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Research Paper

Modelling of moisture movement and irrigation scheduling in drip irrigated tomato using CROPWAT and HYDRUS-1D

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ABSTRACT

The irrigation systems require modernization and management by evaluating water system prerequisites precisely. A study was carried out at Srinagar during *kharif* 2022 to determine the crop water demands, irrigation scheduling and simulation of moisture movement under different irrigation regimes on tomato crop in open field conditions using CROPWAT and HYDRUS-1D models. The results revealed that the average crop water requirement at 100% ET_C per plant per day was 0.24 l $plant^{-1}$ day^{-1} during the initial stage, 0.37 l $plant^{-1}$ day^{-1} during development stage, 0.85 l $plant^{-1}$ day^{-1} during mid-stage and 0.74 l $plant^{-1}$ day^{-1} during the end stage. Soil water content was simulated by HYDRUS-1D model in 0 to 30 cm of soil profile. Higher values (0.86 to 0.95) of coefficient of determination (R^2) indicated that observed and simulated values of moisture content are highly correlated and the model predicts that lower values of mean absolute error (MAE) and root mean square error (RMSE) indicates that the HYDRUS-1D model is more accurate at simulating the movement of moisture under different irrigation regimes.

Keywords: Crop water requirement, CROPWAT, HYDRUS-1D, Irrigation scheduling, Reference evapotranspiration, Simulation

Water shortages are developing in many countries and the agricultural water has become more and more scarce due to climatic changes and increasing demand of water in various sectors (Azad *et al.,* 2018). The water scarcity, climatic conditions such as evapotranspiration and uneven rainfall distribution patterns, soil fertility and soil characteristics have a significant limitation on the land productivity (Osama *et al.,* 2017). Presently agriculture is the largest consumer of water 82.8% in the country (Rattan and Biswas, 2014). It is expected that reduction in size in land holding, decreasing per capita water availability for agriculture due to fierce competition from industrial, power and domestic use will seriously affect the sustainable use of water resources (Smakhtin *et al.,* 2004). To meet the irrigation demand, it is crucial to understand crop water requirements and irrigation timing. Crop simulation models, like DSSAT, CROPWAT, HYDRUS, AQUACROP etc are forecasting tools that support decision-makers to perform efficient water resource planning and provide reliable information on crop water requirements (Mehta and Pandey*,* 2016). These models can compute reference evapotranspiration (ETo), crop evapotranspiration (ETc), effective rainfall, irrigation scheduling and crop growth. For calculating crop water requirements and evapotranspiration, the Penman-Monteith method is considered as one of the most reliable and comprehensive method (Noreldin *et al.,* 2016; Pandey *et al.,* 2022). Irrigation scheduling is very important, deciding time and amount of water that is applied to a field.

Root water uptake, which contributes to the water cycle and a component of water balance in the field, helps to run the irrigation system effectively (Pandey 2023; Koech and Langat, 2018). Water deficiency in the root zone of soil reduced the plant growth and affects crop yield, thus irrigation is given to the root zone in order to maintain adequate moisture content, so that crop yield is not affected adversely (Dandekar *et al.,* (2018). HYDRUS-1D is a program designed to simulate water flow, heat transport and solute movement in variably saturated one-dimensional media (Simunek *et al.,* 2016). Moreover, it has been employed to assess the influence of salinity and root water uptake dynamics (Cai *et al.,* 2018). Tomato considered as remunerative vegetable crop is universally treated as protective food, since it is a rich source of vitamins, mineral organic acids and antioxidants viz., lycopene and beta-carotene

