Simulation of Consumption Water Scarcity Effect in Agriculture

Ahmadzadeh Kaleybar F.[1]* and Aliabadi E.[2]
[1] Department of water sciences and engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran.
[2] Former MSc student, Department of water sciences and engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran.

*corresponding author:
e-mail: f.ahmadzadeh@iaut.ac.ir

Abstract Models are the best methods to select most efficient irrigation method that would lead to high performance and yield response. In this research, the effect of Consumption Water Scarcity in Bilasuvar plain on the north-west of Iran has been simulated on Wheat and Corn crops using Budget soil and water balance model. By choosing the product, minimum and seasonal methods with different time steps has been calibrated for the observation years and amount of yield is estimated. Result of the statistical analysis shows that choosing the product method with 10 day time periods provides the best simulation using potential evapotranspiration with amounts in R^2 of 0.98, RMSE of 78% and an EF of 0.83 that between observed and simulated data of Wheat and amount in R^2 of 0.87, RMSE of 7.4% and an EF of 0.83 of Corn. later water consumption graphs, performance for each statistic period under different irrigation strategies have been drawn. Results demonstrates significant impact of rainfall amount, water consumption management and water tension in both crops during the middle stage of its growth compared to there stages of growth including first and final stage. This important fact must be considered for planning the water deficit irrigation schedule.

Keywords: deficit irrigation management, potential evapotranspiration, Bilasuvar plain, Budget model

1. Introduction

considering significant investments in drainage and irrigation patterns, limitations on water, soil and financial resources, fresh water paucity and gradual increase in their pollution level, daily increase in population and its corresponding demand for water to be used for different purposes, meticulous and astute management of consumption of water resources in regional and national level along with maintenance of these resources is an inevitable task. Choosing the right and most efficient method of irrigation and increasing the outcome by effective management is very important. Budget model is computer software that was developed and introduced in faculty of agricultural and biologic sciences with cooperation of soil and water management institute in Belgium. This model includes a set of rules that describe different water absorption processes by plant roots and water movements in soil according to its characteristics. During the periods in which water stress of plants increase, reduction in yield caused by recession could be estimated using plants response factor. by choosing correct and precise time and depth factors we can define the proper irrigation plan for the field. daily climate data including average potential evapotranspiration for 10 days or a month and rain fall amount . During the implementation 10 day or monthly data are analyzed to calculate daily rainfall amount. By choosing proper parameters for the plant from pool of parameters of the environment Budget software provides a set of parameters which can be modified at any time during the execution. Soil profile maybe a combination of different layers with specific characteristics for each layer. this model contains a set of predefined parameters and characteristics which can be chosen from according to soil type and profile.
By calculating water and salt content of soil profile under effect of entrance and exit of water and salt in simulation period, we can use the software for these purposes:

- to assess the water stress of the plant under rainfed irrigation
- to estimate plants response to water
- to design irrigation plan
- to study salt consternation in root zone under reverse irrigation
- to analyze irrigation strategies

2. Materials and methods

Using the Budget (soil water balance model) we can measure amount of changes in the root soil water content by indicating water inflows and outflows. Considering the water content in the root zone and its related water stress in simulation, we can assess the decrease in the yield that was estimated by Ky approach.

2.1. Yield reaction to water

Considering simulated average water stress in growth season we can calculate decrease in the seasonal yield using a seasonal yield response factor in equation (5). We can also use first equation to calculate effect of water stress on seasonal yield using a stage specific yield response factor. This factor (Ky) shows crops sensibility to water stress during that exact stage. Budget model offers different options for combining effects of water stress in different stages. These options provide the opportunity to examine effects of water stress on differences in seasonal yield for each specific stage.

