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Modeling the response of onion crop to deficit irrigation

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Proper irrigation planning is not only essential for water saving, but also for yield enhancement and it is only possible when an accurate and reliable decision making tool (DMT) has been adopted. A best agriculture model is that which has dynamic climatic, soil and crop components. AquaCrop is one of the models extensively used for irrigation planning purposes. To evaluate it performance an experimental field was laid down in Agricultural Research Institute (ARI) Tarnab, Peshawar, Pakistan, during 2011, using onion as a test crop. Four different irrigation treatments of 100, 80, 60 and 40% of crop water requirements (CWR) were applied on each growth stage. Two statistical parameters including root mean square error (RME) and Nash Coefficient of efficiency (NCE) were used as performance indictors. Results indicated that the biomass and yield estimated through model showed overestimation for all irrigation treatments; similarly underestimation was observed for water productivity without any discrimination among full and sever water stress conditions. The performance of model to estimate biomass, yield and water productivity was not satisfactory, confirmed by performance indictors. The unreliability and differences in results may be due to other factors including crop structure and phenology, rather than climatic, soil and water supply parameters. For better performance of water productivity model adopted for global agriculture estimation, focus should also be given to undergrounds stems and bulb like crop along with cereals and cash crops to obtain more realistic results.

Key words: AquaCrop, Water stress, Biomass, yield and Bitter gourd

Introduction

Proper water management practices are the need of the day. Water one of the most important natural recourse has direct influence on our social life. To ensure food security it is must to use the water wisely in order to enhance food production while save water as much possible or in other words to increase water use efficiency of field crops. World population is increasing day by day which pose a serious threat on future agriculture production especially in areas

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where water is the most limiting factor for agriculture production. Besides the increasing demand of water for other purposes (industry and domestic use), degradation of water quality will also limit the water availability for agriculture sector in the coming future (FAO, 56). So the only tool to overcome this phenomenon is the enhancing of water use efficiency, it is also called water productivity. The largest sector of water consumption is agriculture, so increasing water use efficiency will not only increase agriculture production but will also save the water for other purposes.

Vegetable production in Pakistan is very low despite having surplus labour and fertile land suitable for growing a variety of vegetables in the country. Vegetable production in the country could be enhanced in three possible ways such as by allocating more area, by developing and adopting new technologies and by utilizing the available resources more efficiently (Bakhsh *et al.,* 2007). Onion is one of the important vegetable crops, and it yield and grade are very responsive to careful irrigation scheduling and maintenance of optimum soil moisture (Shock *et al.,* 1998). Bekele *et al.* (2007) concluded that water deficit at first and fourth growth stages, gave non-significantly different yield from the optimum irrigation application. However it is reported that when water stress was imposed 30 days after transplanting for a period of 15 days, leaf area and bulb growth were considerably decreased with a reduction of 17–26% in onion yield (Bhatt *et al.,* 2006). Soil water stress caused by withholding irrigation at both the third-leaf and seven-leaf stages reduced onion yield by 26% (Pelter *et al.,* 2004).

Advancement in technology has brought myriad changes in every field of life. Like other science disciplines, model simulation has taken prestigious position in agriculture water management (Nazeer, 2009). Models are mainly used as prediction tools to make the right decision for future scenario. As water is the main driven factor for all crop process and has direct effect on plant survival, so main focus was given on water models in last few decades. AQUACROP is one of the models extensively used in the field of water management throughout the world in order to estimate biomass (B), harvest index (HI) and finally yield (Y) under different climatic and water application conditions. Many researchers (Hsiao *et al.,* 2009, Heng *et al.,* 2009, Raes *et al.,* 2009, Steven *et al.,* 2009, Greets *et al.,* 2009, Araya *et al.,* 2010) conducted studies on different crops (mainly cereals) using AquaCrop model and results they obtained were satisfactory in full irrigation while severed water stress misestimated biomass and yield. However little wok has been done taking vegetables in to account, in this study we used bitter gourd as a test crop to evaluate the performance evaluation of the AquaCrop model.

Materials and methods

Climatic data

Climatic data required for model as input include maximum and minimum temperature (˚C), evapotarnspiartion (mm/day) and rainfall (mm). However for determination of evapotranspiration the humidity (%), wind speed (km/day) and sunshine (hours) data is required. All the required climatic data was collected on daily base (converted to monthly) from weather station installed inside the field.

