Indian Journal of Agricultural Sciences **87** (3): 350–4, March 2017/Article
https://doi.org/10.56093/ijas.v87i3.68712

Evaluation of reference evapotranspiration models using single crop coefficient method and lysimeter data

ROHITASHW KUMAR[1] and MUKESH KUMAR[2]

Sher-e-Kashmir University of Agricultural Science and Technology, Kashmir-Srinagar, J&K 190 025

Received: 6 October 2016; Accepted: 29 August 2016

ABSTRACT

The field experiment of lysimeter set-up was conducted at Solan, Himachal Pradesh on Pea (*Pisum sativum*) to determine the water requirement, single crop coefficient of pea using a lysimeter. Six reference evapotranspiration models were used to compute reference evapotranspiration and compared with actual crop evapotranspiration for different crop growth stages. Results showed that Penman Montieth crop evapotranspiration model gives the closest agreement with the corresponding values obtained in field as a result of water balance study with R^2, SEE and ARE; 0.97, 9.5 and 11.6, respectively. The results emphasized the utility of lysimeter for ecohydrological crop evapotranspitaion model at sub- temperate, sub-humid regions.

Key words: Crop coefficient, Crop evapotranspiration, Lysimeter, Reference evapotranspiration

The determination of crop coefficients and evapotranspiration are important for estimating irrigation water requirements in order to have better irrigation scheduling and water management (Mostafazadeh-Fard *et al.* 2009). Evapotranspiration is very important for hydrologic cycle because it represents a considerable amount of moisture lost from a plant canopy. Rasul (2009) reported that estimation of reference crop reference evapotranspiration has immense importance for determination of water demand for crops and irrigation scheduling. Therefore, mathematical models are commonly used for estimation of crop evapotranspiration.

Many empirical and semi-empirical methods for estimation of reference evapotranspiration (ET_0) are being used by individual scientists and researchers as per their claimed validations in other parts of the world (Allen *et al.* 1998, Kumar *et al.* 2002, Trajkovic *et al.* 2003). The different methods of ET_o estimation can be grouped into empirical formulations based on radiation (Priestley-Taylor), temperature (SCS Blaney-Criddle, Hargreaves Samani), combination theory types (Penman Monteith, FAO-24 Penman (c=1), FAO-24 corrected Penman) and pan evaporation (FAO-24 pan). However, lysimeter data are believed to be the best judge, to assess the performance of any method. Suitability of Penman-Monteith (P-M) equation was assessed by different authors for different climatic conditions (Dehghani Sanij *et al.* 2004 and Gavilan *et al.* 2006). The Blaney-Criddle equation is a temperature based equation and its use for estimation of evapotranspiration for different climatic conditions have been reported extensively in literature (Singandhupe and Sethi 2005, Chauhan and Shrivastava 2009, Fooladmand and Ahmadi 2009, Benli *et al.* 2010, Horvath *et al.* 2010 and Mohawesh O E 2011).

India is inherited by a variety of climates ranging from arid to humid and temperate. The local scientists generally apply the well-known methods believed to be giving good results in other parts of the world despite the fact that their accuracy is highly sensitive to climate. Therefore, to reduce the uncertainty associated with the ET_o estimation methods, further systematic studies are required to compare their performance under different climatic conditions. The field experiment of lysimeter set up on Pea (*Pisum sativum*) was conducted in sub-temperate, sub-humid agro-climate of Solan, Himachal, India. The objectives of this study were: validate reference crop evapotranspiration model was done on the basis of lysimeter and determining single crop coefficient of pea.

MATERIALS AND METHODS

A field experiment on pea crop was conducted during November, 2009 to February, 2010 at Dr Y S Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh, India. The average rainfall of the area ranges from1 100-1 300 mm with most rain falling between June-September. Pan evaporation rate ranges from 1-12 mm/day. The soil is loam type with shallow depth. All the meteorological data required for the estimation of reference evapotranspiration has been obtained from all weather station at the institute.