By selecting the minimal option (equation 2) (Allen, 1994) we consider minimum determined yield (using Eq (5)) for each stage and for the whole growth season as expected seasonal relative yield.

$$\frac{Y_a}{Y_m}=\mathrm{Min}\left\{\frac{Y_{a,1}}{Y_{m,1}},\frac{Y_{a,2}}{Y_{m,2}},........,\frac{Y_{a,N}}{Y_{m,N}},\frac{Y_{a,tot}}{Y_{m,tot}}\right\} \quad \text{Eq(2)}$$

in which (Ya,tot/Ym,tot) is the calculated yield using the seasonal evapotranspiration and Ky factor and (Ya,1/Ym,1), (Ya,2/Ym,2), . . ., (Ya,N/Ym,N) are the expected relative yields caused by water stress in 1 to N stages. but in the additive method (Hiler and Clark, 1971; Stewart et al., 1977; Varlev et al.,)for calculating expected seasonal yield we should subtract total of the right side terms in first equation for each specific step from one. but considering the risk that this method may lead to unrealistic low yield estimates it is not covered in the Budget model.

in multiplicative approach (equation 3) (Jensen, 1968; Hanks, 1974) total relative yield can be calculated by the following equation:

$$\frac{Y_a}{Y_m}=\prod_{i=1}^{N}\left[1\text{-}K_{y,i}\left(1\text{-}\frac{ET_{a,i}}{ET_{c,i}}\right)\right] \quad \text{Eq(3)}$$

In this equation ∏ represents product of the N functions (total number of growth stages) between square brackets and Ky,i and (ETa,i/ETc,i) for yield response factor and its related evapotranspiration for i-growth stage.

In order to show integrated effect on yield caused by water deficiency at short time periods (shorter than growth stage) Budget model supplants each of N functions of 3-th equation by product of M functions as below (equation 4) (Raes, 2004):

$$1\text{-}K_{y,i}\left(1\text{-}\frac{ET_{a,i}}{ET_{c,i}}\right)=\prod_{i=1}^{M}\left\{1\text{-}K_{y,i}\left(1\text{-}\frac{ET_{a,j}}{ET_{c,j}}\right)\right\}^{\Delta t_j/L_i} \quad \text{Eq(4)}$$

in this function ∏ is the product of the M functions between square brackets, M is the number of time steps with special duration (Δtj days) during i-growth stage, Li is the total length of the stage (in days) and ETa,j and Etc,j respectively represent real and maximum evapotranspiration during J-time step . Consider the fact that .(Δt1+ Δt2 +… +ΔtM) / Li = 1 (Δtj) which represents total number of days can be modified and ranges from a few days to total duration of the stage. the pre-defined amount for it is equal to 10 days. Since in calculating soil water balance we can barely determine how much water is lost via soil evaporation (E) or by crop transpiration (T). in the equation crop water stress by is shown by (ETa/ETc) which is evapotranspiration rate in place of using transpiration rate (Ta/Tc). If we choose Ky-approach Budget model provides the option to choose between evapotranspiration (ET) and (T) transpiration, since this model separates soil evaporation and crop transpiration. In this condition (Ta/Tc) supplants (ETa/ETc) in the equation. If we choose the transpiration option, for estimating transpiration rate (Tc) only transpirations above a certain threshold is considered. (Default 0.5 mm day1)

2.2. Simulation

Benefiting from the Budget model expected crop yields in different water stress levels for two distinct climate regions is calculated and juxtaposed withe filedobserved yields.Performanceof different methods for integrating effects of water stress in each step and effects of using shorter time periods for yield updates are examined. (equation 5)

$$1\text{-}\frac{Y_a}{Y_m}= K_y(1\text{-}\frac{ET_a}{ET_c}) \quad \text{Eq(5)}$$

3. Results and discussion

3.1. Calibration, validation and simulation

In the Budget model, for simulation we can choose from three different relations - product, minimum and seasonal – to simulate the performance. The time periods in these product methods can be chosen differently. The model can also estimate the yield based on potential transpiration or relative evapotranspiration. All of these situations have been analyzed for wheat during the observation year (2014-2015) and the amount of comparison factors including RMSE, R^2 and EF have been calculated for computed and observed data and the results are included in the table below. Ef is the model's efficiency and ranges from -∞ to 1 and the higher the number the higher the value and negative data indicates that computed data are worse than average observed data. (Table 1)