Crop data

Crop data was obtained from an experimental field. The experiment was laid in Randomized Complete Block Design (RCBD) with split plot arrangement. The row to row and plant to plant distance was kept 0.2×0.2 m and 0.1×0.1 respectively. The crop component divided to 4 sub-components including initial canopy, canopy development, flowering and yield formation and rooting depth. The later two were observed visually while the canopy was measured in field at regular intervals.

Soil data

The model required full dataset of a given soil texture including wilting point, field capacity, bulk density, hydraulic conductivity, saturation, totally available water (TAW) and it nutrients (fertility) status.. All these parameters were determined through different techniques, as shown in Table.1. The soil of the experimental field was found sandy clay loam and the fertility was improved trough fertilizer application at regular interval before each irrigation event.

Table 1. Soil properties of the research site

Properties	**Value**
Soil texture	Sandy clay loam
Wilting point	18.2% by volume
Field capacity	28.1% by volume
Bulk density	1.51g/cm^3
Saturation	43%
Available water	0.10cm/cm
Hydraulic connectivity	7.86mm/hr
Nutrients status	poor

Irrigation Application

Sixteen subplots were prepared according to four different water application treatments. One cultivar (Swat-I) , same sowing date (03 feb2011) , same fertilizer doses were used in order to remove the ambiguities. 40, 60, 80 and 100% irrigation were applied according to crop water requirements on growth stage base. The crop water requirements were determined through CROPWAT programme

Water use efficiency

Water use efficiency or water productivity was determined according using following equations

$$WUE = \frac{[Y]}{[\sum ET]} \tag{1}$$

Where Y is the yield in kg / m^3 and ET is Evapotarnspiration in mm (converted to m^3) while the water productivity for biomass was determined through following equation;

$$BWUE = \frac{[B]}{[\sum ET]} \tag{2}$$

Where B is final aboveground biomass in kg /m^3.

Model Description

AquaCrop is FAO's crop water productivity simulation model resulting from the revision of the FAO Irrigation and Drainage Paper No. 33 "Yield Response to Water". Similarly to many other crop-growth models, AquaCrop further develops a structure (sub-model components) that includes: the soil, with its water balance; the crop, with its development, growth and yield; the atmosphere, with its thermal regime, rainfall, evaporative demand and carbon dioxide concentration (CO_2); and the management, with its major agronomic practice such as irrigation and fertilization. Simulation runs of AquaCrop are executed with daily time steps, using either calendar days or growing degree days. Several features distinguish AquaCrop from other crop-growth models achieving a new level of simplicity, robustness and accuracy.

Model data engine

AquaCrop has four main components the climate, crop, soil and management. Each component has sub-components as shown in Figure-1. Data was collected accordingly.

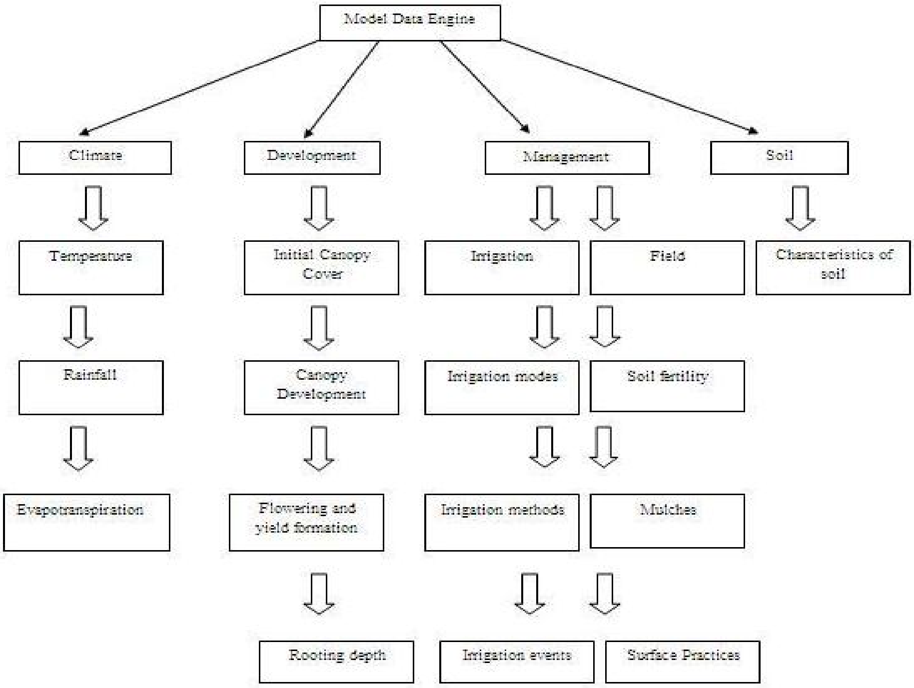

Fig .1. Model data engine

Model simulation

The model was run for four different irrigation treatments, keeping in mind the variation of the input data of the crop affected by different irrigation depths. However the soil and climate data were keep the same for all cases.

