__Original Research Article__

Determination of crop-coefficients and estimation of evapotranspiration of field pea (*Pisum sativum* L.) using lysimeter and different reference evapotranspiration models for temperate region.

ABSTRACT:

During Rabi 2020-21, a field experiment was conducted at SKUAST-K, Shalimar, Srinagar, focusing on field Pea (*Pisum sativum* L.). The aim was to determine the water requirement and single crop coefficient (K_c) of pea using a lysimeter setup. Four reference evapotranspiration models were employed to calculate the reference evapotranspiration and were then compared with the actual crop evapotranspiration at different growth stages. The K_c values for field pea were 0.50, 0.80, 1.15, and 1.10 during the initial, development, mid-season, and late season stages, respectively. The water requirement was found as 239.9 mm for the whole cropping period of the pea. Among the models, the Penman Montieth crop evapotranspiration model exhibited the closest agreement with the corresponding values obtained in the field through water balance study, yielding RMSE, RSR, and NSE values of 0.97, 9.5, and 11.6, respectively. These findings highlight the significance of using lysimeters for eco-hydrological crop evapotranspiration modeling in temperate regions.

Keywords: Crop Evapotranspiration, Drainage type lysimeter, Crop coefficient, Pea.

INTRODUCTION:

The accurate assessment of water losses through evapotranspiration by crops is crucial due to limited water resources. Weather stations record climatic parameters such as air temperature, solar radiation, relative humidity, and wind speed, which are used to estimate plant water needs (Incrocci *et al*., 2014). Reference evapotranspiration (ET_0) is determined by various mathematical models based on these parameters. The crop coefficient (K_c) is obtained by dividing actual crop evapotranspiration (ET_c) measured using lysimeters by the reference evapotranspiration (ET_0) and represents crop-specific water use. Accurate estimation of K_c is essential for determining the irrigation requirements of different crops in diverse climatic conditions (Doorenbos and Pruitt, 1977). Developing a specific crop coefficient (K_c) for field pea is vital for precise irrigation water planning. By utilizing lysimeters to measure crop water use and established methods to calculate reference evapotranspiration rates, daily crop coefficients can be determined. Properly scheduling irrigations based on the averaged water requirement and correct timing is crucial to meet the crop's water demands and achieve optimal crop production (Mehta and Pandey, 2016).

Research indicates that gaining a better understanding of actual crop water requirements through modern technologies can lead to saving at least 50% of irrigation water (Ragab *et al.*, 2017). Numerous studies have explored various evapotranspiration models in different locations. For instance, Dehghani Sanij *et al.* (2004) assessed four ET_0 models in Karaj, Iran; Bormann (2011) investigated 18 PET models in the German climate; Nag *et al.* (2014) examined 14 models in India; Djaman *et al.* (2015) studied 16 ET_0 models in the Senegal River Valley; and Muniandy *et al.* (2016) tested 26 ET_0 models in Kluang, Malaysia.

Among the empirical models, the Food and Agricultural Organization recommends the Penman-Monteith equation (FAO-PM) as the standard method for estimating ET, requiring meteorological parameters such as temperature, humidity, wind speed, sunshine hours, and net radiation (Allen *et al.*, 1998). However, some researchers have also used simpler empirical models like Hargreaves-Somani, Turc, and Blaney-Criddle, as they require fewer meteorological parameters.

In the Kashmir valley, pea is mainly cultivated as a Rabi crop, but in higher altitudes, it is grown as an off-season vegetable during summer. Peas can tolerate temperatures ranging from 7 to 30°C in higher tropical altitudes (Duke, 2012). Being a winter crop, peas can withstand relatively low temperatures, especially during the early stages of growth, but may not survive severe and prolonged frost (Prabhakara *et al.*, 2008). To estimate evapotranspiration accurately, it is essential to develop crop coefficients (K_c) for different models. Based on the above considerations, this experiment was undertaken to determine the crop coefficients (K_c) and estimate the evapotranspiration of field pea using four reference evapotranspiration models.

MATERIALS AND METHODS:

During the period from November 2020 to May 2021, a field experiment was conducted on pea crops at Sher-e-Kashmir University of Science and Technology-Kashmir (SKUAST-K), located in Shalimar, Srinagar, Jammu & Kashmir, India. The geographical coordinates of the experimental site are approximately 34°1' N latitude and 74°9' E longitude, with an altitude of 1586 meters above mean sea level. The climate at the experimental site is characterized as temperate, experiencing moderately hot summers and bitterly cold winters, with the majority of precipitation occurring as snow during winter. Summer temperatures typically range between 30°C to 35°C, while winter temperatures can drop as low as -10°C. The recorded annual rainfall was approximately 710 mm. Throughout the year 2020-21, the average relative humidity at the experimental site was 70%. During the Rabi season, the average number of sunshine hours recorded was 4 hours per day.

