Evapotranspiration Based Micro Irrigation Scheduling of Tomato Crop under Naturally Ventilated Polyhouse

Abstract

The present study was undertaken to investigate the “Evapotranspiration Based Micro Irrigation Scheduling of Tomato Crop under Naturally Ventilated Polyhouse”, at experimental field of Department of Irrigation and Drainage Engineering, G. B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand during 2017-18. The average of mean monthly ET_0 estimated under polyhouse by FAO-PM (benchmark) model was 39.44 mm, but that of the FAO Penman, Hargreaves Stanghellini, Priestley-Taylor and FAO Radiation models were 38.37, 18.18, 37.80, 48.17 and 53.87 mm, respectively. Whereas, the average of mean monthly ET_0 estimated under open environment by FAO-PM (benchmark) model was 116.34 mm, but that of the FAO Penman, Hargreaves Stanghellini, Priestley-Taylor and FAO Radiation models were 119.33, 133, 126.41, 113.17 and 117.37 mm, respectively. The FAO Penman and Hargreaves model are found to be most and least appropriate models for estimating daily ET_0 under polyhouse. Whereas, FAO Radiation and Stanghellini model observed to be most and the least appropriate models in open environment for estimating daily ET_0 under polyhouse for the Pantnagar *tarai* condition of Uttarakhand. During the six month growing period, the average water requirement for tomato crop under polyhouse and open environments were 0.2149 and 0.2924 liter per day per plant, respectively, showing that the water requirement in the open environment was estimated as 30 % higher than that of polyhouse. The experimental results also revealed that the treatment T_2 (100 % water application of ETc without mulch under polyhouse) recorded significant yield (18.97 kg/m^2), water use efficiency (135.26 kg/m^3) and maximum fruit weight (106.66 gm).

1. INTRODUCTION

Efficient use of water is the prime objective of precision irrigation management. The widespread aim is to increase water productivity and reduce the adverse impact of the environment on irrigation (Parvizi et al., 2014). Evapotranspiration (ET) plays an important role in maintaining the water balance of the ecosystem. Accurate measurement of evapotranspiration is necessary for proper irrigation management, crop production, water resources management, environmental assessment, ecosystem modellers and solar energy system. Reference evapotranspiration (ET_0) has been usually applied to estimate the actual evapotranspiration, which is very difficult to assess by lysimeter, and water balance approach under the open field conditions at all places. ET_0 is useful to estimate the atmospheric water demand of the region and hence can be used for various applications including drought monitoring, irrigation scheduling, and understanding climate change impacts. Precise estimation of reference evapotranspiration (ETo) and crop evapotranspiration (ETc) on a daily basis is important to apply water through drip system for crops grown in the greenhouse (Singh et al., 2016, Tiwari et al., 2014).

Many models have been reported, to estimate reference evapotranspiration (ET_0) however, due to availability of the observed data, it is very difficult to choose the best one. Therefore, many comparative studies and evaluation of various, models have been conducted. Meanwhile, (Oudin*et al.,* 2005) investigated optimal, method to calculate Potential evapotranspiration (PET) for use in rainfall–runoff model; (Tegos*et al.,* 2015) summarized historical developments of ET_0 methods using standard meteorological data; and (Mcmahon*et al.,* 2016) considered the simplification of the Penman-Monteith model was having high efficiency in the estimating of ET_0. The FAO Penman Monteith, method (FAO-PM) was considered as the standard ET_0 method based on both physiological and aerodynamic criteria under Food and Agriculture Organization (FAO) and World Meteorological Organization (WMO). As a standard method, FAO-PM can be used widely in many regions without any extra adjustments of parameters. The present study was undertaken to investigate the "Evapotranspiration Based Micro Irrigation Scheduling of Tomato Crop under Naturally Ventilated Polyhouse", at experimental field of Department of Irrigation and Drainage Engineering, G. B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand during 2017-18.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The study area comes under the climatic zone of the western Himalayan region and is located in the Shivalik foothills of the Himalayas and represents the *Tarai* regions of Uttarakhand. The experiment was conducted in a single-span polyhouse E-W oriented, located at Irrigation and Drainage Engineering Department, College of Technology, G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand. The experimental site is located at 29.0210° N latitude, 79.4897° Elongitude and at an altitude of 243.83m above mean sea level. The meteorological data such as temperature, relative humidity, wind speed, rainfall, pan evaporation and sunshine hours were acquired from the meteorological observatory located at Norman E. Borlaug Crop Research Centre (NECRC), Pantnagar, which is one km away from the experimental site and the microenvironmental parameters were obtained from polyhouse microenvironment monitoring system installed in the polyhouse. All the microenvironmental parameters recorded at 15 minutes time interval were downloaded from the data logger for the estimation of reference evapotranspiration.

