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Moisture dynamics and irrigation modelling in apple (*Malus domestica*) trees using CROPWAT model in temperate region of India

ROHITASHW KUMAR[1], RUHUL NISSA[2] and MUKESH KUMAR[3]

Sher-e-Kashmir University of Agricultural Science and Technology-Kashmir, Shalimar Campus, Srinagar, Jammu and Kashmir

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ABSTRACT

A quantitative study of water transport in the soil-root system is an important aspect for optimum irrigation scheduling and sound water management. The present study was conducted for high density apple (*Malus domestica* Borkh.) (var. Silver Spur) orchard in temperate region of Kashmir valley, India to evaluate moisture uptake/depletion at different depth of root zone.Soil moisture depletion at different root depth was determine dusing CROPWAT model. The maximum depletion of moisture took place in the top 16 cm layer of crop root zone. The crop coefficient values were modified for local agro-climatic conditions using the procedure outlined by FAO. The Modified crop coefficient (K_c) value for different growth stages of $K_{c\ ini}$, $K_{c\ mid}$ and $K_{c\ end}$ were found 0.5, 1.13 and 0.76, respectively. The crop water requirement was determined using CROPWAT model and compared with field observed value.The results showed that the model predicted the crop evapotranspiration with reasonable error statistics with RMSE; 0.19 mm/day, R^2; 0.97 and percent error; 10.90. The CROPWAT model can be used for estimating crop water requirement for high density apple crop for irrigation scheduling.

Key words: Apple, Crop evapotranspiration, CROPWAT model, Moisture uptake/depletion

Water is most precious gift of nature, essential for human and animal life (Clothier 1990, Coelho and Or 1996, 1999) and plays an important role for plant growth (Richards and Wadleigh 1952, Wesseling and Feddes 2006, Kumar *et al.* 2012, Kumar *et al.* 2013a). Water resources play an important role as a catalyst for the economic development of a nation. Therefore, it is necessary to develop, conserve, utilize and economically manage this critically important resource on an integrated basis so as to meet the ever-growing demand for agriculture, industry, domestic use and power generation.

Sound irrigation management requires information about crop water requirement and root water uptake pattern of different crops. Water is useful in the process of plant growth. Deficiency of water in the root zone of soil results in reduced plant growth and affects the crop yield, thus objective of irrigation is to maintain adequate moisture content in the root zone, such that crop yield is not affected adversely (Green *et al.* 2006, Kumar *et al.* 2012). The importance of the unsaturated zone as an integral part of the hydrological cycle has long been recognized as it plays an inextricable role in many aspects of hydrology, including infiltration, soil moisture storage, evaporation, plant water uptake, ground water recharge, runoff and erosion. Initial studies of the unsaturated (vadose) zone focused primarily on water supply studies, inspired in part by attempts to optimally manage the root zone of agricultural soils for maximum crop production (Yadav *et al.* 2009). The transport process has critical effects on crop yield, as well as the quality and quantity of infiltration recharge to groundwater systems under croplands (Gardner 1960, Wallach 1990, Schmidhalter *et al.* 1994) simulates water flow into individual roots. Water application rate and soil properties affect the soil wetting zone which developed around the crop root zone is important for proper designing and management of irrigation system (Kumar *et al.* 2013b, Kumar *et al.* 2014b, Kumar *et al.* 2015).

Drip irrigation is one of the advance irrigation methods and apply required amount of water directly in the root zone at frequent intervals which may save sufficient quantity of water as compared to surface method of irrigation (Kumar *et al.* 2014a). Deficiency of water in the root zone of soil results in reduced plant growth and affects the crop yield, thus objective of irrigation is to maintain adequate moisture content in the root zone, such that crop yield is not affected adversely (Green *et al.* 2006, Kumar *et al.* 2012, Kumar *et al.* 2013a,b; Kumar *et al.* 2014). Initial studies of the unsaturated (vadose) zone focused primarily on water supply studies, inspired in part by attempt to optimally manage the root zone of agricultural soils for maximum crop production

[1]Associate Professor (e mail: rohituhf@rediffmail.com), [2]Research Scholar, Division of Agricultural Engineering, SKUAST-Kashmir, Shalimar Campus, Srinagar. [3]Assistant Professor, School of Agriculture, Block G-2, IGNOU, Maidan Garhi, New Delhi.

(Yadav *et al.* 2009, Shankar *et al.* 2012).