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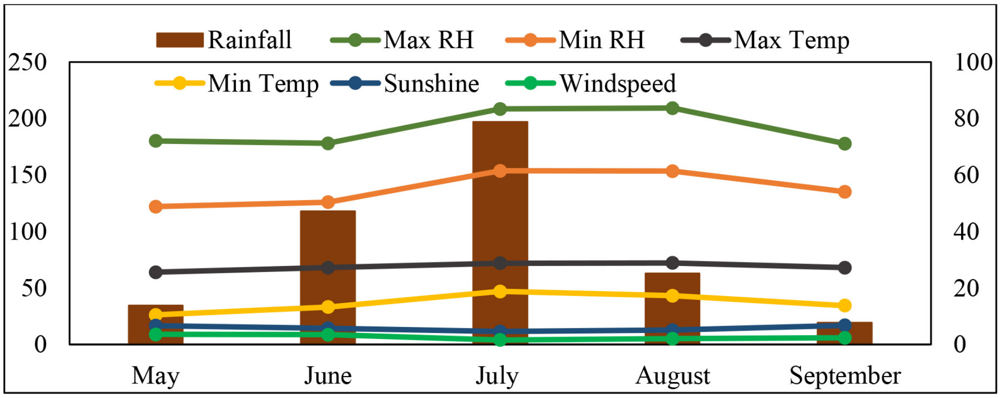

Fig. 1: Monthly metrological data from May to September 2022

(Kalloo, 2012). The area under tomato cultivation in India is 7.94 lakh hectares with annual production of 191.70 lakh tonnes. In Jammu and Kashmir, an area of 2.28 thousand hectares with an annual production of 52.96 thousand MT (Anonymous, 2019). The present study was conducted to analyze the precise amount of water needed for a crop and irrigation scheduling to assess the crop water requirement under different irrigation regimes in tomato.

MATERIALS AND METHODS

A field experiment was conducted at the experimental farm of the College of Agricultural Engineering and Technology (CoAE&T), Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar during *kharif*-2022. It is located at 34°14′53″ North latitude and 74°87′79″ East longitude with an altitude of 1586 m above mean sea level. Tomato crop variety S1 was planted at spacing of 0.60 m × 0.45 m, under five irrigation treatments (I1- Irrigation with 100% ETc, I2- Irrigation with 90% ETc, I3- Irrigation with 80% ETc, I4- Irrigation with 70% ETc and I5- Irrigation with 60% ETc) having 20 plants per row with 5 replications using randomized block design (RBD).

Metrological observations

The climate of the experimental site is of temperate type and remains moderately hot in the summers to bitterly cold in winters. The metrological data during tomato growth period were acquired from the Agro metrology field unit (AMFU) observatory, SKUAST-K, Shalimar. The mean monthly meteorological observations recorded during the full growing season of the crop growth period are graphically represented in Fig. 1.

Evapotranspiration estimation by CROPWAT model

CROPWAT 8.0 model is a windows compatible decision support system uses the daily/ monthly climatic data (viz., temperature, wind speed, relative humidity, hours of sunshine, and precipitation) in order to determine reference evapotranspiration (ET_O), crop and irrigation water requirements. Under drip irrigation, the daily water consumption of each tomato plant was calculated as (Sharan and Jadhav, 2002);

$$Q = A \times B \times C \times D$$

Where, Q = Quantity of water required per plant (l $plant^{-1}$ day^{-1}), A = Gross area per plant (m^2), B = Percentage of land covered by vegetation (fraction), C = Crop coefficient (fraction), D = Reference evapotranspiration, ET_O (mm)

Modelling of moisture movement

HYDRUS-1D a model for simulation of root water uptake, solute transport, heat transport and water flow. It has a graphics-based interactive user interface module that consists of a project manager and a unit for pre and post processing (Jiang *et al.,* 2010). Precipitation and evapotranspiration during study period were given as input parameters in HYDRUS 1D model. The input parameters for the simulation of root-water uptake include meteorological data, upper and lower boundary conditions of root- water uptake and soil parameters.

The root water uptake is determined using Richard's equation as given below;

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}[(k\ (h)\frac{\partial h}{a1} + 1)]\text{-}S(h)$$

Where, θ = volumetric water content (L^3 L^{-3}), h = pressure head (L), S = Volumetric sink term for root water extraction (T^{-1}), t = time (T),

The soil moisture meter was used to monitor soil water content during the whole crop period which easily and accurately measures moisture content of soil. Soil moisture status at different depth during whole crop period indicates the availability of moisture for root water uptake. The soil hydraulic parameters namely water retention parameters θ(h) and unsaturated hydraulic conductivity k(θ) required for numerical simulation of daily water content in the soil profile are calculated by using equations

$$Se = \frac{\theta - \theta r}{\theta s - \theta r}$$

$$K(\theta) = K_s S_e\ [(1\text{-}Se^{1/m})^{\ m}]^2$$

$$m = 1\text{- } 1/n,\ n > 1$$

Where, Se = effective soil water content, θs = Saturated soil moisture content, θr = Residual soil moisture content, K(θ) = unsaturated hydraulic conductivity, K_s = Saturated hydraulic conductivity, n = Index representing the pore size distribution.