2.2 Reference Evapotranspiration Calculation and Experimental Field Design

The reference evapotranspiration (ET_0) models of Priestly Taylor, FAO Radiation, Hargreaves, FAO Penman and Hargreaves were compared with FAO Penman Monteith (FAO-PM) for both polyhouse and open environment**.** Tomato (*Lycopersiconesculentum*L.) variety Heemsohna was selected as a test crop for study. The experimental sites of area $100m^2$ and $60m^2$ respectively were provided polyhouse and open field crops. For planting the seedlings the field was ploughed manually followed by smooth planking. Vermi compost was added after the first ploughing so that it was thoroughly mixed in the soil during subsequent ploughing. Then the field was brought to a clean and fine tilth. The raised bed and layout of the experiment were prepared for the experiment as per plan. The area under polyhouse and open field were divided into 18 and 9 plots respectively of size 3m × 1m (Figure 2.1). The experiment was laid out in randomized block design having 6 treatments for polyhouse and 3 treatments for open were replicated thrice as represented in Table 2.1. A gap of 0.5m between each plot and 0.5m path was left in center of the polyhouse for mainline. The drip irrigation systems were installed with the mainline with pressure rating up to 4 kg/cm^2. The drip tapes of diameter 20 mm having emission points at 20 cm spacing with a flow rate of and 1.1 l/h were laid parallel between the two rows of crop. The rate of application of water at a different level was maintained by operating the valve at the inlet of each lateral. The irrigation scheduling was done on the basis of crop evapotranspiration estimation using Class A Pan Evaporimeter data, installed in polyhouse and open field, respectively. Daily pan evaporation readings were recorded for the determination of crop evapotranspiration.

