SIMULATION OF MAIZE CROP UNDER IRRIGATED AND RAINFED CONDITIONS WITH CROPWAT MODEL

Muhammad Nazeer
Department of Water Management, NWFP Agricultural University, Peshawar, Pakistan
E-Mail: hydro_shah12@yahoo.com

ABSTRACT

CROPWAT is an irrigation management and planning model simulating the complex relationships of on-farm parameters the climate, crop and soil. The CROPWAT facilitate the estimate of the crop evapotranspiration, irrigation schedule and agricultural water requirements with different cropping patterns for irrigation planning. The field experimental data of maize crop from the Mardan district of NWFP, Pakistan were collected and analyzed then input the results to the CROPWAT irrigation management model that was developed by the Food Agricultural Organization (FAO). The aim of this paper was to study CROPWAT simulation under irrigated and rainfed conditions for maize crop, in order to provide information necessary in taking decisions on irrigation management. The model, that calculates evapotranspiration and crop water requirements, allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions and yields reduction under various conditions. For the purpose of this paper, the model was run for the specific weather conditions of the year 2006, at two demonstration plots located in Mardan. Simulation results analysis suggests that areas, where the maize water requirements exceeds the water supply, by application of adequate irrigation scheduling the yield losses can be significantly reduced.

Keywords: model, CROPWAT, climate, irrigation, yield losses, Mardan.

INTRODUCTION

Computer model simulation is an emerging trend in the field of water management. Water managers, irrigation agronomists, engineers and researchers taking keen interest in model simulation for the easier solution of problems faced by them. CROPWAT is one of the models extensively used in the field of water management throughout the world. CROPWAT facilitate the estimate of the crop evapotranspiration, irrigation schedule, and agricultural water requirements with different cropping patterns for irrigation planning. The general objective of the study was to compare the simulation results of various options for water supply and irrigation management conditions (rainfed and irrigated) and, to estimate the yield reduction due to crop stresses under rainfed and irrigated conditions on maize crop. Previous studies by Craciun *et al.* (1994), Itier *et al.* (1996), and Adriana *et al.* (2000) have simulated CROPWAT for maize crop and have found that when the maize water requirements exceeds the water supply, by application of adequate irrigation scheduling the yield losses are significantly reduced. Models that adequately simulate the effects of water stress on yield can be valuable tools in irrigation management. These models can be used to optimize the allocation of irrigation water between different crops and/or the distribution of water during the crop season (Bryant et al 1992). Maize (*Zea mays* L.) an important Kharif (summer) cereal crop and staple food after wheat and rice, cultivated throughout the world, is of significant importance for countries like Pakistan, where rapid increase in population have increasing pressure on agricultural commodities. Maize is one of the most important crops in irrigated semiarid areas of the world. It has high irrigation requirements and is very sensitive to water stress (Rhoads and Bennett, 1990). Tariq and Jamal (2003) studied that optimal crop production demands decision-making processes of irrigation scheduling such as number of irrigation and their frequency to meet the crop water requirement. Proper irrigation scheduling is essential for efficient use of water and crop production. Under scarce and costly water supplies, it may sometimes be advantageous to stress the crop to some degree.

The irrigation demand of maize crop is varied according to climatic condition but in Pakistan it grow in the season of moonsoon rainfall from July-November. Musick and Dusek (1980) studied the yield response of irrigation maize to water deficits, and concluded that the seasonal irrigation water requirement was 400 mm, grain yields were 9.52-10.85 t/ha and seasonal water use efficiencies were 1.25-1.46 kg m^{-3}. Doorknobs and Pruitt (1983) reported that the water requirements of maize for maximum production varied between 430-490 mm per season depending on climate and length of growing period. Beside soil moisture status the climate have also direct impact on plant growth and yield. The rate of water uptake required to sustain normal plant growth at any given time depends not only upon soil water status but also upon the atmospheric conditions and properties of the plants (Ahuja and Neilson, 1990) So the CROPWAT is one of the computer models used to study climatic impact as well planning and management of irrigation scheduling.

In this study CROPWAT4 (Windows4.3) was applied to two maize crop plots in Mardan district. The objectives of this study were to:

- Apply CROPWAT model to maize crop in Mardan;
- Simulate results of various options for water supply and irrigation management conditions; and
- Study yield losses under irrigated and rainfed conditions.

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MATERIALS AND METHODS

Model description and input data

CROPWAT for Windows is a decision support system developed by the Land and Water Development Division of FAO, Italy with the assistance of the Institute of Irrigation and Development Studies of Southampton, UK and National Water Research Center, Egypt. The model carries out calculations for reference evapotranspiration, crop water requirements and irrigation requirements in order to develop irrigation schedules under various management conditions and scheme water supply. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules and the assessment of production under rainfed conditions or deficit irrigation. (Adriana *et al.*, 1999). CROPWAT for Windows uses the FAO (1992) Penman-Monteith method for calculation reference crop evapotranspiration. The development of irrigation schedules and evaluation of rainfed and irrigation practices are based on a daily soil-moisture balance using various options for water supply and irrigation management conditions. Scheme water supply is calculated according to the cropping pattern provided in the program. (Smith, 1992).