Performance Evaluation Indicators (statistical parameters)

The following indictors were used for the performance of the model using a spread sheet.

Root Mean Square Error (RMSE)

This indicator will show the overall deviation between observed and simulated values.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(O_i - S_i)^2}{N}} \qquad (3)$$

Where Si is simulated value, Oi is observed value (actually measured), and N is number of observations. For better model performance the value of RMSE should be near to zero.

Nash Coefficient of Efficiency (NCE)

Nash and Sutcliffe (1970) derived an equation in order to find out how much the overall deviation between observed and simulated values departs from the overall deviation between observed values (O_i) and their mean value ($\overline{O}_i$). NCE has the ability to find out how the model working during the simulation process. Furthermore the RMSE is unable to detect large deviation between observed and simulated values, while the NCE accounts for the different deviations, as they depart from mean value so the smaller the departure from mean value the higher the performing efficiency of the model. NCE value ranging from $-\infty$ to +1, with better model simulation efficiency when values are closer to +1.

$$E = 1 - \frac{\sum_{i=o}^{N}(O_i - S_i)^2}{\sum_{i=0}^{N}(O_i - \bar{O}_i)^2} \qquad (4)$$

Results and discussion

The simulated and observed biomass and yield of onion crop affected by different irrigation depths are shown in Figures. 2 and 3 respectively. The Shapiro-Wilk (1965) normality test (fit curve) was applied on simulated and observed data and it was found significant having 0.56 and 0.62 values of standard deviation for biomass and yield respectively. The model overestimated the biomass and yield for optimum with out discrimination among full and deficit water supply. The unreliable results obtained here may be due to crop phenology. Much work has been done on cereal and other vegetable crops while no one have taken bulbs into account, so there is no proper literature to confirm these results with their findings. Results obtained in this study are in contrast with that of Steduto *et al.* (2007) and Hsiao *et al.* (2009) , who reported that the model is unable to predict severe water deficit conditions due to different growth stages and soil moisture characteristics. Many scientists (Heng *et al.,* 2009; Raes *et al.,* 2009; Steven *et al.,* 2009; Greets *et al.,* 2009 and Araya *et al.,* 2010) also reported that the maximum yield simulated by AquaCrop was underestimated whereas minimum yield was slightly overestimated.

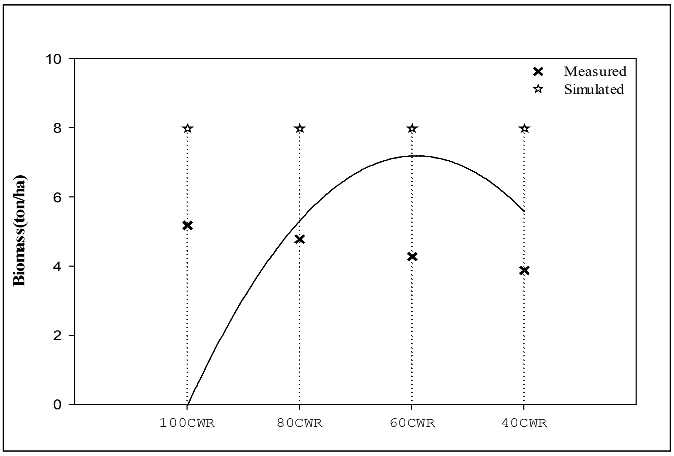

Fig. 2. Comparison between observed and simulated values of biomass for different irrigation treatments