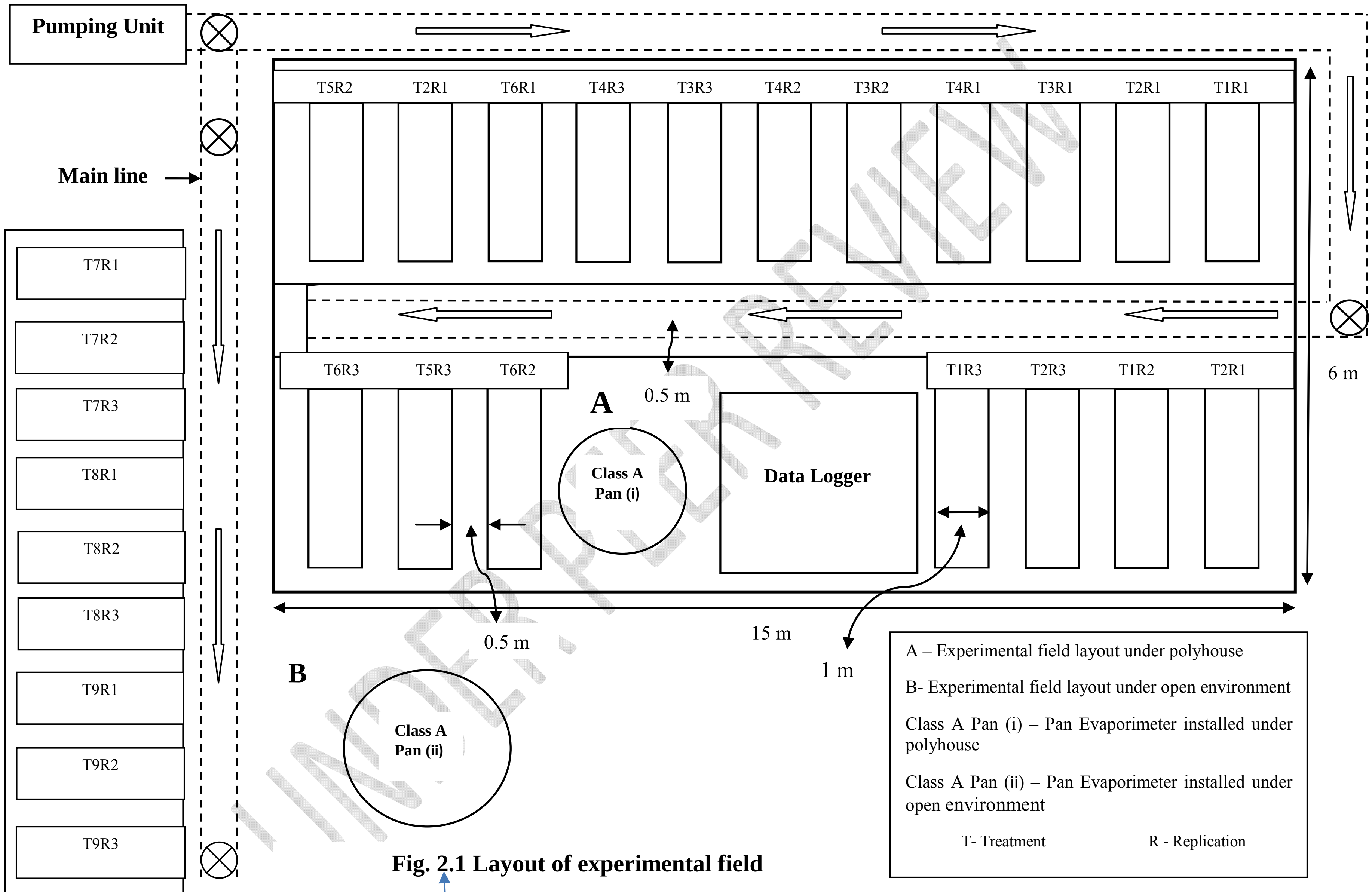

Fig. 2.1 Layout of experimental field

Table 2.1 Details of treatments in Experiment

Polyhouse Treatments		
Sr. No	**Treatment**	**Details of Irrigation**
01	T_1	100% of ET_c with plastic mulch
02	T_2	100% of ET_c without plastic mulch
03	T_3	75% of ET_c with plastic mulch
04	T_4	75% of ET_c without plastic mulch
05	T_5	50% of ET_c with plastic mulch
06	T_6	50% of ET_c without plastic mulch

Open field Treatments		
Sr. No	**Treatment**	**Details of Irrigation**
01	T_7	100% of ET_c
02	T_8	75% of ET_c
03	T_9	75% of ET_c

ET_c= crop evapotranspiration

2.3 Drip Irrigation Scheduling of Tomato Crop

The volume of water applied using drip irrigation system was estimated with the following relationship as given in INCID, (1994):

$$V = \sum (E_p \times K_C \times K_p \times S_p \times S_r \times WP - ER) \quad \text{... (2.1)}$$

V= Total amount of water applied (l/day/plant); E_p =Pan Evaporation (mm); K_c=Crop coefficient K_p= Pan coefficient; S_p = Plant to plant spacing (m); S_r = Row to row spacing (m); WP=Percentage wetted area (90%); and ER = Effective rainfall(mm).

The effective rainfall (ER) was calculated on monthly basis based on USDA, S.C.S method (United States Department of Agriculture, Soil Conservation Service) as:

$$ER = P_t \left[\frac{125 - 0.2 \times P_t}{125}\right] \quad \text{for} P_t < 250 \text{ mm}$$

... (2.2)

$$ER = 125 + 0.1 \times P_t \quad \text{for} P_t > 250 \text{ mm} \quad \text{... (2.3)}$$

ER = Effective rainfall (mm); P_t= Total rainfall (mm)

In this study the calculation of crop coefficient(K_c) for different growth stages of tomato were considered based on the published report and local studies carried out in India. The crop coefficient K_c values are varying with the type of crop, its growing stage, growing season and prevailing weather conditions. The crop coefficient values for initial stage $K_{c\ init}$ was taken as 0.6, for mid stage was taken as 1.15 and for end stage it was taken as $K_{c\ end}$ as 0.80 for open environment. For inside polyhouse, the crop coefficient values for initial stage $K_{c\ init}$ was taken as 0.6, for mid stage was taken as 1.40 and for end stage it was taken as $K_{c\ end}$ as 1.0.

