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Estimation of Irrigation Water Requirements and Yield Reduction under Different Soil Moisture Depletion Levels for Maize, Using Fao Cropwat Model

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Abstract: A research study was conducted to investigate the effect of different soil moisture depletion levels on yield of maize crop by using FAO CROPWAT window model. Four soil moisture depletion levels 100, 80, 60 and 40% SMD were simulated for the average climatic data of 1984-2008. 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 simulation results showed that during maize growing season the temperature and rainfall uncertainty reduced the crop yield appropriately. Most of the yield reduction occurred in the growth stage third (GS3) and growth stage four (GS4). By planning and management of adequate irrigation scheduling at these stages, the yield losses can be significantly reduced.

Key words: Yield · Maize · CROPWAT · Soil Moisture · Simulation · Tarnab

INTRODUCTION

Maize (*Zea mays* L.) is 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 [1]. 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 [2] 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}. Doorenobs and Pruitt [3] 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 [4]. So the CROPWAT is one of the computer models used to study climatic impact as well planning and management of irrigation scheduling.. Under scarce and costly water supplies, it may sometimes be advantageous to stress the crop to some degree. The water stress may reduce the crop yield to some extent but it will remain economically feasible as long as the marginal benefit from reduced cost of water is equal or greater than marginal cost of reduced yield [5]. critical crop growth stages and irrigation schedules for maximizing production are highly desirable along with the availability of adequate amount of water to meet the crop requirement [6-8].

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

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agricultural water requirements with different cropping patterns for irrigation planning [9]. Previous studies by Cavero *et al.* [10], Craciun and Craciun [11], Itier and Brunet [12] and Maria Adriana and Cuculeanu [13] 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 [14]. The objectives of the study were to evaluate the maize crop water requirement on the basis of 25 years climatic data analysis, compare the simulation results and to estimate the yield reduction due to different soil moisture depletion levels of irrigation water supply using FAO CROPWATW Model.

MATRERIALS AND METHODS

CROPWAT 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 [15]. CROPWAT for Windows uses the FAO [16] 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 [17].

The potential evapotranspiration (ETo) was computed by Penman-Monteith Model [18]. 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 given in Equation 1:

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

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]
= slope vapour pressure curve [kPa°C^{-1}]
a = psychrometric constant [kPa°C^{-1}].

Site Description: Agriculture research station Tarnab, Peshawar is the oldest research station in NWFP, Pakistan. The Peshawar district lies from 34 degrees 05 to 34 degrees 32 north latitudes and 71 degree 48 to 72 degree 25 east longitudes with an altitude of 348 meters. The average annual maximum and minimum temperature of the area are 29.6 and 13.8°C respectively, with 455.87 mm of annual rainfall.

Table 1: Average Climatic Data of Tranab, Peshawar (1984-2008)

	T max	T min	Air humidity	Avg. wind speed	Sunshine	Rainfall
Months	°C	°C	%	Km/hr	hours	mm
Jan	18.6	2.1936	53.3488	50.6932	5.81	38.0124
Feb	20.6724	4.7844	50.69	63.2304	6.338889	54.36536
Mar	24.9748	9.3408	51.728	61.5864	6.473158	73.8952
Apr	30.848	13.7892	48.218	61.3128	7.322105	44.9744
May	36.5936	18.608	39.4172	78.0044	8.214211	19.0496
Jun	39.4424	22.2144	39.94	84.2904	8.4025	15.0648
July	36.9012	24.6224	54.386	93.1856	7.733	53.9376
Aug	35.5408	24.4736	59.8992	82.5944	7.244444	71.9856
Sep	34.6376	21.4156	55.0096	56.838	7.271667	27.774
Oct	30.9544	14.0264	55.3336	41.9868	7.343333	18.426
Nov	25.4968	7.6408	58.2988	34.5604	6.537778	14.6792
Dec	20.4836	3.1728	57.936	38.8504	5.661875	23.8344

Climatic Data: The monthly average climatic data of twenty five years (1984-2008) of for the research site were used including, maximum and minimum air temperature, relative humidity, wind speed, sunshine duration and rainfall. The Department of water Management provided these data (Table 1).