The unsaturated zone of the soil profile embodies many complex processes such as infiltration, evaporation, soil moisture storage, root water uptake and others (Kumar *et al.* 2013b). Hydrological perspective, water uptake by root systems and their spatial distribution exert a large degree of control on the water fluxes to the atmosphere and the groundwater (Canadell *et al.* 1996). For understanding of the magnitude of these fluxes, accurate estimates of the temporal and spatial root water uptake patterns are needed. Spatial and temporal characterization of soil water is important for optimization of water use (Yadav *et al.* 2009). Plant root water uptake rate depends upon transpiration rate, root distribution, soil hydraulic properties and water availability. During the past few decades, many hydrologic models have been developed to simulate water flow in the subsurface, utilizing different techniques to couple the atmospheric evaporative demand with the resulting extractions of evapotranspiration from the canopy and subsurface (Kumar *et al.* 2013b).

For determination of crop evapotranspiration and yield responses to water, various models are used. Several researchers have used Crop Water Analysis Tool (CROPWAT), model for analyzing crop water and requirements in different parts of the world (Kumar *et al.* 2013b). In Kashmir, apple is one of the most widely cultivated temperate climate fruit-trees. It gives the highest yield of good quality fruits in regions having long day hours with high light intensity and relatively warm days with cool nights and low relative humidity during the growing season and dormant, chilling, winter season below 7°C. Apple trees are particularly sensitive to low soil moisture supply, water stress during growing season reduces number and size of fruits. The study of CROPWAT model can adequately predict the effects of water stress, but requires calibration of the main crop parameters (Malekian *et al.* 2009, Nagy *et al.* 2010, Darshana *et al.* 2012). The present study was conducted to evaluate CROPWAT model focused on the moisture extraction pattern in the root zone and water requirement of crop.

MATERIALS AND METHODS

The present study includes the measurement of soil moisture depletion; plant parameters such as root depth, plant height, soil parameters, bulk density, particle density and hydraulic, Crop evapotranspiration, modification of crop coefficient and analysis of water requirement using CROPWAT model.

The study was conducted in a high density apple orchard at Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar research farm, located at 34.145° N latitude and 74.87° E longitude and 1585 m above mean sea level. The study area planted apple (*Malus domestica* Borkh.) (Silver Spur variety) at 2 × 3 spacing, in April, 2012. Drip irrigation system was installed which comprises pressure compensated emitters of 4 lph capacity placed on a single line per tree.The meteorological data on temperature, humidity, rainfall, sunshine and wind speed was collected from the Division of Agronomy, other data was determined from the empirical formulas given in the FAO-56 manual.

The most important and permanent feature of a soil is its texture. Soil samples were collected from the experimental farm from different depths.The soil texture, bulk density, particle density and saturated hydraulic conductivity were analyzed. Texture (sand 19.6%, silt 48.0%, clay 32.4%) were determined using a set of sieves and a calibrated hydrometer, followed by the methodology suggested by Trout *et al.* (1982). The bulk density, particle density and saturated hydraulic conductivity were found 1.41 g/cm^3, 2.58 g/cm^3 and 0.6 cm/h, respectively.

The crop parameters have a dominating role in predicting the moisture uptake by plant. The root depth, leaf area index and plant height of crop was recorded. The duration of crop stages have been considered on the basis of study of Doorenbos and Pruitt (1977). FAO recommended K_c values were modified for the study area for different growth stages.

In order to study the moisture depletion in the apple plant, a digital soil moisture meter was used to find out the daily moisture depletion. The moisture meter consist a probe which is inserted into the soil at different depths in order to find out the available moisture. It measures directly, how much moisture plants have absorbed from the soil since the previous sampling occasion. The period of moisture depletion commences with a uniform distribution of available moisture in the soil profile, which approximates to the field capacity.Occurrence of rain between two sampling, results in the predominance of moisture movement from one soil layer to another, over the removal of soil moisture within any soil layer, this is inherent drawback of the method.

CROPWAT is a model that can be used to calculate crop water and irrigation requirements using climatic and crop data. This model allows developing irrigation schedules for different management conditions and the estimation of scheme of water supply for varying cropping patterns. The CROPWAT model is based on a water balance where the soil moisture status is determined on a daily basis from calculated evapotranspiration and inputs of rainfall and irrigation data. The programme used daily climatic data (temperature, relative humidity, wind speed, sunshine hours, and rainfall) for determination of reference evapotranspiration. Effective rainfall was calculated using USDA Soil Conservation method. The input data used for model were growth stages, K_c, root zone depth and allowable soil moisture depletion. The model calculates the crop water requirements for 19 days interval.CROPWAT model also calculates the reference crop evapotranspiration (ET_o).The model determined ET_o using in built of Penman-Monteith method.The Penman-Monteith equation is given as:

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

Meteorological factors, including air temperature, humidity, solar radiation, sunshine hours and wind speed at a 2m height above the ground surface, were recorded daily at the experimental field.

