



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

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### **Authors' contributions**

*This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.*

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### **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,

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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<sub>2</sub> (100% water application of ET<sub>c</sub> without mulch under polyhouse) recorded significant yield (18.97 kg/m<sup>2</sup>), water use efficiency (135.26 kg/m<sup>3</sup>) and maximum fruit weight (106.66 gm).

*Keywords: Reference evapotranspiration models; performance regression statistics; polyhouse; open environment; water productivity.*

## 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 [1]. 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<sub>0</sub>) 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<sub>0</sub> 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 (ET<sub>0</sub>) and crop evapotranspiration (ET<sub>c</sub>) on a daily basis is important to apply water through drip system for crops grown in the greenhouse [2,3].

Many models have been reported, to estimate reference evapotranspiration (ET<sub>0</sub>) 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. [4] investigated optimal method to calculate Potential evapotranspiration (PET) for use in rainfall-runoff model; Tegos et al. [5] summarized historical developments of ET<sub>0</sub> methods using standard meteorological data; and McMahon et al. [6] considered the simplification of the Penman-Monteith model was having high efficiency in the estimating of ET<sub>0</sub>. The FAO Penman Monteith, method (FAO-PM) was considered as the standard ET<sub>0</sub> 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. Himalaya's climate is classified as tropical. The rainfall in Himalaya is significant, with precipitation even during the driest month. This climate is considered to be Af according to the Köppen-Geiger climate classification. The average annual temperature is 25.6°C in Himalaya. The rainfall here averages 2890 mm. Precipitation is the lowest in December, with an average of 167 mm. In June, the precipitation reaches its peak, with an average of 317 mm. At an average temperature of 26.2°C, November is the hottest month of the year. At 24.5°C on average, July is the coldest month of the year. 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° E longitude and at an altitude of 243.83 m 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 (*Lycopersicon esculentum* L.) variety Heemsohna was selected as a test crop for study. The experimental sites of area 100 m<sup>2</sup> and 60 m<sup>2</sup> 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 3 m × 1 m (Fig. 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 0.5 m between each plot and 0.5 m 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<sup>2</sup>. The drip tapes of diameter 20 mm having emission points at 20 cm spacing with a flow rate of and 1.1 L h<sup>-1</sup> 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.