Table 1: Stage wise mean crop water requirement in different irrigation regimes for tomato (l plant^{-1} day^{-1})

Growth stages	Mean crop water requirement at different irrigation levels (l plant^{-1} day^{-1})				
	I_1 (100% ETc)	I_2 (90% ETc)	I_3 (80% ETc)	I_4 (70% Tc)	I_5 (60% ETc)
Initial stage (16-05-22 to 14-06-22)	0.24	0.22	0.19	0.17	0.14
Development stage (15-06-22 to 24-07-22)	0.37	0.33	0.30	0.26	0.22
Mid stage (25-07-22 to 2-09-22)	0.85	0.77	0.68	0.60	0.51
End stage (3-09-22 to 22-09-22)	0.74	0.67	0.59	0.52	0.44

Table 2: Irrigation schedule chart during May to September (2022)

Day after planting	Stage	Volume of water applied (l plant^{-1} day^{-1})
4	Initial	0.58
9	Initial	0.58
14	Initial	0.61
20	Initial	0.65
25	Development	0.66
31	Development	0.70
41	Development	0.75
46	Development	0.79
52	Development	0.82
60	Development	0.85
65	Development	0.91
73	Mid	1.2
81	Mid	1.5
86	Mid	1.0
95	Mid	0.91
104	Mid	0.85
111	Mid	0.75
118	End	0.40
123	End	0.42

The various parameters namely saturated water content (θs), residual water content (θr), empirical factors and saturated hydraulic conductivity for silty clay loam soils were taken from the neural network prediction model available in HYDRUS-1D soil catalogue. Initial condition in different soil layers for water was given as initial water content within the flow domain, as observed in the experimental field. Free drainage boundary was considered as bottom boundary and flux was kept as zero during no irrigation period. Time variable boundary condition option in the model was used to manage the flux boundary during irrigation and no irrigation period.

The output of the model was validated through root mean square error (RMSE), coefficient of determination (R^2), and mean absolute error (MAE) (Willmott, 1981).

RESULTS AND DISCUSSION

Water requirement of tomato crop

The average crop water requirement of tomato crop at different growth stages in different irrigation regimes is presented in Table 1. The average value of crop water requirement was low during the initial stages of growth because only 10% of ground was covered by vegetative growth and higher during mid stage due to the advancement of vegetative stage and development of crop (i.e ground cover, leaf area, crop height increases) and higher evapotranspiration losses occurred during this stage (Table 1).

Irrigation scheduling

During crop period, the highest water requirement was recorded at mid stage (1.5 l plant^{-1} day^{-1}) and lowest was found (0.58 l plant^{-1} day^{-1}) during the initial stage. The demand of water is more during the mid-season stage due to the progress and development of vegetative stage of crop presented in Table 2.

Comparison of soil water content in I_1 and I_5 irrigation regime

The soil water content (SWC) findings from the field experiment and HYDRUS-1D model for all the layers i.e (15, 20 and 30 cm) were compared under all the treatments and the result showed good agreement to those recorded in the field. A comparison of observed and simulated SWC under I1 and I5 treatments for all the layers shows good agreement with R^2 ranging between 0.86 to 0.95 (Fig. 2).

CONCLUSION

On the basis of the experimental results, it can be concluded that the efficient irrigation practices, especially at critical stages of growth are necessary to ensure good yield, particularly in absence of rainfall during the growing season. The average crop water requirement per plant per day at 100% ET_C was 0.24 l plant^{-1} day^{-1} during the initial stage, 0.37 l plant^{-1} day^{-1} during development stage, 0.85 l plant^{-1} day^{-1}during mid stage and 0.74 l plant^{-1} day^{-1} during the end stage. The amount of irrigation water applied significantly affect the crop growth, crop yield and irrigation water productivity. The simulated moisture values when compared with observed values showed lower RMSE and MAE values. Overall, significant R^2 values obtained, indicated good performance of the model in simulating soil profile moisture content. Therefore, HYDRUS-1D model can be successfully adopted for simulating moisture movement.