The different crop data were determined, i.e. the crop planting date, the crop coefficient (K_c) values at the different growth stages, the length of growth stages, the crop rooting depth at the different growth stages, the allowable soil moisture depletion levels and the yield response factors. The soil parameters are required for irrigation scheduling in CROPWAT model are total available soil moisture content, maximum rooting, maximum rain infiltration rate, initial soil moisture depletion and initial available soil moisture. After the input of the crop and soil data, CROPWAT proceeds to calculate the crop water and irrigation requirements of the given cropping pattern, using the entered data.

The collected data was statistically analyzed using several statistical parameters, i.e. root mean square error (RMSE), coefficient of determination (R^2), percent error (PE) and mean bias error (MBE). The statistical indicators are determined using following equations:

RMSE is an index of the actual error produced by the model and is determined by equation (2) given as (Thomann 1982):

$$\text{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{1}{n}(P_i - O_i)^2} \quad (2)$$

Coefficient of determination (R^2) gauges well data fit a statistical model. This coefficient usually ranges from zero to one. It is calculated using equation (3) given as (Bansal *et al.* 1991):

$$R^2 = \frac{\left[\sum_{i=1}^{n} (O_i - \bar{O})\sum_{i=1}^{n} (P_i - \bar{P})\right]^2}{\sqrt{\sum_{i=1}^{n} ((O_i - \bar{O})\sum_{i=1}^{n} (P_i - \bar{P})^2}} \quad (3)$$

Percent error shows that how much percentage variation is shown by the predicted values with respect to observed values. This is calculated as (Martinec and Rango 1989):

$$\text{Percentage error} = \frac{(O_i - P_i)}{O_i} \times 100 \quad (4)$$

Mean bias error is the difference between the expected value and the true value of the parameter being estimated. It is calculated by equation (5) given as:

$$MBE = \frac{1}{N}\sum_{i=1}^{n} (P_i - O_i) \quad (5)$$

RESULTS AND DISCUSSION

Evaluation of moisture uptake/depletion at different depth of root zone was conducted for high density apple (var. Silver Spur) orchard in temperate region of Kashmir valley, India using CROPWAT model. Daily moisture depletion (January-June, 2014) was collected at regular intervals.The recorded results were compared with the model simulated values. The results of moisture depletion, crop evapotranspiration, modified crop coefficient and crop water requirement using CROPWAT are described in this section.

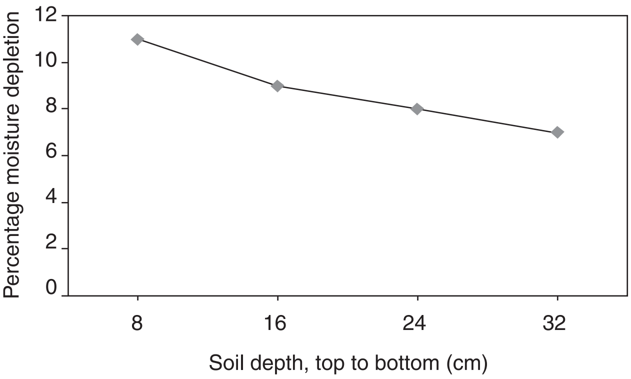

Fig 1 Moisture depletion for the period 640-655 DAP for apple.

Moisture depletion

Soil moisture status at different root depths in the root zone gives an idea about the availability of moisture for plant moisture uptake. It indicates the part of crop root zone, most susceptible to moisture depletion. The duration was selected between two rainfall events, two rainfall/snowfall and irrigation events or two irrigation events for computing moisture depletion of apple crop. The results of moisture depletion was measurement at different depths over the cropping period of 640-805 and 670-685 days after planting (DAP). The results of moisture depletion are shown in Fig 1 for the period of 640-805 and 670-685 DAP. It is evident from the Fig 1 that there is minimum depletion of moisture in the initial months of the study period due to lesser plant canopy (Shankar *et al.* 2012, Kumar *et al.* 2013a). At the development stage of plant there is a considerable increase in the moisture depletion as the temperature has started rising and the plant has attained maturity stage. In the month of June, water requirement of crop was increased due to canopy is reached 80–90 % of the full shape and crop was in fruiting stage. The variation of moisture depletion at different depth was also determined. It is observed that the maximum depletion of moisture takes place at the top 16 cm layers of soil and is considerably less in the lower layers (Kumar *et al.* 2013a). Similar trend was observed over the entire study period. In the upper part of the root zone where root density is high, moisture depletes very fast, whereas in the lower part of the root zone sufficient moisture for the plant is continuously available (Shankar *et al.* 2012, Kumar *et al.* 2013a).The peak values of water requirement were found around 35–40 l/day/tree in middle of June (Green *et al.* 2003, Dragoni *et al.* 2004). The moisture content was maintained to close the field capacity throughout the growing season, which requires large quantities of irrigation water in dry seasons.