The potential evapotranspiration (ETo) was computed by Penman-Monteith Model (Allen *et al.*, 1998). In this model, most of the equation parameters are directly measured or can be readily calculated from weather data. The equation can be utilized for the direct calculation of any crop evapotranspiration (ETc). The FAO Penman-Monteith method to estimate ETo is:

$$ET_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma \dfrac{900}{T+273} u_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34u_2\right)} \quad \ldots\ldots\ldots (1)$$

ETo = reference evapotranspiration [mm day-1]
Rn = net radiation at the crop surface [MJ m-2 day-1]
G = soil heat flux density [MJ m-2 day-1]
T = mean daily air temperature at 2 m height [°C]
U2 = wind speed at 2 m height [m s-1]
es = saturation vapour pressure [kPa]
ea = actual vapour pressure [kPa]
es - ea = saturation vapour pressure deficit [kPa]
$\triangle$ =slope vapour pressure curve [kPa °C-1]
and
a = psychrometric constant [kPa °C-1].

The average climatic data and ETo calculated by P-M model is presented in Table-1.

Experimental fields

The Mardan district lies from 34° 05’ to 34° 32’ N latitudes and 71° 48’ to 72° 25’ E longitudes with an altitude of 283m. Two Plots situated in the main agricultural production zone of Mardan were selected. These plots were located in the southern part of Mardan and cover the diversity of the agro-pedo-climatic conditions in the main agricultural zone.

Climatic data

The monthly average climatic data (Table-1) of the year 2006 for the both sites were used including maximum and minimum air temperature, relative humidity, wind speed, sunshine duration and rainfall. The Department of Water Management provided this data.

Crop and soil data

For this study, sets of standard maize crop data that are included in the program were used. The crop coefficient (Kc) and crop yield data (Ky) have been updated by FAO. Maize crop was planted on 18th and 23rd of June, respectively. The crop is assumed to be planted all at the same time and cover 100% of the projected area. The model simulation requires of soil data, such as: heavy soil, medium soil and light soil which is fulfill by CROPWAT automatically having soil data option.

Simulations

The key steps in the simulation were:

I. CROPWAT model was run for maize crop with the monthly average climatic data for the two plots and different scheduling criteria: the rainfed Plot (Plot A) is simulated only on rainfall command while the irrigated Plot (Plot B) was simulated with fixed amount (25mm) and fixed interval (14 days).

II. Analyzed the model results and select the most suitable irrigation schedule options.

RESULTS AND DISCUSSIONS

The simulated values of reference evapotranspiration (ETo), Crop water requirement (CWR) and irrigation water requirement (IWR) for the maize crop in mardan district is shown in Figure-1.The reference crop evapotranspiration is at peak (6.08mm/day) at the beginning stage, slightly reduced at growing stage (5.20mm/day), than at mid stage (3.58mm/day) and at last stage it reaches to 1.36 mm/day. The decreasing of ETo values is due to increase in rainfall. The crop water requirement graph show that maize water requirement is increasing with the passage of time and required peak amount of water at the growing and developmental stage. The graph of irrigation water requirement remained below than the crop water requirement throughout the vegetation season of maize at both plots causing severe yield reduction. The criteria, which create, distinguish between CWR and IWR is the amount of rainfall.

Simulation under rainfed condition is done for maize sown; depend only on rainfall water, where there is no other source of irrigation, as shown in Figure-2. So the calculated soil moisture deficit (SMD) shows the effect of rainfall only. The values of SMD are very low for the first three-four decade during maize vegetation, follow increasing up, when it reaches to cross the limit of readily available moisture (RAM) in first decade of august. From

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the second decade of august the values of SMD remained higher than RAM values due to which severe yield reduction in maize crop occurred (96.2%) in growth stage three of maize vegetation season. The loss in total yield reduction was 53.3% (Table-2). The total available moisture (TAM) remained higher from (RAM) and (SMD) throughout the maize vegetation season.

Simulation for irrigated field of maize crop is done using the criteria of fixed interval of 14 days with irrigation application of fixed depth of 25mm from the first day of sowing (Figure-3). During the first four-irrigation application 73.8mm of water is lost, the first irrigation lost 23.2mm, the second lost 23.2mm, the third 22.8mm and fourth one irrigation lost 4.70 mm water. The main cause for losing of irrigation water is the bare soil. The relation of soil moisture deficit (SMD) and readily available moisture (RAM) is just like rainfed condition but having little differences in value as compared to rainfed condition simulation. The largest yield reduction (34.8%) occurred in growth stage three of maize vegetation season. Simulation estimated 16.9% yield reduction under irrigated condition (Table-3). Total available moisture (TAM) is same as in rainfed condition because the soil characteristic is same for irrigated as well rainfed plots.