2.4 Regression analysis

Simple linear regressions were used in order to determine the correlation between estimated daily reference evapotranspiration (ET_0) by different models with estimated from FAO

Penman model from polyhouse and open environment. Root mean squared error (RMSE), relative error (RE), agreement index (D) and the coefficient of determination (R^2) were also used for model's evaluation and calculated as follow:

$$RMSE = \sqrt{\frac{1}{(N)}\sum_{i=1}^{N}(E_i - O_i)^2} \quad \text{... (2.4)}$$

$$RE = \frac{RMSE}{ET_{Omean}} \times 100 \quad \text{... (2.5)}$$

$$D = 1 - \frac{\sum_{i=1}^{n}(O_i - E_i)^2}{\sum_{i=1}^{n}(|E_i - O| + |O_i - O|)^2} \text{... (2.6)}$$

The value of D is 1.00 indicates perfect agreement, whereas, its values of 0.00 indicates a poor agreement (Willmott, 1984; Legates and McCabe, 1999).

Where; E_i is the estimated ET_0 with different models, O_i is ET_0 estimated with FAO-PM Model, at the i^{th} data point and n is the total number of data points.

Linear regressions to determine the correlation of estimated daily ET_0 values with the FAO-PM Model values, as follows

$$ET_{O\text{-}DMO} = a\,(ET_{O\text{-}FAO\ PM}) + b \quad \text{... (2.7)}$$

Where; $ET_{0\text{-}DMO}$ and $ET_{O\text{-}FAOPM}$ represent the value of ET_0 estimated by different models and ET_0 by FAO-PM Model, respectively. Whereas, a and b are the regression coefficients. The best prediction method according to linear regression is the one which has the highest coefficient of determination (R^2), b value closest to zero and a value closest to unity. Despite being widely used to assess the "goodness of fit" of evapotranspiration equations, R^2 is oversensitive to extreme values and is insensitive to additive and proportional differences between estimated and measured values. Considering these limitations, R^2 values might misjudge the best method, when used alone. Therefore, method performance was evaluated by using both regression and different indices like RMSE, RE and D.

3. RESULTS AND DISCUSSION

3.1 Performance of Different Reference Evapotranspiration Models Under Playhouse and Open Environment

The results indicate that under polyhouse conditions, FAO Penman and Hargreaves models were the most and the least appropriate models, respectively. The slope of the linear regression equation in the FAO Penman model was 0.997 which is near to 1.0 and the R^2 was 0.999, which is also near to 1. The values of the RMSE and RE for the FAO Penman models were (0.0097 and 0.779%). According to the value of a, b, R^2, D, RSME and RE, the FAO Penman model showed better performance than other models. The Priestley Taylor and Stanghellini models were placed as the second and third best models respectively. Jhajharia *et al.* (2004) also found the similar result as mentioned in Table 3.1. Whereas, in open environment, FAO Radiation and Stanghellini models were found to be the most and the least appropriate models. The slope of the linear regression equation in the FAO Radiation model was 1.030, which is close to 1.0. The intercept value was 0.166 which is close to zero and the R^2 was 0.916, which is close to 1. The value of the RMSE and RE for the FAO Radiation were (0.660 and

17.18 %) but higher than FAO Penman. According to the value of R^2, RSME and RE, the FAO Penman model showed an even better performance than the FAO Radiation model. But the slope of the straight regression line and the intercept in the FAO Penman model were 0.807 and 0.716 which were not satisfying. So, FAO Penman and Priestley Taylor models were placed as the second and third best models respectively (Table 3.2). The results are in agreement with earlier investigators (Moazed *et al.,*2014).