Depletion of moisture by plant from the root zone is governed by the daily crop evapotranspiration (ET_c) values. The crop coefficient was modified for the local conditions using the procedure recommended by FAO (Allen *et al.* 1998). The crop coefficient curve was developed for apple using FAO-56 method. The crop coefficient curve has three important stages, i.e. initial stage ($K_{c\ ini}$), mid-season (K_c

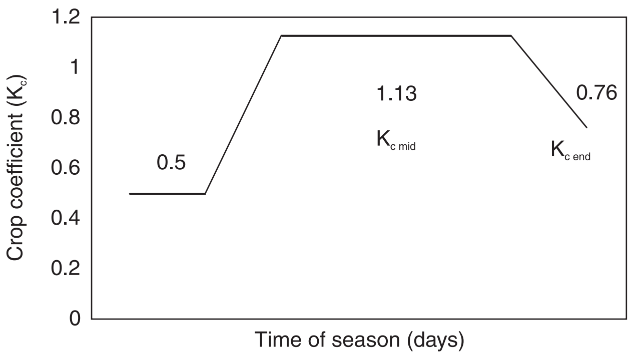

Fig 2 Moisture depletion for the period 670-685 DAP for apple.

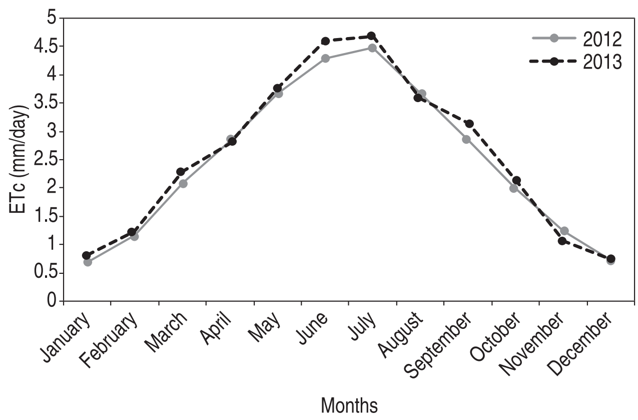

Fig 4 Reference evapotranspiration for the year 2012 and 2013 from CROPWAT model.

mid) and end stage ($K_{c\ end}$), respectively. The modified crop coefficient curve is summarized for different growth stages in Fig 2. The modified crop coefficient values of initial stage ($K_{c\ ini}$), mid-season ($K_{c\ mid}$) and end stage ($K_{c\ end}$), was found 0.5,1.13 and 0.76, respectively as compared to FAO recommended value of 0.6, 1.2 and 0.85, respectively.

CROPWAT model was used to simulate the crop water requirement. The input files were used to calculate the reference evapotranspiration. The model calculates the crop water requirement on the basis of the crop and soil data. The variations in reference evapotranspiration (ET_0) with different climatic parameters are shown in Fig 3. It is evident from Fig 3 that, the higher temperature gives higher evapotranspiration. It is evident that low reference evapotranspiration was found due to high humidity in the study area (Abdalla *et al.* 2009). The ET_o also determined for the year 2012 and 2013 using CROPWAT model, which is shown in Fig 4. It is evident from Fig 4 that, the ET_o was low in January to April months, increased during the May to July and reached maximum value of 4.49 mm/day in 2012 and 4.68 mm/day in July in 2013.It was found that ET_0value declined during October to December months. It is indicated that the lowest ET_o occurred during rainy season and the highest during the dry season (Abdalla *et al.* 2009). The difference in ET_o is attributed to combined effects of temperature, sunshine hours, radiation, wind speed and humidity.