Crop and Soil Data: For this research 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 CROPWAT. Maize crop was usually planted in july in the research site. 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 Process

The Key Steps in the Simulation Were:

- CROPWAT model was run for maize crop with the monthly average climatic data of the past 25 years for Tarnab, with 100, 80, 60 and 40% soil moisture depletion levels.
- Analyzed the model results for Irrigation water requirements, crop water requirements and yield reduction to select the most suitable irrigation schedule options.

RESULTS AND DISCUSSION

Analysis of Climatic Data: Analysis of climatic data is much important for precise management of agriculture commodities. The Effects of weather and climate variability on crop production, agrometeorological variables are one of the key inputs required for the operation of crop simulation models. These include maximum and minimum air temperature, air humidity, wind speed, sunshine hours, total solar radiation and total rainfall. Out of these the temperature and rainfall have very sensitive and direct impact on crop production. Maize crop are usually sown in the month of July in Pakistan, Figure-1 indicates on the basis of twenty five years climatic data analysis, that from July the temperature remains almost high which cause adverse effect on crop production if no rainfall occur. Due to high temperature the evpotranspiration also remain in the extent of 5.5 mm to 3 mm per month during maize growing season.

Figure 2 indicates that the humidity of the research site is up to 55% average, during maize growing season. Wind speed is at peak during July at the beginning of maize crop which tends to decrease and reached to 45 km/day in the harvesting stage of the crop. Eight hours sunshine is observed during sowing stage after this there is no fluctuation in sunshine's hour's graph.

Figure 3 describes that the average rainfall of july, sowing season is 53.9 mm which reached to peak in the month of august up to 72 mm per month and then decreased to 18.4 mm per month during maize crop growing season.

Crop Water Requirements and Irrigation Water Requirements: The simulated values of reference evapotranspiration (ETo), Crop water requirement (CWR) and irrigation water requirement (IWR) for the maize crop in Tarnab,Peshawar is shown in Figure 4. The reference crop evapotranspiration is at 100 mm per fourteen days period at the growth stage one (GS1) slightly reduced then tends to move up to peak during growth stage second (GS2), while steadily decreasing during growth stage third (GS3) and at last growth stage (GS4) it reaches to 20 mm/period. 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 growth sage second (GS2) and growth stage third (GS3). The graph of irrigation water requirement remained below than the crop water requirement throughout the vegetation season of maize. The criteria, which create, distinguish between CWR and IWR is the amount of rainfall.

Soil Moisture Depletion Levels and Yield Reduction: To estimate that how much irrigation required by each soil moisture depletion (SMD)level the models was run at 40%SMD, 60%SMD, 80%SMD and 100%SMD shown in Fig. 5. The irrigation water requirement of maize crop is 400-450 mm depend on the growing season and climate. To keep root zone at 40, 60, 80 and 100%SMD the irrigation applied must be 130, 100, 60 and 0 mm for each SMD level, respectively.

Estimated yield reduction as consequence of the applied soil moisture depletion levels is shown in Fig. 6. It is obvious the highest average yield reduction (30.4%) estimated in 100%SMD having the largest yield reductions in growth stage third (GS3) and growth stage fourth (GS4) of 54.1 and 33.3%, respectively.