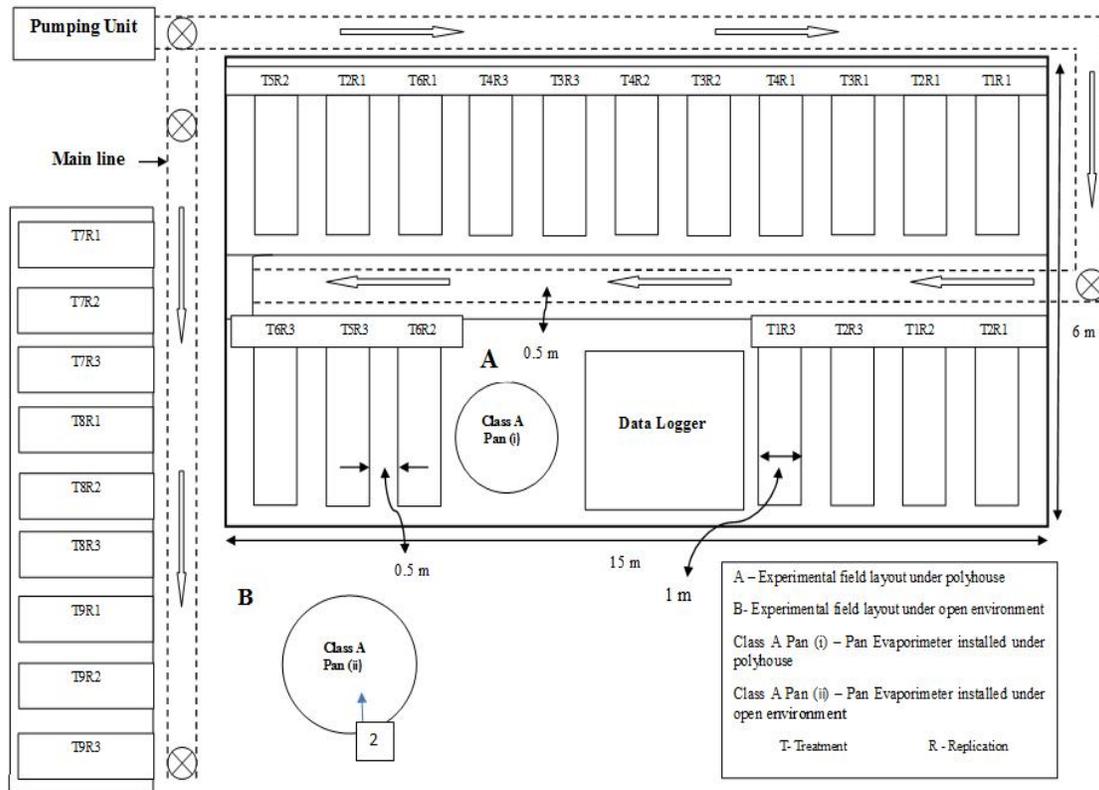


Fig. 2.1. Layout of experimental field

Table 2.1. Details of treatments in experiment

Polyhouse treatments			Open field treatments		
Sr. no.	Treatment	Details of irrigation	Sr. no.	Treatment	Details of irrigation
01	T <sub>1</sub>	100% of ET <sub>c</sub> with plastic mulch	01	T <sub>7</sub>	100% of ET <sub>c</sub>
02	T <sub>2</sub>	100% of ET <sub>c</sub> without plastic mulch	02	T <sub>8</sub>	75% of ET <sub>c</sub>
03	T <sub>3</sub>	75% of ET <sub>c</sub> with plastic mulch	03	T <sub>9</sub>	75% of ET <sub>c</sub>
04	T <sub>4</sub>	75% of ET <sub>c</sub> without plastic mulch			
05	T <sub>5</sub>	50% of ET <sub>c</sub> with plastic mulch			
06	T <sub>6</sub>	50% of ET <sub>c</sub> without plastic mulch			

*ET<sub>c</sub> = 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):

$$V = \sum (E_p \times K_c \times K_p \times S_p \times S_r \times WP - ER) \quad (2.1)$$

V = Total amount of water applied (l/day/plant); E<sub>p</sub> = Pan Evaporation (mm); K<sub>c</sub> = Crop coefficient, K<sub>p</sub> = Pan coefficient; S<sub>p</sub> = Plant to plant spacing (m); S<sub>r</sub> = 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:

$$ER = P_t \left[ \frac{125 - 0.2 \times P_t}{125} \right] \quad \text{for } P_t < 250 \text{ mm} \quad (2.2)$$

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

ER = Effective rainfall (mm); P<sub>t</sub> = Total rainfall (mm)

In this study the calculation of crop coefficient (K<sub>c</sub>) for different growth stages of tomato were considered based on the published report and local studies carried out in India. The crop coefficient K<sub>c</sub> 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<sub>c,init</sub> was taken as 0.6, for mid stage was taken as 1.15 and for end stage it was taken as K<sub>c,end</sub> as 0.80 for open environment. For inside polyhouse, the crop coefficient values for initial stage K<sub>c,init</sub> was taken as 0.6, for mid stage was taken as 1.40 and for end stage it was taken as K<sub>c,end</sub> as 1.0.

### 2.4 Regression Analysis

Simple linear regressions were used in order to determine the correlation between estimated

daily reference evapotranspiration (ET<sub>0</sub>) 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<sup>2</sup>) were also used for model's evaluation and calculated as follow:

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

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

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

The value of D is 1.00 indicates perfect agreement, whereas, its values of 0.00 indicates a poor agreement [7,8].

Where; E<sub>i</sub> is the estimated ET<sub>0</sub> with different models, O<sub>i</sub> is ET<sub>0</sub> estimated with FAO-PM Model, at the *i*<sup>th</sup> data point and *n* is the total number of data points.

Linear regressions to determine the correlation of estimated daily ET<sub>0</sub> values with the FAO-PM Model values, as follows

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

Where; ET<sub>0-DMO</sub> and ET<sub>0-FAOPM</sub> represent the value of ET<sub>0</sub> estimated by different models and ET<sub>0</sub> 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<sup>2</sup>), 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<sup>2</sup> is oversensitive to extreme values and is insensitive to additive and proportional differences between estimated and measured values. Considering these limitations, R<sup>2</sup> 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 Polyhouse 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. [9,10] 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 [11].

#### 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<sup>2</sup> in treatment  $T_2$  while the minimum was 6.12 kg/m<sup>2</sup> in treatment  $T_9$ . The treatment  $T_3$  showed only a small difference with control and the production was almost the same.

**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

**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 <sup>2</sup> )	WU (m <sup>3</sup> /plant)	WUE (kg/m <sup>3</sup> )	Water productivity (l/kg)
T <sub>1</sub>	96	4.78	17.64	0.038	125.78	7.94 b
T <sub>2</sub>	106.66	5.14	18.97	0.038	135.26	7.39 b
T <sub>3</sub>	103.33	5.01	18.50	0.029	172.75	5.78
T <sub>4</sub>	92.44	4.56	16.83	0.029	157.24	6.35
T <sub>5</sub>	89.41	3.92	14.47	0.019	206.31	4.84
T <sub>6</sub>	85.13	3.52	12.99	0.019	185.26	5.39
T <sub>7</sub>	90.12	2.54	9.38	0.052	48.84	20.47 a
T <sub>8</sub>	82.14	2.04	7.56	0.039	52.30	19.12 a
T <sub>9</sub>	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

In polyhouse the average yield per plant in treatments T<sub>1</sub>, T<sub>2</sub>, T<sub>3</sub>, T<sub>4</sub>, T<sub>5</sub> and T<sub>6</sub> 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<sub>7</sub>, T<sub>8</sub> and T<sub>9</sub> were 2.54, 2.04 and 1.64 kg/ plant, which is lower than that of control (T<sub>2</sub>). 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<sub>3</sub>.

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<sub>7</sub> (100% of ET<sub>c</sub>) 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.

#### 4. 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<sub>0</sub> 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<sub>0</sub>

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<sup>2</sup> at 100% level of water use (100% of ET<sub>c</sub> 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<sup>2</sup> at 100% level of water use (100% of ET<sub>c</sub> without mulch) with the water productivity of 20.47 l/kg.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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