WATER YIELD RELATIONSHIP AND TRANSPIRATION EFFICIENCY OF MAIZE *(ZEA MAYS L.)* UNDER SEMI-ARID SUBTROPICAL CONDITION OF FAISALABAD

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ABSTRACT : *Pakistan is blessed with the largest naturally flowing irrigation system in the world, with total inflow of about 150 MAF. Out of which only about 103 MAF is available for irrigation. This available quantity is not sufficient for sustainable crop production. However, the efficiency of the system is quite low resulting in lower CWP. Keeping in view the future projection of climate change it is necessary to enhance/increase crop water production at field scale, which can be achieved through deficit irrigation. In this study, the experiment was conducted at the experimental fields of the Nuclear Institute for Agriculture & Biology (NIAB), Faisalabad With three different treatment of deficit irrigation (0% deficit, 20% deficit, 40% deficit) under RCBD with 3 replicates. Irrigation was applied after 3 days, 5 days, 7 days irrigation interval. Crop growth model was used to simulate water yield relationship and transpiration efficiency under control and deficit condition.*

INTRODUCTION

Pakistan is blessed with the largest naturally flowing irrigation system in the world. It is serving as an agent for the sustainability of agriculture in Pakistan which has a diverse climate due to arid to semi-arid behavior. According to Köppen–Geiger climate classification Pakistan falls in Bwh region. The long history of irrigation in the Indus basin originates from the Indus civilization. The share of water for each province has been decided in the Water Apportionment Accord in 1991. The total inflow to the rivers of Pakistan is about 150 MAF out of which only 103 MAF able to reach the field. Drainage canals were built as an improvement strategy in middle of 19^{th} century. These canals were converted to purely regulated crops which are perennial & non perennial canals by placing weirs and barrages. A chain of Indus basin link canals and storage reservoirs were built as a result of the Indus water treaty from 1960 – 1975(PIDA, 2011).

The irrigation system of Punjab is an integral part of Indus basin irrigation system of Pakistan. It was built with the aim to bring as much barren land under initial cropping intensity approximately ranging from 60% to 80%. Due to inclusion of groundwater from tube wells swelled the intensity to 122% on an average and 150% as maximum.

To increase cultivable land from the existing water resources is a difficult task. The world population is increasing gradually and it is expected to reach up to 8.9 billion by 2050 (World Population, 2004). The main effect of the projected population would be an increase in the demand for food and it would further raise immense demand on limited water resources. So single option is to increase crop water productivity either by high efficiency irrigation system (HEIS) or emerging techniques of deficit irrigation

Regulated deficit irrigation (RDI), first proposed by (Chalmers et al., 1981) as an irrigation strategy to save water without reducing crop yields, consists of the reduction of irrigation water to predetermined levels at certain developmental stages when the effects on crops are neutral or positive. Deficit or regulated deficit irrigation is one way to maximize the water use efficiency for higher yield per unit of irrigation. The purpose of deficit irrigation is to increase crop water use efficiency (WUE) by reducing the amount of water at irrigation or by reducing the number of irrigation events (Kidra, 2002).In this practice, crops are deliberately exposed to water stress, which may (Smith et al., 2002; Prichard et al.,2004; Zhang et al., 2004)reduce crop yield . However, the reduction in yield is not proportional to planned reduction in irrigation water. The determination of transpiration under field condition $cwp=\sum Y/\sum T$ are difficult to measure which can be simulated using crop growth model.

There are different Crop models viz. CERES-Maize (Jones and Kiniry, 1986), WOFOST model, CropSyst (Stockle et al., 2003), and the Hybrid-Maize model (Yang et al., 2004) have been used for prediction of yield of maize crop.

In this situation, the recently developed FAO Aqua Crop model (Raes et al., 2009; Steduto et al., 2009) is a user-friendly and practitioner oriented type of model, because it maintains an optimal balance between accuracy, robustness, simplicity and requires relatively small number of model input parameters. The particular features that differentiates Aqua crop from crop models are, it is water based, its basic equation is water driven, the use of ground water canopy instead of leaf area index (LAI).in fact, the model converts daily transpiration (Tr) directly to daily biomass production, using daily reference evapotranspiration (ETo) and normalized water productivity (WP). In the model, the effects of water deficit, quantified as fractional depletion of soil water relative to water holding capacity of root zone, are manifested through four stress response functions which include inhibition of foliage canopy growth, inhibition of stomatal conductance, acceleration of canopy senescence, and changes in harvest index (HI).