[1]Associate Professor (e mail- rohituhf@ rediffmail.com), Division of Agricultural Engineering, SKUAST-Kashmir, Srinagar (J&K) 190 025, [2]Assistant Professor, School of Agriculture, IGNOU, New Delhi 110 068 India.

Table 1 Reference evapotranspiration estimation methods

Method of ET_0 estimation	Equations used	Basic reference	Required meteorological data
FAO-24 corrected Penman (c = 1), (F c P-Mon)	$ET_o = c\left[\frac{\Delta}{\Delta+\gamma}(R_n - G) + \frac{\gamma}{\Delta+\gamma} 2.7 W_f (e_a - e_d)\right]$	Doorenbos J and Pruitt W O (1977)	Net radiation, vapour pressure deficit and wind velocity
Priestley-Taylor (P-T)	$ET_o = \alpha \frac{\Delta}{\Delta+\gamma}(R_n - G)$	Shuttleworth W J (1992)	Net radiation, soil heat flux and vapour pressure deficit
FAO-24 Blaney-Criddle, (F B-C)	$ET_o = a + b\left[p\left(0.46\overline{T} + 8.13\right)\right]$	Doorenbos J and Pruitt W O (1977)	Annual day time hours, temperature and wind velocity
Hargreaves-Samani (H-S)	$ET_o = 0.0135(KT)(R_a)(TD^{1/2})(TC + 17.8)$ $KT = 0.00185(TD)^2 - 0.0433TD + 0.4023$	Hargreaves G H and Samani Z A (1982) Hargreaves G H and Samani Z A (1985)	Net radiation, min/max temperature
FAO Pan Evaporation (F E-Pan)	$ET_o = K_p\ E_{pan}$	Allen *et al.* (1998)	Pan evaporation
Penman Monteith (P-M)	$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$	Allen *et al.* (1998)	Vapour pressure deficit, radiation flux, wind velocity, temperature and soil heat flux.

In order to investigate actual crop evapotranspiration in the field lysimeter-set up was installed. The method consists of assessing the incoming and outgoing water flux into the crop root zone over crop period. Fluxes such as subsurface flow and deep percolation are difficult to assess for short time periods hence, soil water balance method usually only gives crop evapotranspiration (ET_c) estimates over long time period (Allen *et al.* 1998).

Precipitation (P), irrigation (I_r), if any and the quantity of water drained off from the bottom of the lysimeter (D_r), was carefully measured. Runoff component (RO) is assumed to be insignificant. Changes in soil moisture storage were measured by soil moisture sampling at different depths of the root zone within lysimeter. The crop evapotranspiration is computed using the following water balance equation

$$P + I_r = D_r + ET_c + RO + \Delta S \quad (1)$$

where, ET_c are the crop evapotranspiration and ΔS is the soil moisture storage change. The change in the soil moisture for the specific depth (d_z) and for the specific time period is computed as:

Moisture storage change

$$(\Delta S_z) = (\theta_z, \text{final} - \theta_z, \text{initial}) * d_z \quad (2)$$

where θ_z, initial and θ_z, final are final and initial water content in the soil profile in a discrete time interval.

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ET_o. The most commonly used six reference evapotranspiration models are summarized in Table 1. For suitability of these reference evapotranspiration models, using local climatic data and modified crop coefficient value, crop reference evapotranspiration have been computed. It is very difficult to decide an appropriate ET_o estimation method among the different available methods for a particular agroclimatic conditions.