Table 3.1: Ranking and statistical analysis of different daily ET_0 model estimations vs. FAO PM Values under polyhouse

Sr. No	ET_0 Models	Rank	a	b	R^2	RMSE (mm/day)	RE (%)	D
1	FAO Penman	1	0.99	0.004	0.99	0.0097	0.77	0.992
2	Priestley Taylor	2	1.26	-2.00E-14	1.00	0.355	2.83	0.923
3	Stanghellini	3	1.78	-0.495	0.91	0.717	5.73	0.808
4	FAO Radiation	4	1.20	0.021	0.57	0.639	5.11	0.788
5	Hargreaves	5	0.27	0.259	0.48	0.775	6.18	0.552

a and b - linear regression coefficients, R^2 - Coefficients of determination, RE- Relative error, RMSE- Root mean squared error, D- agreement index

Table 3.2: Ranking and statistical analysis of different daily ET_0 model estimations vs. FAO PM Values under the open environment.

Sr. No	ET_0 Models	Rank	a	b	R^2	RMSE (mm/day)	RE (%)	D
1	FAO Radiation	1	1.030	0.166	0.916	0.660	17.18	0.972
2	FAO Penman	2	0.807	0.716	0.945	0.523	13.60	0.967
3	Priestley Taylor	3	0.820	0.477	0.846	0.779	20.25	0.952
3	Hargreaves	4	0.773	1.390	0.846	0.923	23.99	0.931
4	Stanghellini	5	1.378	-0.729	0.832	1.563	40.65	0.892

a and b - linear regression coefficients, R^2 - Coefficients of determination, RE- Relative error, RMSE- Root mean squared error, D- agreement index

3.2 Effect of Different Level of Irrigation on Yield and Water Productivity of Tomato Crop under Polyhouse and Open Environment

The maximum average weight of fruit produced was in treatment T_2 i.e 106.66 gm in polyhouse. Table 3.3 shows that the effect of the treatments on the average fruit weight was found to be significance The average weight of fruit was found in treatment T_9 which was 29.30 % less than that of control. The maximum production observed was 18.97 kg/m^2 in treatment T_2 while the minimum was 6.12 kg/m^2 in treatment T_9. The treatment T_3 showed only a small difference with control and the production was almost the same.

In polyhouse the average yield per plant in treatments T_1, T_2, T_3, T_4, T_5 and T_6 were 4.78, 5.14, 5.01, 4.56, 3.92 and 3.52 kg/ plant, respectively, where as for open environment the average yield per plant in treatments T_7, T_8 and T_9 were 2.54, 2.04 and 1.64 kg/ plant, which is lower than that of control (T_2). From Table 3.3, it reveals that the effect of various treatments on average yield per plant was found to be significant. The yield was found maximum in control followed by treatment T_3.

The effect of various treatments on water productivity was found to be significant. The water productivity is the amount of water applied to produce one kg of tomato, which was maximum (20.47 l/ kg) for T_7 (100% of ET_c) in an open environment. Whereas, the amount of water required producing one kg of tomato ranged from 4.84 to 7.94 l/kg under polyhouse condition.

Table 3.3: Effect of various treatments on tomato fruit weight, yield per plant, yield per meter square, water use efficiency and water productivity under polyhouse and open environment

Treatments	Fruit weight (gm)	Yield (kg) per plant	Yield (kg/m^2)	WU (m^3/plant)	WUE (kg/m^3)	Water productivity (l/kg)
T_1	96	4.78	17.64	0.038	125.78	7.94 b
T_2	106.66	5.14	18.97	0.038	135.26	7.39 b
T_3	103.33	5.01	18.50	0.029	172.75	5.78
T_4	92.44	4.56	16.83	0.029	157.24	6.35
T_5	89.41	3.92	14.47	0.019	206.31	4.84
T_6	85.13	3.52	12.99	0.019	185.26	5.39
T_7	90.12	2.54	9.38	0.052	48.84	20.47 a
T_8	82.14	2.04	7.56	0.039	52.30	19.12 a
T_9	75.33	1.65	6.12	0.026	63.46	15.75 a
CD ($P<0.05$)	9.91	0.83	3.08	0.010	4.25	2.43
SEM (±)	4.04	0.34	1.25	0.004	16.84	0.98
CV (%)	10.87	19.72	19.72	33.26	36.37	31.36