MATERIALS AND METHODS

The present study was conducted at Nuclear Institute of Agriculture and Biology (NIAB) Jhang Road, Faisalabad, North 31º 25’0″East 73º5’0″;elevation 182m above sea level during 2013, to simulate maize using aqua crop model under 100% irrigation, 80%, and 60% with 3 days , 5 days and 7 days irrigation intervals on maize yield using furrow irrigation method. Data of 100% ETc at 3 days interval was used for model calibration and validation / simulation of model performed using remaining treatments 3 days 80%, 3days 60%, 5days100%, 5 days 80%, 5 days60%, 7 days100%, 7 days 80% and 7 days 60%.

Aqua Crop used climatic crop, irrigation, soil data and initial soil moisture contents. Climatic data included maximum and minimum air temperatures (ºc), rainfall (mm), reference evapotranspiration ETc (mm/day) and CO_2 concentration, were obtained from NIAB's metrological station, except CO_2 concentration that was already built in Aqua Crop. Reference evapotranspiration was calculated using ETo calculator (Version 3.1), developed by FAO. Crop data included planting population, crop germination, maximum canopy cover (%), maximum root depth (m), senescence (DAS) and crop maturity (DAS). Canopy cover was calculated from LAI using equation developed by Charles-Edwards et al. (1986). Yield and biomass were recorded after crop harvesting.

Amount of irrigation water was applied by using furrow irrigation method. Soil moisture profile was monitored with the help of neutron probe. Moisture contents at the depth of 15-95 cm were monitored before irrigation. The amount of irrigation in mm and 18 irrigation were applied throughout the season, when crop was irrigate after 3 days interval. Similarly 10 and 7 irrigation were applied when crop was irrigate after 5 days and 7 days irrigation interval respectively. Total amount of water applied through furrow system at 100%ETc, 80% ETc and 60% ETc were 257mm, 206mm and 155mm, respectively. Irrigation data used by Aqua Crop was the time and the amount of irrigation applied.

Soil of study area was sandy clay loam having field capacity (FC) of 27% and permanent wilting point (PWP) of 15%. Aqua Crop used soil type, FC and PWP for its simulation. Initial soil water contents were recorded before sowing and it was monitored using neutron probe. At five depth, soil moisture were monitored (0-15, 15-35, 35-55, 55-75 and 75-95cm) using neutron probe. In all five depths, the moisture content below FC.

Aqua Crop (v4) is a crop water productivity model developed by the Land and Water Division of FAO. It simulates yield response to water of herbaceous crop, and is particularly suited to address conditions where water is a key limiting factor in crop production. Aqua crop was developed to achieve a balance between simplicity, accuracy, robustness and requires relatively limited number of input parameters for ease of use. It has a water-driven growth-engine for field crops with growth-module that relies on the conservative behavior of biomass per unit transpiration (Tr) relationship (Steduto et al., 2009) Aqua Crop is a menu-driven program, with a set of input files that describe the soil crop atmosphere environment in which the crop develops, in addition to the seasonal field practices. Aqua Crop use the evapotranspiration data and it divided it into evaporation and transpiration.

Aqua Crop progressed by (i) separating the ET into crop transpiration (T_r) and soil evaporation (E), (ii) developing a simple canopy growth and senescence model as the basis for the estimate of T_r and its separation from E, (iii) treating the final yield (Y) as a function of final biomass (B) and HI, and (iv) segregating effects of water stress into four components: canopy growth, canopy senescence, T_r, and HI. The separation of ET into T_r and E avoids the confounding effect of the nonproductive consumptive use of water (E), which is important especially during incomplete ground cover, and led to the conceptual equation at the core of the Aqua Crop growth engine:

$B = WP \times Tr$

Where WP is the water productivity (biomass per unit of cumulative transpiration), which tends to be constant for a given climatic condition (De Wit,1958; Hanks, 1983; Sinclair, 1998) As in other models, Aqua Crop structures its soil crop atmosphere continuum by including (i) the soil, with its water balance; (ii) the plant, with its growth, development, and yield processes; and (iii) the atmosphere, with its thermal regime, rainfall, evaporative demand, and carbon dioxide concentration. Additionally, some management aspects are explicit, with emphasis on irrigation, but also the levels of soil fertility as they affect crop development, water productivity, and crop adjustments to stresses, and therefore final yield. Pests and diseases are not considered.