CONCLUSIONS

- The model CROPWAT can appropriately estimate the yield reduction caused by water stress and climatic impacts, which makes this model as a best tool for irrigation planning and management in maize;
- The simulation results analysis suggest that in both condition (rainfed and irrigated), the largest yield reduction occurred in the stage three (developmental stage) due to increasing of soil moisture deficit (SMD) than readily available moisture (RAM), irrigation at this stage can reduce the chance of yield reduction appropriately; and
- It is economical to irrigate from the first day of sowing when the ratio of actual crop evapotranspiration to the maximum crop evapotranspiration (ETc/ETm) is 100 %.

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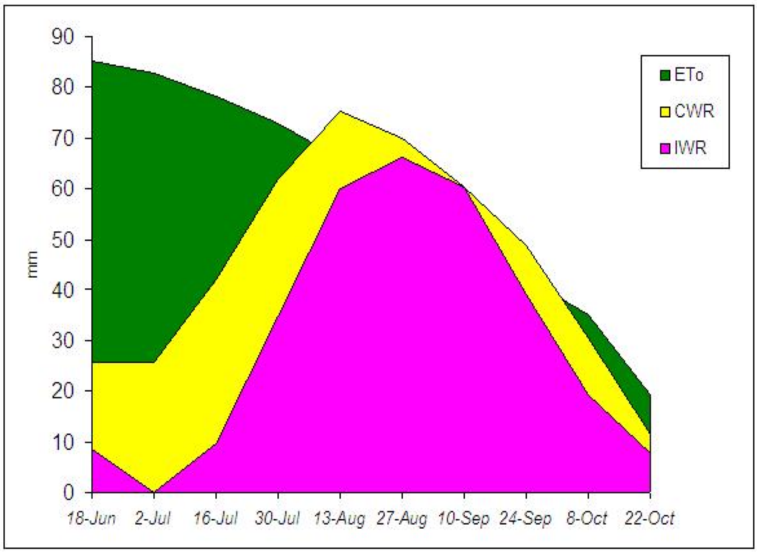

Figure-1. Simulation of CROPWAT model for maize crop in district Mardan.

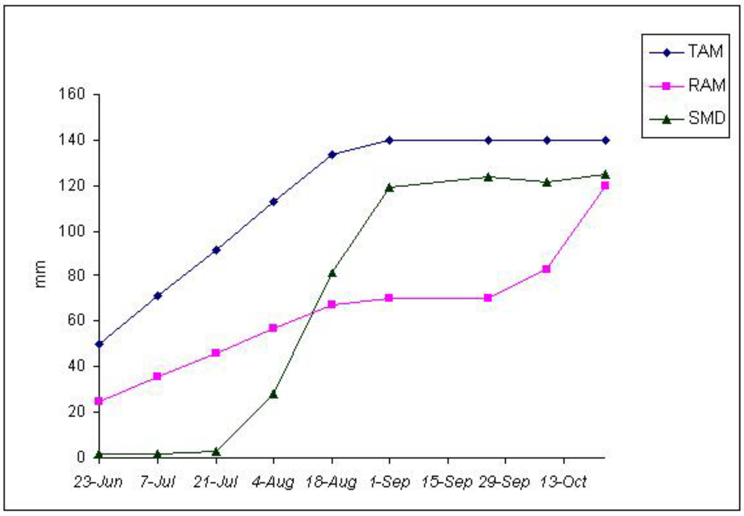

Figure-2. Simulation of maize under rainfed condition (Plot A).

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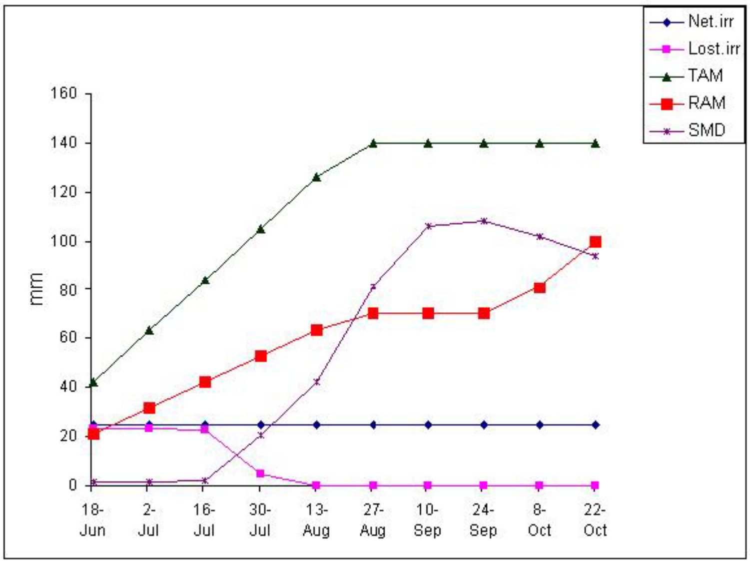

Figure-3. Simulation of maize under irrigated condition (Plot B).