The concept of K_c was introduced by Jensen (Jensen 1968) and further developed by the other researchers (Jensen 1968, Doorenbos and Pruitt 1975, Doorenbos and Pruitt 1977 and Jensen 2011). The determination of K_c value represents the crop-specific water use, and is required for accurate estimation of irrigation requirements. Different climatological parameters which have influence on K_c are used for ET_o estimation. Determination of stage-wise crop coefficients crop, grown under different climatic conditions were suggested by Doorenbos and Pruitt (1977). The Food and Agricultural Organization (FAO) provided various crop growth stages corresponding to standard crop. The numerical procedure is used to modify the crop coefficient (K_c) values (Allen *et al.* 1998). Hence, modified FAO value of crop coefficients is recommended for different ET_o models in the agro-climate of present study. The crop coefficient for initial stage is referred as $K_{c\ ini}$. Similarly, crop coefficient for mid season and end stages are designated as $K_{c\ mid}$ and $K_{c\ end}$, respectively.

For accurate evaluation of different methods, a quantitative assessment procedure has been followed, which involves the use of error statistics (Ambrose and Roesch 1982) is determined as:

$$R^2 = 1 - \frac{\sum_i^n \left(y_i - \hat{y}_i\right)^2}{\sum_i^n \left(y_i - \bar{\hat{y}}\right)^2} \quad (3)$$

$$SEE = \left[\frac{\sum_{i=1}^{n} (y_i - y_i)^2}{n-1} \right]^{0.5} \quad (4)$$

$$ARE = \frac{\sum_{i=1}^{n} (\hat{y}_i - y_i)}{y_i} \quad (5)$$

where, R^2 is coefficient of determination, SEE is standard error estimate and ARE is the average relative error, subscript i denotes the i^{th} crop growth stage in the crop period. $\bar{\hat{y}}$ is average of $\hat{y}_i$, $\bar{y}_i$ is the average of y_i and n is total number of crop growth stages, y_i is Field observed crop evapotranspiration, $\hat{y}_i$ is crop evapotranspiration computed as product of crop coefficient and reference evapotranspiration corresponding to individual method. A value of R^2 close to the unity indicates a high degree of association between the observed and modeled values, SEE provides a measurement of deviation between computed and observed moisture contents and ARE statistics quantify the extent to which, computed values overestimate (positive ARE) or underestimate (negative ARE) the measured values.

FAO recommended K_c values for different growth stages (Allen *et al.* 1998) was modified for different stages for the local climatic condition. Crop evapotranspiration represented crop water requirement, which is determined as the product of K_c value for the particular period and corresponding ET_o.

RESULTS AND DISCUSSION

Depletion of moisture by plant from the root zone is governed by the daily crop evapotranspiration values. Moisture uptake from root zone is equal to the crop evapotranspiration. Crop evapotranspiration is represented by the varying moisture content in the effective root zone to a large extent (Evans *et al.* 1996). Estimated crop evapotranspiration by a particular model (product of K_c and ET_o) given the model predicted crop evapotranspiration. The reference evapotranspiration values for one year duration using different model is illustrate in Fig 1.

Allen *et al*. (1998) provided numerical procedure to compute modified crop coefficient for local agro-climatic condition. FAO proposed $K_{c\ ini}$, $K_{c\ mid}$ and $K_{c\ end}$ values are: 0.5, 1.15 and 1.1 for Pea. These values were modified for the local climatic condition, soil characteristics and crop according to the procedure given in FAO-56 guidelines is shown in Table 2. The crop evapotranspiration predicting is the basis for assessing the efficiency of different reference evapotranspiration models and further validation using lysimeter data.