5 CONCLUSIONS

Based on the summary results of the study on "Evapotranspiration based Irrigation Scheduling of Tomato Crop under Naturally Ventilated Polyhouse", the following main conclusions are drawn:

1. The FAO Penman and Hargreaves model are found to be most and least appropriate models for estimating daily ET_0 under polyhouse. Whereas, FAO Radiation and Stanghellini model observed to be most and the least appropriate models in an open

environment for estimating daily ET_0 for the Pantnagar *tarai* condition of Uttarakhand.

2. The average water requirement for tomato crop under polyhouse and open environment were 0.2149 and 0.2924 lpd/plant, respectively shows that the water requirement in open environment was 30 % higher than that of polyhouse.
3. The production of a tomato crop under polyhouse may be achieved to the level of 18.97 kg/m^2 at 100 % level of water use (100 % of ET_c without mulch) with the water productivity of 7.39 l/kg. Whereas, the production of tomato crop in the open environment may be achieved to the level of 9.38 kg/m^2 at 100 % level of water use (100 % of ET_c without mulch) with the water productivity of 20.47 l/kg.

References

Jhajharia, D., Deb Barma, S. and Agrawal, G. 2004. Comparison of pan evaporation-based reference evapotranspiration model with Penman Monteith FAO-56 model. *Journal of Agricultural Engineering*, *41*(3): 46-52.

Jhajharia, D., DebBarma, S. and Agrawal, G. 2004. Comparison of simpler radiation-based ET models with Penman Monteith model for humid region. *Journal of Agricultural Engineering*, *41*(4): 32-36.

Hargreaves, G. H., &Samani, Z. A. 1985.Reference crop evapotranspiration from temperature. *Applied Engineering in Agriculture*, *1*(2): 96-99.

Legates, D. R. and McCabe, G. J., 1999.Evaluating the use of “goodness of fit” measures in hydrologic and hydroclimatic model validation. *Water Resour. Res.*, 35(1): 233-241.

McMahon, T. A., Finlayson, B. L. and Peel, M. C. 2016.Historical developments of models for estimating evaporation using standard meteorological data. *Wiley Interdisciplinary Reviews: Water*, *3*(6): 788-818.

Moazed, H., Ghaemi, A. A. and Rafiee, M. R. 2014. Evaluation of several reference evapotranspiration methods: a comparative study of greenhouse and outdoor conditions. *Iranian Journal of Science and Technology. Transactions of Civil Engineering*, *38*(C2): 421.

Oudin, L., Hervieu, F., Michel, C., Perrin, C., Andréassian, V., Anctil, F. and Loumagne, C. 2005. Which potential evapotranspiration input for a lumped rainfall–runoff model. Part2- Towards a simple and efficient potential evapotranspiration model for rainfall–runoff modelling. *Journal of Hydrology*, *303*(1-4): 290-306.

Tegos, A., Malamos, N. and Koutsoyiannis, D. 2015.A parsimonious regional parametric evapotranspiration model based on a simplification of the Penman–Monteith formula. *Journal of Hydrology*, *524*: 708-717.

Willmott, C. J. 1984.On the evaluation of model performance in physical geography.*The Netherlands*, 443-460.

Singh, V. K., Tiwari, K. N., & Santosh, D. T. (2016). Estimation of Crop Coefficient and Water Requirement of Dutch Roses (Rosa hybrida) under Greenhouse and Open Field Conditions. *Irrigat Drainage Sys Eng*, *5*(169), 2.

Parvizi H, Sepaskhah AR, Ahmadi SH (2014) Effect of drip irrigation and fertilizer regimes on fruit yields and water productivity of a pomegranate (*Punica granatum* (L.) cv. Rabab) orchard. Agricultural Water Management. 146: 45-56.

Tiwari KN, Kumar M, Santosh DT, Singh VK, Maji MK (2014) Influence of drip irrigation and plastic mulch on yield of Sapota (*Achras zapota*) and Soil Nutrients. Irrigation and Drainage Sys Eng. 3: 116.