The details of irrigation requirement for 10 days interval and crop ET during crop period was simulated using CROPWAT model. The irrigation requirement and crop ET is given in Fig 5. It is evident from graph that the maximum crop water requirement was found 43.5 mm for 10 days during the month of August and the corresponding irrigation requirement was found to be 40.8 mm. For the entire cropping period in 2012 the irrigation requirement was found 1323.8 mm. Similarly, irrigation requirement and crop ET determined for 2013 using CROPWAT model is shown in Fig 6. It is evident from Fig 6 that the maximum crop water requirement was 60.5 mm during the month of July and the corresponding irrigation requirement was found 48.9 mm. For the entire cropping period in 2013 the irrigation requirement was found to be 1197.6 mm. It was observed that, the trend of the simulated values are in close agreement with the observed values of crop evapotranspiration.

The statistical analysis of results of crop water requirement was determined using equation (2-5). The values of R^2, RMSE, Percent error and MBE were found; 0.97, 0.19 mm/day, 10.90 and 0.17 mm/day, respectively. The statistical results were in close agreement between simulated and field observed value. Overall, the CROPWAT model was found to be quite suitable for simulation of crop water requirement in the given agro-climatic conditions.

Conclusion

Present study provides an insight into the crop water

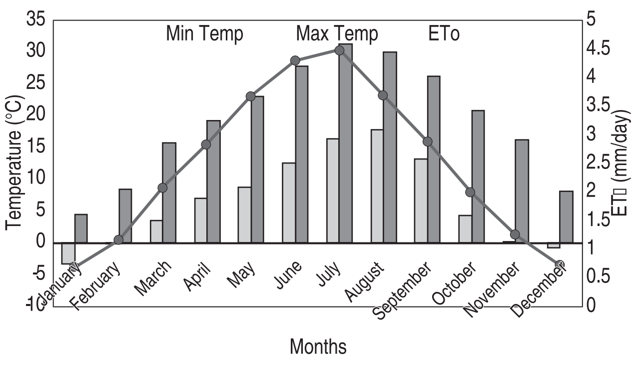

Fig 3 Reference evapotranspiration with minimum and maximum temperature variation.

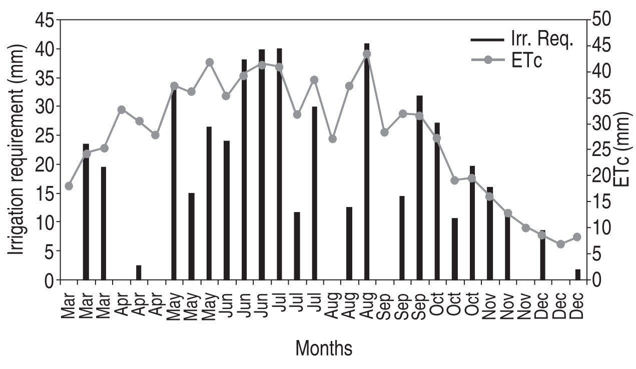

Fig 5 Crop water requirement and irrigation requirement for the year 2012.

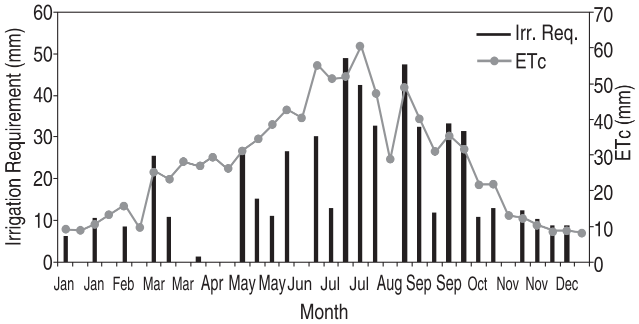

Fig 6 Crop water requirement and irrigation requirement for the year 2013.

requirement of apple crop and understanding the movement of water through the root zone of plant.This study also gives information on the spatial and temporal behavior of the plant-soil-atmosphere continuum. The CROPWAT model was used for irrigation scheduling. The study revealed that the upper part of the root zone where root density is high, moisture depletes very fast, whereas in the lower part of the root zone sufficient moisture for the plant is continuously available. Maximum moisture depletion was seen in the top 16 cm depth of the soil. The maximum crop water requirement simulated by CROPWAT model for 2012 was found 43.5 mm during the month of August and the corresponding irrigation requirement was 40.8 mm. Similarly, in 2013, the maximum crop water requirement was 60.5 mm during the month of July and the corresponding irrigation requirement was found to be 48.9 mm for 10 days interval. CROPWAT model values for crop evapotranspiration compared with field data showed close agreement with R^2 of 0.97, RMSE of 0.19 mm/day, percent error 10.90 and MBE of 0.17 mm/day. Thus, the model can be used for estimating crop water requirement and can help in irrigation scheduling.

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