Performance evaluation of Aqua Crop Model

Aqua Crop was calibrated by using the data of 2013, with three irrigation treatments. Some model parameters, canopy cover and water productivity (gm^{-2}), were adjusted until satisfactory results were achieved. Canopy cover in 2013 was calculated from LAI, because digital photographs were not available. Aqua Crop performance was evaluated and a linear regression was determined between the observed and simulated values of yield and biomass.

Four statistic terms Root Mean Square Error (RMSE), Normalized root mean square error (NRMSE), Model efficiency (ME) and Index of Agreement (d) for model goodness were used.

Root mean square error (RMSE)

The root mean square error (RMSE), calculated according to (Loague and Green, 1991).

$$RMSE = \sqrt{1/(N)\sum_{i=1}^{N}(O_i - S_i)^2}$$

Where,

Oi = Observed value, Si = Simulated value, N = No. of observations

Values of RMSE close to zero indicate the best fit of the model.

Model efficiency (ME)

Model efficiency (ME) was calculated based on (Loague and Green, 1991) Equation. ME is a measure of the robustness of the model:

$$ME = \frac{\sum_{i=1}^{n}(O_i - MO)^2 - \sum_{i=1}^{n}(S_i - O_i)^2}{\sum_{i=1}^{n}(O_i - MO)^2}$$

Where,

Oi= observed values, Si=simulated values, MO = the mean observed value

ME ranges from negative infinity topositive 1; the closer to1, the more robust the model. **Normalised root mean square error(NRMSE)**

The nRMSE, calculated as described by (Loague and Green ,1991), gives a measure (%) of the relative difference of simulated versus observed data

$$nRMSE = \left[\sum_{i=1}^{n} \frac{(P_i - O_i)^2}{n}\right]^{0.5} \times \frac{100}{M}$$

Where,

n =the number of observations, Pi= simulated values, Oi = observed values

M = mean of the observed variable

The simulation is considered to be excellent when the nRMSE is less than 10%, good when it is greater than 10% and less than 20%, fair if greater than 20% and less than 30%, and poor if greater than 30% (Jamieson et al., 1991).

Index of Agreement (d)

The index of agreement (d) was calculated using the (Willmott et al., 1985)equation:

$$\mathrm{IoA} = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}\left(\left|P_i'\right| + \left|O_i'\right|\right)^2}$$

Where,

IoA = Index of Agreement (d), Pi' =Pi – P, Pi =Measured value, P = Mean of measured value, Oi' =Oi – O, Oi =Simulated value, O= Mean of simulated value

Statistical Analysis of Data

The canopy cover, yield, in season biomass and harvest index of maize and yield water use efficiency and biomass water use efficiency data at harvest were analyzed statistically using variance techniques according to the Randomized Complete Block Design (RCBD). Significantly means were separated using LSD at 5% probability level.

RESULTS AND DISCUSSIONS

Data of 100% ET at 3days irrigation interval was used for model calibration.

Fig 4.11 indicates that the simulated and measured biomass are closer, the model calibrated well the seasonal trend in above ground biomass in 100% ETc (Fig 4.10). There was an over prediction in aboveground biomass in 100%ETc irrigation treatments. Simulated values of biomass are higher than the measured values. RMSE=0.803 t ha^{-1}, NRMSE=12.4, EF=0.99 and d=0.99 which are in the range of accepted values.

The calibration of the seasonal evaluation of CC (%) was performed, and the results are shown in Fig.4.12.