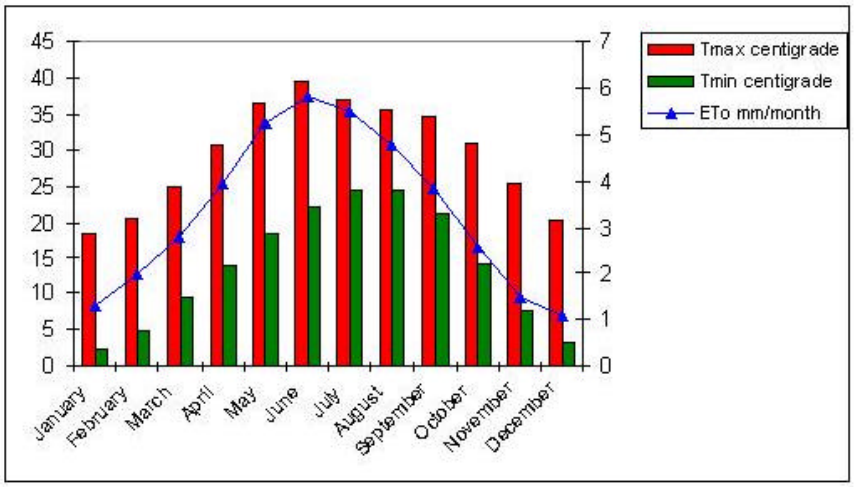


Fig. 1: Average monthly climatic variables of 1984-2008

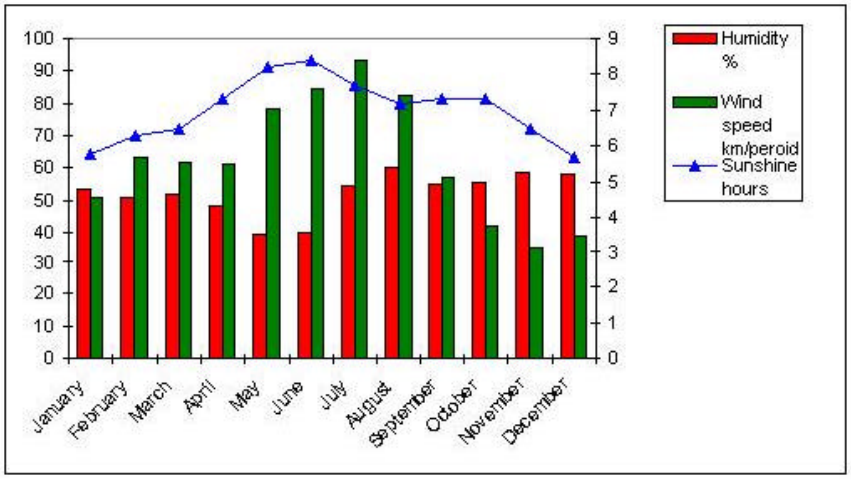


Fig. 2: Average monthly climatic variables of 1984-2008

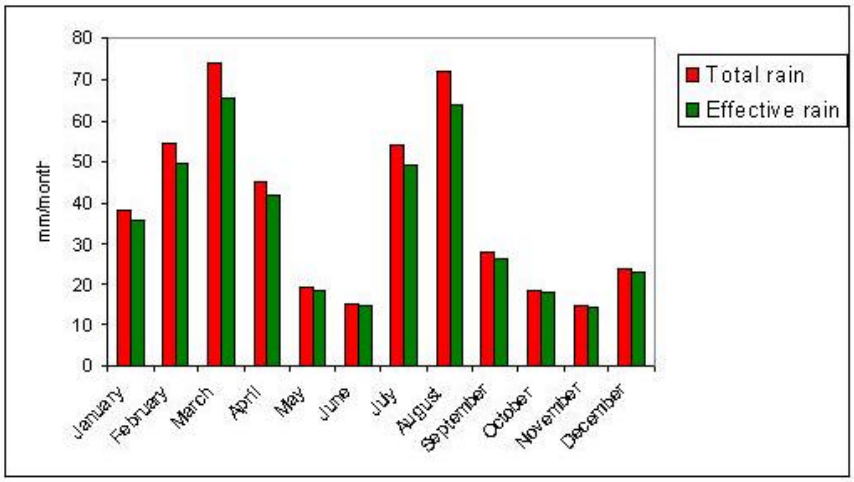


Fig. 3: Average monthly climatic variables of 1984-2008

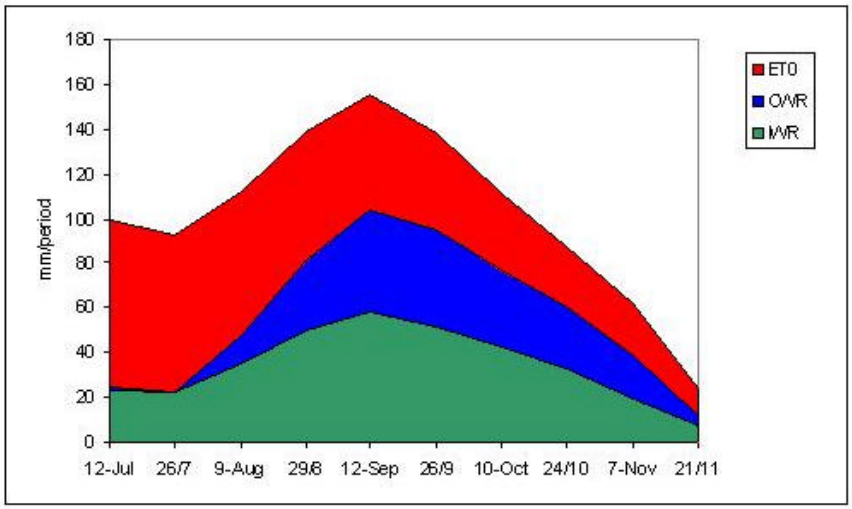


Fig. 4: Simulated values of ETo,CWR and IWR of Maize in Tarnab,Peshawar

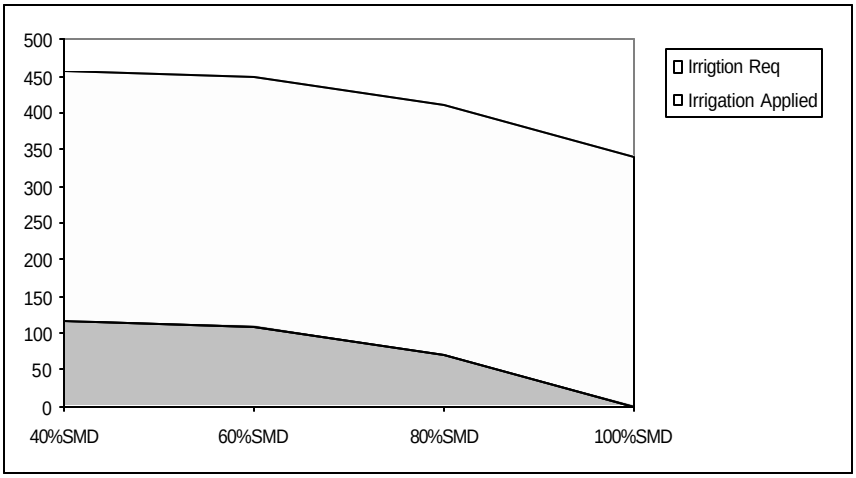
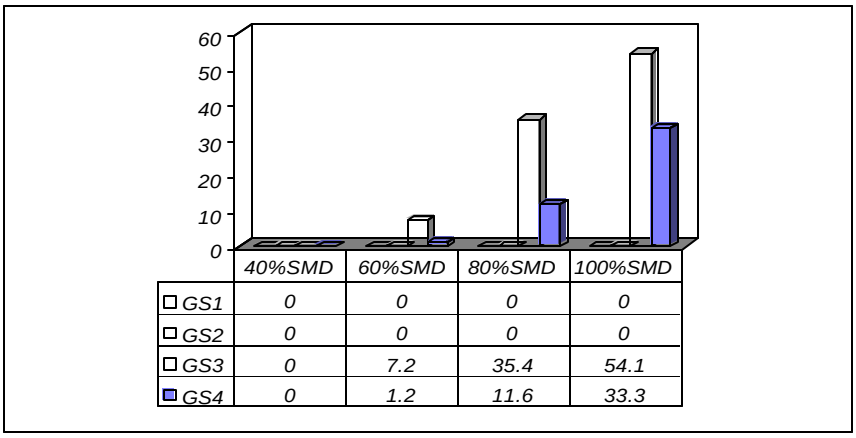


Fig. 5: Different SMD levels with irrigation required and irrigation applied



	40%SMD	60%SMD	80%SMD	100%SMD
GS1	0	0	0	0
GS2	0	0	0	0
GS3	0	7.2	35.4	54.1
GS4	0	1.2	11.6	33.3

Fig. 6: Estimated yield reduction of different SMD levels

The average yield reduction estimation of the 80%SMD is 16.7% with 35.4% and 11.6% of growth stage third (GS3) and growth stage fourth (GS4), respectively. The total estimated yield reduction in 60%SMD is 3.1% with 7.2% and 1.2% in growth stage third (GS3) and growth stage fourth (GS4). The model does not estimated any yield reduction in 40%SMD.

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 suggests that in all soil moisture depletion levels (SMD) conditions, the largest yield reduction occurred in the growth stage three (GS3) irrigation at this stage can reduce the chance of yield reduction appropriately. It is easier to analysis large climatic data of several years trough CROPWAT for decision making, planning and management of on form water management practices.

AKNWOLEDGMENT

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