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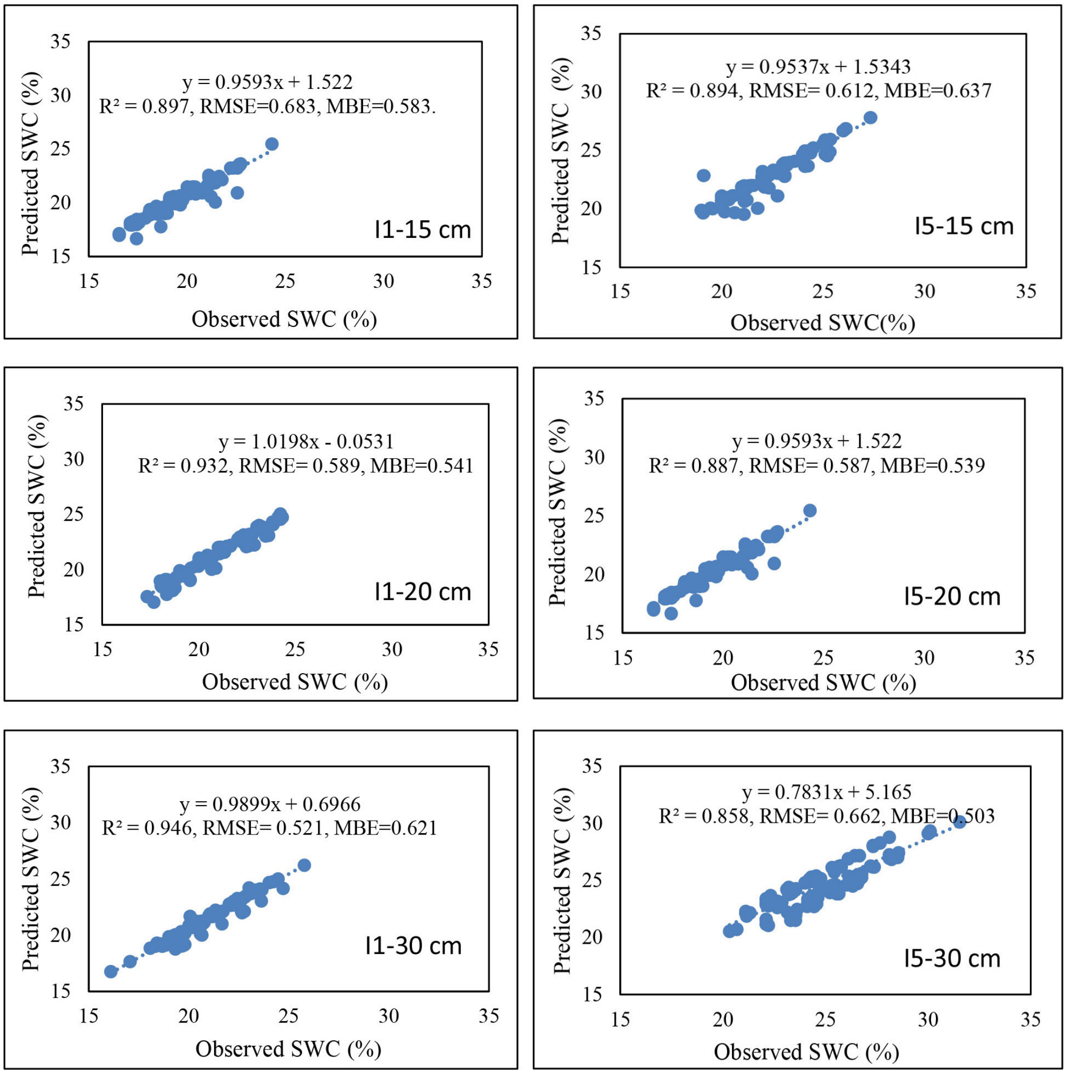

Fig. 2: Observed and simulated values of soil water content at different depths (15, 20 & 30 cm) under two irrigation regimes (I_1 & I_5)

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