Table 1. comparison of fitness factors for observed and calculated data for wheat crop

Comparison factors	Methods used					
	Multiplicative				Minimal	Seasonal
	=stageΔt_i	=10 dΔt_i	=5 dΔt_i	=2 dΔt_i		
	estimating yield based on(T_{a/T_c})					
RMSE(%)	14.5	9.7	11.6	15.1	17.6	3.2
EF(-)	0.83	0.77	0.80	0.77	0.05	0.74
(-)R^2	0.91	0.98	0.89	0.88	0.84	0.90
	estimating yield based on(ET_{a/ET_c})					
RMSE(%)	12.3	7.8	11.9	12.5	15.7	3.1
EF(-)	0.83	0.83	0.85	0.85	-0.26	0.74
(-)R^2	0.90	0.98	0.87	0.88	0.86	0.91

It can be seen from the columns of the table above that product method with 10 day time period using relative evapotranspiration method has the best analyses for the observed data as it can be seen, comparison criteria for it, has been highlighted.

In the figure (1) a comparison of yearly yield of wheat in 2004-2014 period that has been simulated by Budget model in different irrigation depths can be seen.

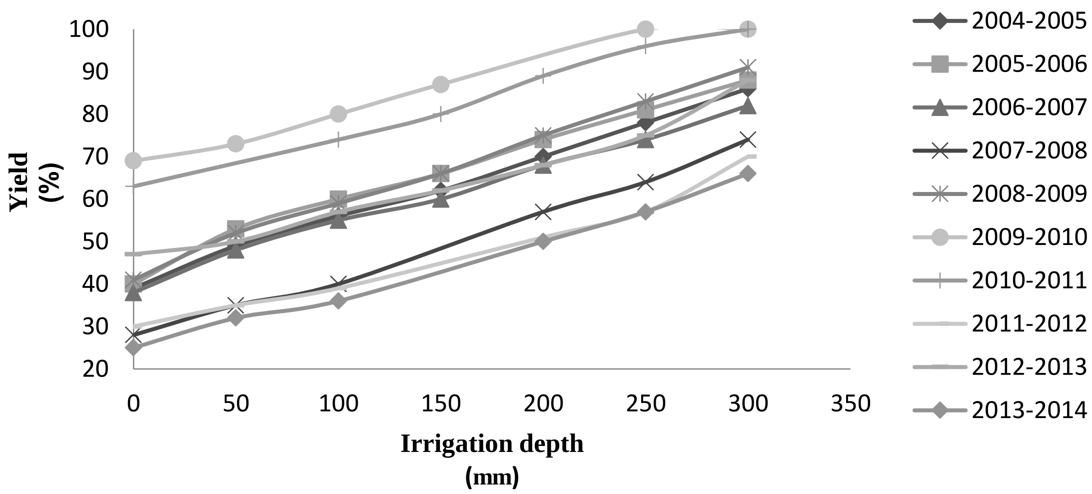

Figure 1. Comparison of the simulated wheat yield (2004-2014) by Budget model.

Similar to previous stages, time periods for corn for the observation year (2004-2005) was set and comparison factors including RMSE, EF, and R^2 for calculated and observed data were extracted (table 2).