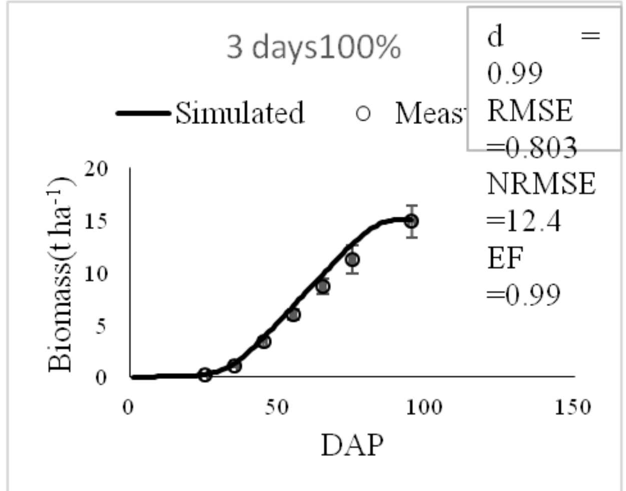

Fig: 4.11: Measured and simulated biomass (t ha^{-1}) for the 100% ETc of growing season (DAP=day after planting)

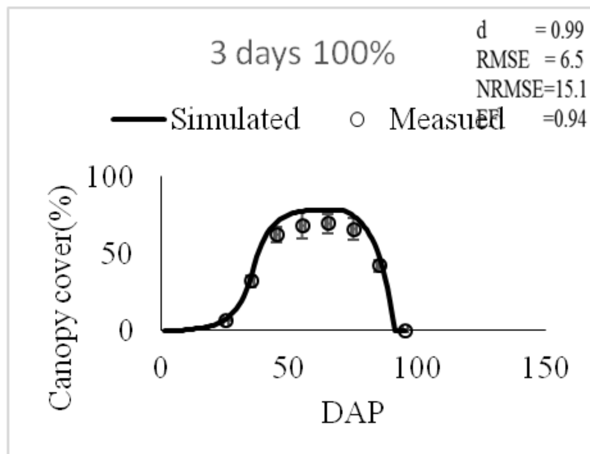

Fig: 4.12: Measured and simulated Canopy Cover (%) for the 100% ETc of growing season (DAP=day after planting)

There was over estimation of CC in 100% ETc irrigation treatment. The simulated maximum value was higher than the measured value. The reason may be due to over estimation of CC and initial soil water content. RMSE=6.5 t ha^{-1}, NRMSE=i5.1, EF=0.94 and d=0.99 which are in the range of accepted values. Statistical evaluation also confirm that the model is accurate.

Model Validation/Simulation

Validation/simulation of the model was performed using the calibrated model for irrigation data from other treatments (80% ET, 60% ET) with 3, 5 and 7 days irrigation interval. Biomass (t ha^{-1}) and canopy cover (%) were very well predicted in all treatments. In the calibrated model, just given the irrigation data of 80 and 60% ET with 3, 5 and 7 days irrigation interval and then results were checked. Model gave good and satisfactory results of biomass and canopy cover (Table 4.15).

Table 4.15: Statistical analysis of treatments by using aqua crop model

Treatment		Parameters	RMSE	NRMSE	EF	IOA(d)
3days	100%	% CC	6.5	15.1	0.94	0.99
		Biomass	o.803	12.4	0.97	0.99
3days	80%	% CC	13.7	36	o.75	0.94
		Biomass	0.840	13.5	0.97	0.99
3days	60%	% CC	5.4	16.7	0.95	0.99
		Biomass	0.903	18.2	0.92	0.98
5days	100%	% CC	7.8	15.9	0.88	0.97
		Biomass	0.804	12.5	0.97	0.99
5days	80%	% CC	6.5	15.2	0.94	0.99
		Biomass	0.807	12.8	0.97	0.99
5days	60%	% CC	5.8	15.9	0.95	0.99
		Biomass	1.048	20.3	0.91	0.98
7days	100%	% CC	6.5	15.2	0.94	0.99
		Biomass	0.788	12.5	0.98	0.99
7days	80%	% CC	6.5	15.2	0.94	0.99
		Biomass	0.781	12.7	0.97	0.99
7days	60%	% CC	6.7	15.0	0.91	0.98
		Biomass	1.322	25.3	0.86	0.97

Table 4.15 indicates that statistical parameters regarding canopy cover and biomass of different irrigation intervals (days) and deficit level by using Aqua Crop model.

The Statistical results of Canopy Cover shows that the minimum value of RMSE was 6.5 t ha^{-1} at 100%ETc when crop was irrigated at 3days and 7 days interval, while maximum RMSE was 7.8 t ha^{-1} was noted at 100% ETc when crop was irrigated at 5 days interval. Value of Normalized root means square error (NRMSE) found in good range (15.1 to 15.9%) at 100% ETc. Value of Nash-sutcliffe model efficiency (EF) found in good range (o.88 to 0.94) near to one at 100% ETc. Value of d (Willmott index of agreement) was near to one(0.97 to o.99).