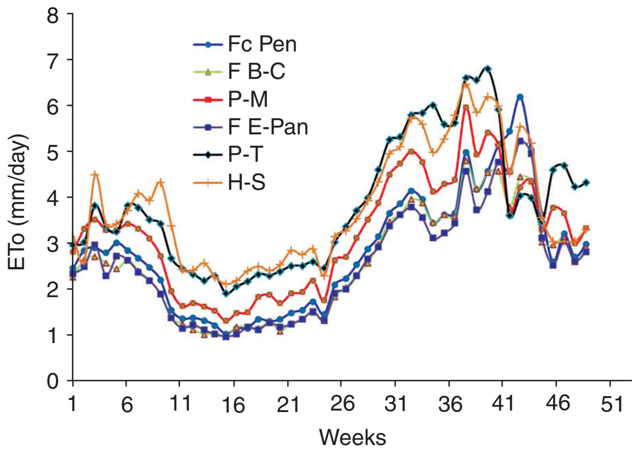

Fig 1 Weekly-average daily ET_o estimates during crop period

Field observed crop evapotranspiration for different growth stages of the crop period is obtained by conducting water balance study with lysimeter set-up. The computed and field observed values of crop evapotranspiration for different stages corresponding to different ET_0 estimation models are compared qualitatively as well as quantitatively. The cumulative and stage wise precipitation, irrigation, deep percolation along with the crop evapotranspiration computed using water balance study are summarized in Table 3 for pea crop. It is evident from Table 3 that, about 50% of ET_c demand (278.7 mm) has been met with irrigation (200 mm).

The field observed and computed crop evapotranspiration, for individual crop growth stages is computed for the whole crop period. The comparison of field observed and computed stage-wise and cumulative crop evapotranspiration is illustrated in Fig 1-2. The H-S and P-T methods highly overestimate but P-M slightly overestimate than observed value, But Fc Pen and F B-C and F E Pan underestimate and shows close agreement with field observed value. For comprehensive evaluation of the agreement between field observed and computed individual stage-wise crop evapotranspiration, based on different reference

Table 2 Modified values of FAO recommended crop coefficients for local conditions

Crop	Crop coefficients								
	$K_{c\ ini}$			$K_{c\ mid}$			$K_{c\ end}$		
	FAO value	Modifying parameters	Modified value	FAO value	Modifying parameters	Modified value	FAO value	Modifying parameters	Modified value
Pea	0.47	Wetting frequency = 12 days Avg. ET_o = 2.1 mm/day	0.5	1.32	u_2 = 2.41 ms^{-1} RH_{min} = 48.1 H = 0.64 m	1.35	1.1	u_2 = 2.05ms^{-1} RH_{min} = 47.7 H = 0.65 m	1.15

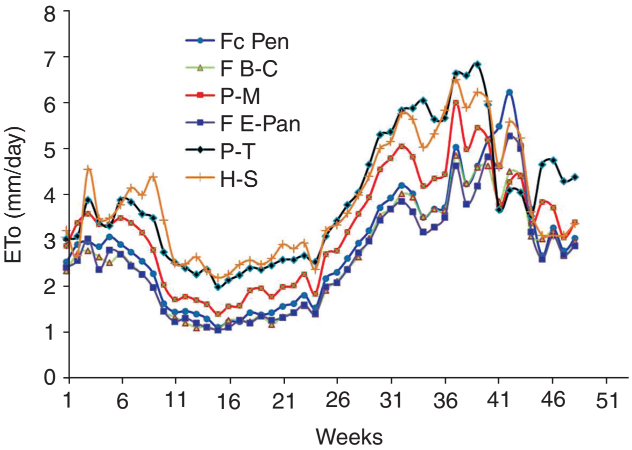

Fig 2 Weekly-average daily ET_o estimates during crop period

evapotranspiration values, statistics error; R^2, SEE and ARE is computed. The detailed summary of the error statistics corresponding to different growth stages is given in Table 4.

It is illustrated from Table 4 that, all models show close agreement but P-M method shows closet agreement with observed value. The P-M method R^2, SEE and ARE values are 0.97, 9.5 and 11.6, respectively. It can be concluded from results summarized in Table 4 and Figs. 3-4 that, Penman Montieth (P-M) model estimated crop evapotranspiration gives the most optimal estimate of the crop water requirement for sub-temperate, sub-humid agro-climate region of India.

