranspiration in different conditions of soil moisture.

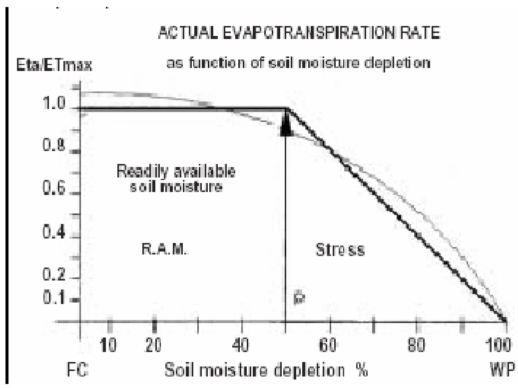

Fig. 1. Crop evapotranspiration rate under soil moisture stress

The effect water stress on plant yield is defined by a experimental index (Ky), in the below form:

$$1-\frac{Ya}{Y\max}=Ky\left(1-\frac{ETa}{ETm}\right)$$

Where:

Y_a and Y_{max} are the actual and potential yields respectively; $1\text{-}Y_a/Y_{max}$ is the relative decrease of yield proportion to relative decrease in evapotranspiration rate ($1\text{-}ET_a/ET_m$). K_y values, by using the above equation and putting mentioned parameters for different stages of plant life, is obtained and used in the model. Finally the model was developed and the results are presented in Figures 2-10.