The Statistical results of biomass shows that the minimum value of RMSE was 0.788 t ha^{-1} at 100%ETc when crop was irrigated at 7 days interval, while maximum RMSE was 0.804 t ha^{-1} was noted at 100% ETc when crop was irrigated at 5 days interval. Value of Normalized root means square error (NRMSE) found in good range (12.4 to 12.5%) at 100% ETc. Value of Nash-sutcliffe model efficiency (EF) found in good range (o.97 to 0.98) near to one at 100% ETc. Value of d (Willmott index of agreement) was near to one(o.99).

The Statistical results of Canopy Cover shows that the minimum value of RMSE was 6.5 t ha^{-1} at 80%ETc when crop was irrigated at 5days and 7 days interval, while maximum RMSE was 13.7 t ha^{-1} was noted at 80% ETc when crop was irrigated at 3 days interval. Value of Normalized root means square error (NRMSE) found in good range (15.2%) at 80% ETc when crop was irrigate at 5days and 7 days interval, while value of NRMSE was not satisfactory (36%) when crop was irrigate at 3days interval. Value of Nash-sutcliffe model efficiency (EF) found in good range (o.75 to 0.94) near to one at 80% ETc. Value of d (Willmott index of agreement) was near to one (0.94 to o.99).

The Statistical results of biomass shows that the minimum value of RMSE was 0.781 t ha^{-1} at 80%ETc when crop was irrigated at 7 days interval, while maximum RMSE was 0.840 t ha^{-1} was noted at 80% ETc when crop was irrigated at 3 days interval. Value of Normalized root means square error (NRMSE) found in good range (12.7 to 13.5%) at 80% ETc. Value of Nash-sutcliffe model efficiency (EF) found in good range (o.97) near to one at 100% ETc. Value of d (Willmott index of agreement) was near to one (o.99).

The Statistical results of Canopy Cover shows that the minimum value of RMSE was 5.4 t ha^{-1} at 60%ETc when crop was irrigated at 3days interval, while maximum RMSE was 6.7t ha^{-1} was noted at 60% ETc when crop was irrigated at 7days interval. Value of Normalized root means square error (NRMSE) found in good range (15.0 to 16.7%) at 60% ETc. Value of Nash-sutcliffe model efficiency (EF) found in good range (o.91 to 0.95) near to one at 100% ETc. Value of d (Willmott index of agreement) was near to one(0.98 to o.99).

The Statistical results of biomass shows that the minimum value of RMSE was 0.903 t ha^{-1} at 60%ETc when crop was irrigated at 3 days interval, while maximum RMSE was 1.322 t ha^{-1} was noted at 80% ETc when crop was irrigated at 7 days interval. Value of Normalized root means square error (NRMSE) found in satisfactory range (18.2 to 25.3%) at 60% ETc. Value of Nash-sutcliffe model efficiency (EF) found in good range (o.86 to 0.92) near to one at 100% ETc. Value of d (Willmott index of agreement) was near to one (o.97 to 0.98).

Aqua Crop simulated biomass all for treatment with the RMSE was satisfactory. Overall biomass was over estimated by the model for all the treatments but RMSE shows that's results were satisfactory.

The model simulate the grain yield with good accuracy under optimal nand water stress conditions. Maximum value of yie;d was obtain for 100% ETc at 3 days interval i.e.7.052 t ha^{-1}. In Aqua Crop, for the evalution of yield throught the crop cycle, acceptable precision was reached. Good results were obtained for simulation of yield at harvest. Model over predict the yield.

CONCLUSIONS

The maize yield and irrigation water use efficiency simulation data we derived and analyzed suggest that the Aqua Crop model can be used with a high degree of reliability in practical management, strategic planning of the use of water resources for irrigation, or estimation of yield with regard to climate change. Input data can readily be obtained from the field and the model is relatively easy to use. In the majority of cases, the parameters it suggests are applicable in different climatic regions. This fact is important because the model can be used even if limited input data are available. Although numerous other models have produced good crop yield simulation results, compared to them, this model is simpler, requires fewer input data, is generally available, and is highly reliable for the simulations of biomass, yield, and water demand. As such, it is recommended for applications under different climatic conditions.

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