The comparative study of different models was made on the basis agro-climatic data with modified empirical crop coefficient and actual measurements of crop

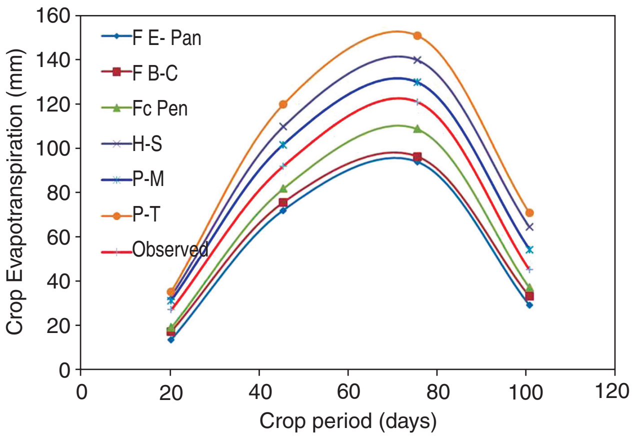

Fig 3 Computed and observed stage-wise crop evapotranspiration for pea

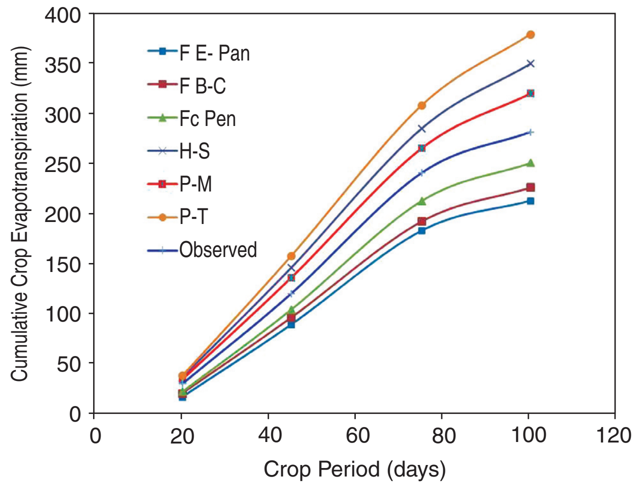

Fig 4 Computed and observed cumulative stage-wise crop evapotranspiration for pea

Table 3 Water balance components for the crops under lysimeter study

Component (mm)	Crop Stage				Total (mm)
	Initial	Development	Mid-season	Late-season	
			Pea		
Precipitation	0	6.8	4.7	97	108.5
Irrigation	20	80	100	0	200
Percolation	4.5	6	5.4	42	57.9
Moisture storage change (ΔS)	-10.6	-11.4	-21.7	15.6	-28.1
Crop Evapotranspiration (ETc)	26.1	92.2	121	39.4	278.7

Table 4 Statistical analysis between observed and different ET_o estimation models based stage-wise crop evapotranspiration

Statistical terms	Reference evapotranspiration method					
	P-Mon	Fc Pen	P-T	F B-C	H-S	F E-Pan
			Pea			
COD	0.97	0.95	0.89	0.93	0.93	0.92
SEE	9.5	11.13	28.15	19.12	21.7	22.67
ARE (%)	11.6	-13.00	31.2	-21.16	18.56	-26.15

COD: Coefficient of determination; SEE: Standard error estimate; ARE: average relative error.

evapotranspiration using lysimeter. The FAO recommended crop coefficient values were modified for the local agro-climatic conditions. The Penman Monteith model was found to give close agreement with field measured values of lysimeter. Hence, Penman Monteith model is the most suitable reference evapotranspiration model with modified crop coefficient values for sub-temperate and sub-humid agro-climate. Determination of accurate reference evapotranspiration motivates researchers to resolve the problem of optimum irrigation scheduling.

ACKNOWLEDGEMENT

The author is highly thankful to Department of Civil Engineering, NIT, Hamirpur (Himachal Pradesh) and Department of Soil Science, University of Horticulture and Forestry, Solan (Himachal Pradesh) for providing lab facilities, field equipments, meteorological data and computational facilities required for carrying out the study.

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