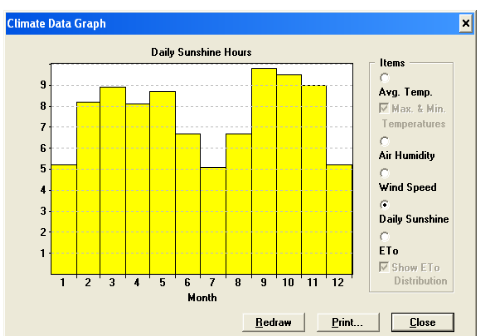

Fig. 2. Climatic data graph for sunshine hours

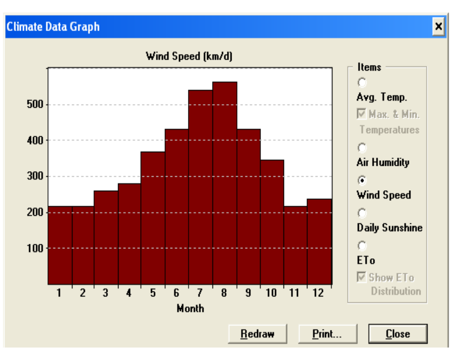

Fig. 3. Climatic data graph for wind speed

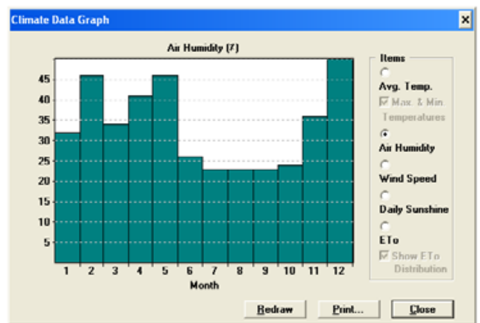

Fig. 4. Climatic data graph for relative humidity percentage

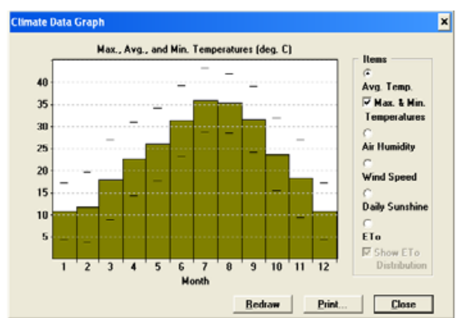

Fig. 5. Climatic data graph for maximum and minimum temperature

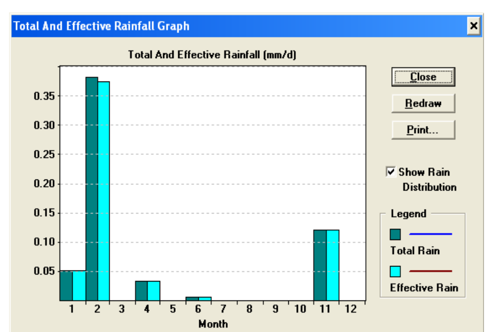

Fig. 6. Input data graph for rainfall and effective rainfall

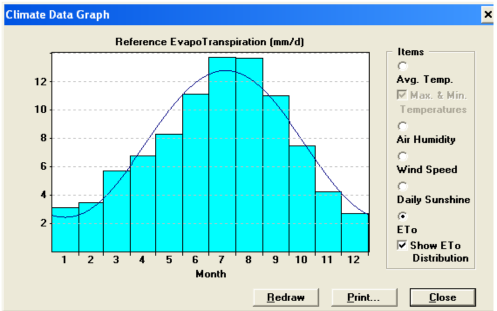

Fig. 7. Input data graph for evapotranspiration of reference plant

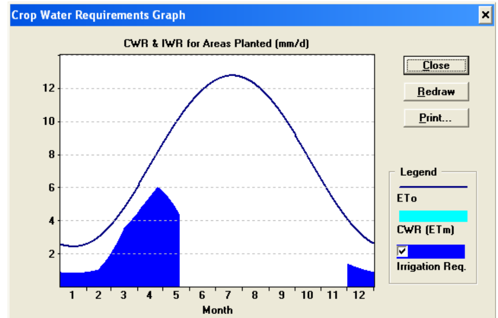

Fig. 9. Irrigation water requirement outputs

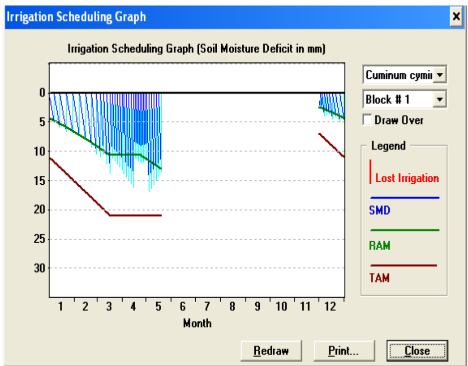

Fig. 8. Irrigation schedule output

3. Results and Discussion:

Table 3 shows the results of analysis of variance which indicates that the effect of irrigation treatment on economical yield, the number of umbel and the weight of seeds in the %1 probability, is meaningful while the effect of irrigation treatment on height of plant, number of seed in the umbrella, straw yield and index of harvest is statistically non significant.

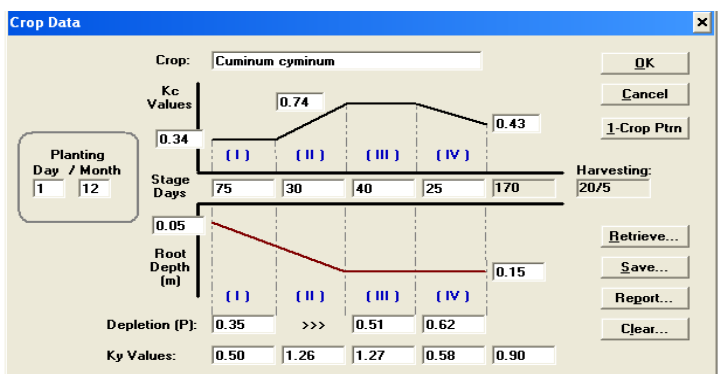

Fig. 10. Plant coefficient data of cumin in the study area

Comparison of the average of data (Table 4) showed that increasing the consumption water from 2 to 3 times, led to the significant increase of the average of the number of the umbel in a plant, economical and biologic yield, number of seed in plant in the average of the weight of the grain ($p<0.05$), while it had no effect on number of seed in umbel, height of plant, straw yield and index of harvest.

Table 3. The results of ANOVA for yield of cumin under different irrigation treatments

Harvenst index	StraW yield	Biologic yield	Seed yield	No. of seeds in each plant	No. of umbel in each plant	Plant height	Seed weight	Seed number in umbel	df	Source of variation
^{ns}145	^{ns} 8043	^{ns} 1513	12753**	29348**	88.7**	^{ns} 29.8	^{ns} 0.222	^{ns} 3.24	3	Replication
^{ns} 12.2	^{ns} 19546	60520*	11436**	11349*	78.82**	15.45	0.986**	^{ns} 0.385	2	Irrigation level
29.1	8251	11413	1407	4456	9.74	9.97	0.108	1.39	15	Error
10	14	13	9	14.5	9	11.5	12	6.5	0	Coefficient of variation (%)

Non significant in: ns Significamt in 5%: * Significant 1%: **

The results also showed that there is no significant differences between treatments of I_2 and I_3; which shows that irrigation in final phase of growth(filling of plant seeds), not only had no effect on increasing of the yield but also caused decreasing it somehow. Short time between duration of two final irrigation stages and sensitivity of the plant at this phase to irrigation, excessive heat of the region as well as physiological disorder between growth and production phases, could be among the causes of being ineffective in final phase of irrigation as well as decreasing of yield. The effect of water shortage in decreasing yield of cumin seed and being ineffective at the final phase, is also reported in the works of Aminpour and Mousavi (1995) and Tatary (2004).

Index of harvest in all treatments was the same and there was no meaningful difference in the treatments. This shows that, irrigation has no effect on harvest index and by increasing and decreasing of biologic yield; the seed follows the same response. According to inherited properties of plant, which allocates more than half of its whole aerial weight to the seed, the causes increasing harvest index restricted and then cumin in the different environmental conditions shows a fixed and relatively clear index harvest (1).

Table 4. The comparison of the irrigation treatment of the yield of cumin

Harvest index	Weigh of 1000 grains(gr)	Plant height (cm)	No. of seeds in each plant	Seed yield	Biologic yield	Straw yield	Treat ment	Seed number in umbel	Seed weight (gr)
a 55	a 3.16	a 25.38	b 287	b 374	b 686	a 312	I1	21.18b	a13.56
a 53	b 2.51	a 28.58	a 357	a 448	a 850	a 403	I2	27.28a	13.13a
a 53	b 2.61	a 27.55	a 347	a 427	a 817	a 391	I3	25.53a	13.38a

I1: Two time irrigation, I2: Three times irrigation, I3: Four times irrigation, significance level: 5%

4. Conclusion

As shown in Table 5, water consumption in the form of three times irrigation, with the suitable efficiency (1756 m^3/ha), is less than the amount which is computed by the CROPWAT model in 2003(6070 m^3/ha), and 2004 (5363 m^3/ha). One of the reasons for difference between the results of model output and treatments is the climatic condition of the region which includes hot winds, high temperature and lack of sufficient precipitation which affects on the outputs of CROPWAT model and then makes it in effective for prediction process for the studied plant in the region.

Table 5.Comparison of the water requirement of the model in different irrigation treatments

Irrigation treatments/Model output	Result of CRW Model	I1	I2	I3
Water volume(m^3/ha)	6070	1200	1750	2350

Then it is concluded that the model for planning of irrigation water requirements of cumin, has not the needed efficiency and by focusing to the climatic condition as well as other related conditions in Zabol, it gives incorrect evaluation from water consumption of this plant.

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