Table-1. Average climatic data and ETo of Mardan district (2006).

Months	**T max**	**T min**	**Air humidity**	**Avg. wind speed**	**Sunshine**	**Rainfall**	**ETo**
	°C	°C	%	km/hr	hours	mm	mm/day
Jan	15.4	4.27	74.12	28.9	4.7	63.2	2.70
Feb	23.36	10.22	68.07	25.3	5.4	12.2	4.42
Mar	23.92	12.65	96.64	43.3	5.6	57	2.36
Apr	33.66	16.95	48.73	59.3	9.04	42	4.47
May	42.8	24.8	38.87	69	10.31	5.2	6.15
Jun	43.06	26.01	41.3	81.3	10.31	18.6	6.61
July	40.81	28.31	62.77	82.4	7.89	80	5.78
Aug	36.08	27.1	71.41	62.2	6.45	46.6	4.46
Sep	38.85	24.14	61.24	52.9	7.96	6.8	4.27
Oct	31.2	18.9	65.93	35.8	7.12	25.4	2.61
Nov	22.68	12.93	78.64	19.8	4.5	23.6	1.26
Dec	17.27	6.36	79.8	23.9	4.43	79	0.85

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Table-2. Simulation of maize under rainfed condition (Plot A).

Date	TAM	RAM	Total Rain	Efect. Rain	ETc	ETc/ETm	SMD	Interv.	Net Irr.	Lost Irr.	User Adj.
	(mm)	(mm)	(mm)	(mm)	(mm)	(%)	(mm)	(Days)	(mm)	(mm)	(mm)
23/6	49.5	24.8	24.2	9.2	1.8	100.00%	1.8				
7/7	70.6	35.3	35	25.3	1.8	100.00%	1.8				
21/7	91.8	45.9	35.8	29.1	2.8	100.00%	2.8				
4/8	112.9	56.4	25.7	25.7	4.3	100.00%	28.2				
18/8	134	67	10.8	10.8	4.6	92.90%	81.4				
1/9	140	70	1.3	1.3	1.6	52.40%	119.4				
15/9	140	70	12.5	12.5	0.9	16.00%	124				
29/10	140	0 82.6	11.1	11.1	0.9	18.90%	121.6				
13/10	140	102.2	5	5	0.6	30.50%	125.1				
Total			**161.4**	**130**		**57.30%**			**0**		**0**

Yield Reduction:
- Estimated yield reduction in growth stage # 1 = 0.0%
- Estimated yield reduction in growth stage # 2 = 2.3%
- Estimated yield reduction in growth stage # 3 = 96.2%
- Estimated yield reduction in growth stage # 4 = 36.8%

- Estimated total yield reduction = 53.3%

Table-3. Simulation of maize under irrigated condition (Plot B).

Date	TAM	RAM	Total Rain	Efct. Rain	ETc	ETc/ETm	SMD	Interv.	Net Irr.	Lost Irr.	User Adj.
	(mm)	(mm)	(mm)	(mm)	(mm)	(%)	(mm)	(Days)	(mm)	(mm)	(mm)
18/6	42	21	10.6	0	1.8	100.00%	1.8	0	25	23.2	
2/7	63.1	31.6	36.1	23.7	1.8	100.00%	1.8	14	25	23.2	
16/7	84.2	42.1	36.1	23.8	2.2	100.00%	2.2	14	25	22.8	
30/7	105.3	52.7	23.2	23.2	3.8	100.00%	20.3	14	25	4.7	
13/8	126.4	63.2	21	21	5.1	100.00%	42	14	25	0	
27/8	140	70	9.6	9.6	4.8	97.50%	81	14	25	0	
10/9	140	70	3.2	3.2	2.4	76.90%	106	14	25	0	
24/9	140	70	7.3	7.3	1.9	58.40%	108	14	25	0	
8/10	140	81.2	11.5	11.5	1.9	62.60%	102	14	25	0	
22/10	140	100.8	11.3	11.3	1.5	97.90%	94.2	14	25	0	
Total			**170**	**134.6**		**86.5%**			**250**	**73.8**	**0**

Yield Reduction:
- Estimated yield reduction in growth stage # 1 = 0.0%
- Estimated yield reduction in growth stage # 2 = 0.0%
- Estimated yield reduction in growth stage # 3 = 34.8%
- Estimated yield reduction in growth stage # 4 = 9.2%

- Estimated total yield reduction = 16.9%