Table 2. comparison of fitness factors for observed and calculated data for corn crop

Comparison factors	Methods used					
	Multiplicative				Minimal	Seasonal
	=stageΔt_i	=10 dΔt_i	=5 dΔt_i	=2 dΔt_i		
	estimating yield based on(T_{a/T_c})					
RMSE(%)	13.5	9.2	12.3	14.6	17.2	14.8
EF(-)	0.83	0.77	0.80	0.77	0.05	0.71
(-)R^2	0.92	0.09	0.85	0.84	0.89	0.89
	estimating yield based on(ET_{a/ET_c})					
RMSE(%)	6.04	7.4	5.70	5.70	16.37	7.45
EF(-)	0.83	0.83	0.85	0.85	-0.26	0.74
(-)R^2	0.74	0.87	0.80	0.78	0.89	0.88

As it can be seen in the columns of the table above, the product method with 10 day time period whilst using potential relative evapotranspiration (ET_{a/ET_c}) provides the best fitness for the observed data. Their comparison factors are highlighted.

We are going to compare the simulated crop yield responsefor ten years (2004-2014) for corn (maize) using Budget model, in different irrigation depths, considering that: (figure 2).

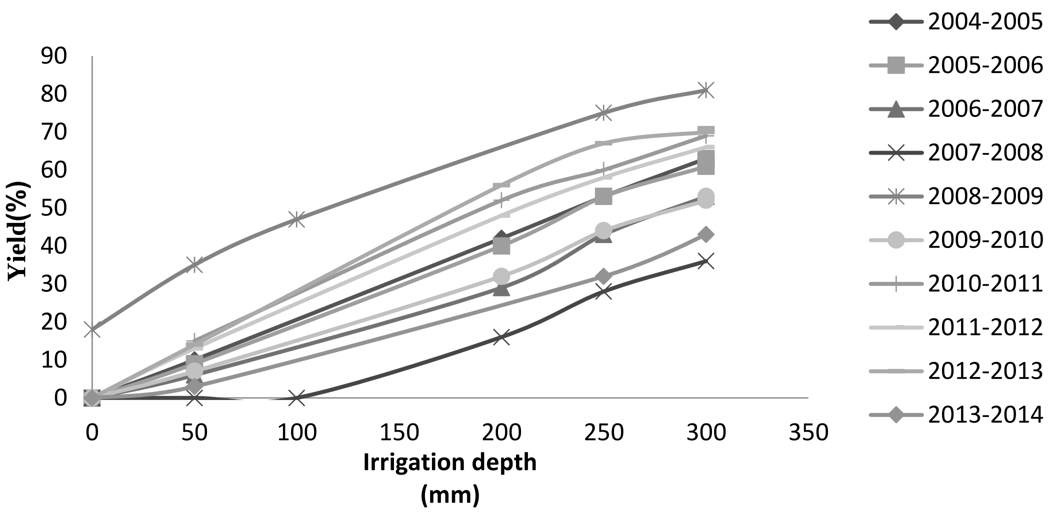

Figure 2. Comparison of simulated corn yield for 10 years (2004-2014) using the Budget model

4. Conclusions

Results of statistical analysis for 2 wheat fields under classic sprinkler irrigation and 2 corn fields with similar irrigation method shows that in simulation with product method with 10 day time periods and using potential relative evapotranspiration, model has a high accuracy. Amount of R^2between observed and simulated wheat crop yield is high and equal to 0.97. RMSE is low and around 7.6% and amount of EF is equal to 0.81. These amounts for Corn are respectively equal to 0.87, 7.4% and 0.83. therefor in order to simulate consumption water relations with performance or in other words to estimate crop yield under different irrigation schedule using Budget model in "Bilasovar" plain we should use product method with 10 time periods and potential relative evapotranspiration for model calibration.

Since plantation and harvest period of wheat crop covers winter to spring period in which temperature and evapotranspiration are low and there is a lot of rainfall during mid-season stage of its growth, this crop in rain fed conditions, when no irrigation has been done provides a yield equal to 40% to 70%. Whilst for forage corn in rained conditions except for one exception, provides yield response equal to 0%. Which is also due to the season in which plantation and harvest occurs. Meaning that since the mid-season stage of growth is in summer with high temperature and high evapotranspiration and low rainfall, crop does not receive enough water. All the mentioned conditions depends on the geographical and climate conditions of each region, that effects deficit irrigation conditions.

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