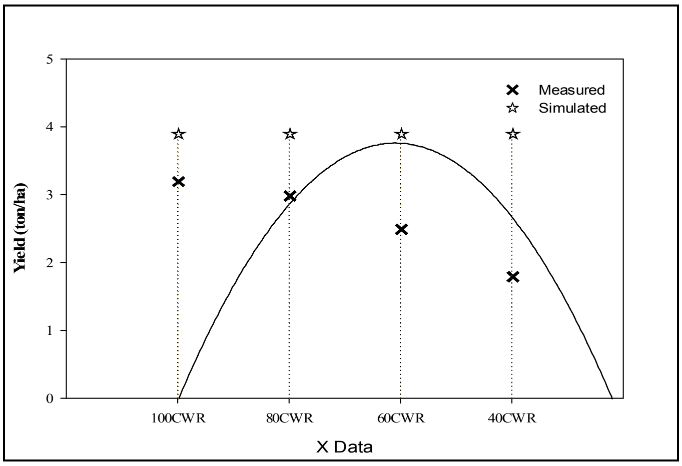

Fig. 3. Comparison between observed and simulated values of yield for different irrigation treatments

The model performance was evaluated through statistical parameters shown in Tables. 1. The performance indicators show various results for observed and simulated values of biomass and yield. The RMSE was unsatisfactory for biomass estimation while NCE was in poor agreement between observed data and model simulated data for biomass. Similarly results were obtained for the yield with lower value of RMSE (0.62) and NCE (0.42).

The water productivity of different irrigation depths for biomass and yield of onion crop are shown in Figure. 4 and 5. Reciprocal results were obtained as in case of biomass and yield. The water productivity for biomass and yield were underestimated by the model in all case of water application ignoring the fact of severe water stress condition. The normality curve was passed between simulated and observed values and significant variation was found which is confirmed by 0.69 and 1.06 standard deviation for biomass and yield water productivity respectively.

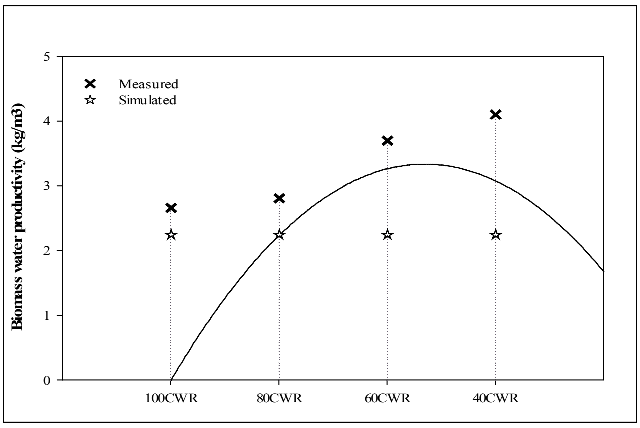

Fig. 4. Comparison between observed and simulated values of biomass water productivity for different irrigation treatments

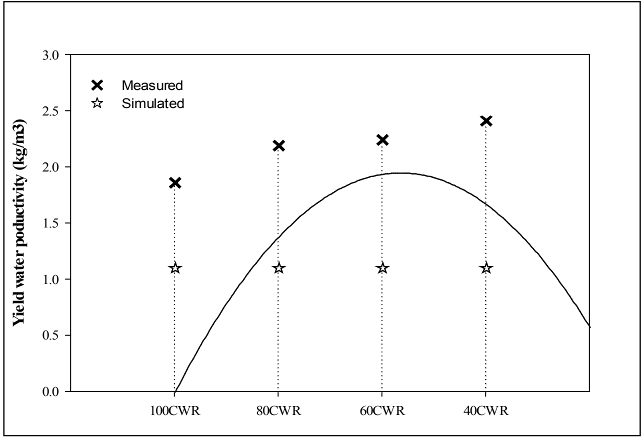

Fig. 5. Comparison between observed and simulated values of yield water productivity for different irrigation treatments

The model performance evaluation for water productivity of biomass and yield are shown in Table 1. RMSE and NCE were in poor agreement for biomass in all case of the water productivity estimated by the model. Similarly trend was observed for yield water productivity. No clear-cut differences were observed for different treatments. Although the model indicated over and under estimation for different crop parameters including biomass, yield and water productivity. In the light of the results the model is not suitable or less satisfactory for underground stems or bulbs simulation.

Conclusion

The model overestimated biomass and yield as well as underestimated water productivity for all irrigation treatments without any discrimination of full and deficit water supply conditions. Model evaluation using RMSE and NCE showed that model performed unsatisfactory for biomass, yield and water productivity. The comparison between observed and simulated results for four different irrigation treatments showed unreliable results. This is not the drawback of the model but the type of crop phenology. To improve the reliability of this model and its usage in water management focus should be given on onion like crops

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