To explore the actual crop evapotranspiration, a field lysimeter setup was established. This method involves monitoring the water inflow and outflow within the crop root zone throughout the crop's growth period. However, certain fluxes like subsurface flow and deep percolation are challenging to accurately assess over short time frames. Consequently, the soil water balance method typically provides estimates of crop evapotranspiration (ET_c) over longer durations (Allen *et al*., 1998).

The inflow and outflow variables required in the water balance equation are measured in the lysimeter setup. The inflow to the field can consist of precipitation and applied irrigation water and water can leave the field through evapotranspiration, surface runoff, seepage, and vertical percolation. Changes in soil moisture storage were measured by soil moisture sampling at different depths of the root zone within the lysimeter. The crop evapotranspiration is computed using the following water balance equation:

$$\Delta S = P + I - ET - DP - HS - R \quad (1)$$

where ΔS is the change in storage in the root zone (mm), P is precipitation amount (mm), I is irrigation water (mm), ET is actual evapotranspiration (mm), DP is vertical deep percolation (mm), HS is horizontal seepage through bunds (mm) and R is surface runoff (mm).

As the experiments are conducted in a lysimeter, horizontal seepage (HS) is zero and as the soil is not filled in the lysimeter, surface runoff (R) is negligible. So, the water balance equation for the lysimeter set-up becomes:

$$\Delta S = P + I - ET - DP \quad (2)$$

Change in storage (ΔS) is calculated using the initial and final moisture content readings over the required time duration. Precipitation (R) data is taken from the meteorological observatory of Agromet Field Unit, SKUAST-K, Shalimar. Evapotranspiration (ET) is estimated using the FAO-Penman-Monteith equation (Allen *et al*., 1998). Irrigation (I) to the crop is measured by a calibrated hosepipe.

The evapotranspiration rate from a well-watered reference surface not short of water is referred to as the reference crop evapotranspiration or ET_0. Table 1 provides a summary of the four most commonly used reference evapotranspiration models. To determine the suitability of these models for specific agro-climatic conditions, crop reference evapotranspiration has been calculated using local climatic data and modified crop coefficient values. Selecting an appropriate ET_0 estimation method among the various available methods for a particular agro-climatic condition can be challenging.

The concept of crop coefficient (K_c) was first introduced by Jensen in 1968 and further developed by other researchers such as Jensen (1968), Doorenbos and Pruitt (1975), Doorenbos and Pruitt (1977), and Jensen (2011). Determining the K_c value is essential as it represents crop-specific water use, enabling accurate estimation of irrigation requirements. Various climatological parameters that influence K_c are utilized for estimating reference evapotranspiration (ET_0). To accommodate different growth stages of crops under diverse climatic conditions, Doorenbos and Pruitt (1977) suggested determining stage-wise crop coefficients.

The Food and Agricultural Organization (FAO) provides standard crop growth stages corresponding to various crops. A numerical procedure is employed to modify the crop coefficient (K_c) values (Allen *et al*., 1998). Therefore, the modified FAO values of crop coefficients are recommended for different ET_0 models in the agro-climatic conditions of the present study. Specifically, the crop coefficient for the initial stage is denoted as K_c ini, while the coefficients for the mid-season and end stages are referred to as K_c mid and K_c end, respectively.

~~In order to~~ To precisely evaluate various methods, a quantitative assessment procedure has been employed, incorporating error statistics as proposed by Ambrose and Roesch in 1982. The error statistics used for this evaluation include the Root Mean Square Error (RMSE), the Ratio of the Root Mean Square Error to the standard deviation of measured data (RSR), and the NashSutcliffe Efficiency (NSE) suggested by Moriasi *et al*. in 2007.

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\text{ETobs} - \text{ETcal})^2} \qquad (3)$$

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n}(\text{ETobs}-\text{ETcal})^2}{\sum_{i=1}^{n}(\text{ETobs}-\text{ETmean})^2} \qquad (4)$$

$$\text{RSR} = \frac{\sqrt{\sum_{i=1}^{n}(\text{ETobs}-\text{ETcal})^2}}{\sqrt{\sum_{i=1}^{n}(\text{ETobs}-\text{ETmean})^2}} \qquad (5)$$

Where, $ET_{\mathbf{cal}}$ = calculated ET_c by Models (mm)

$ET_{\mathbf{obs}}$ = observed ET_c by lysimeter method (mm)

$ET_{\mathbf{mean}}$ = average daily ET_c observed over the season (mm)

The FAO-recommended K_c values for various growth stages (Allen *et al.*, 1998) were adjusted to suit the local climatic conditions for different stages. Crop evapotranspiration reflects the crop's water requirement, which is calculated as the product of the specific K_c value for the given period and the corresponding reference evapotranspiration (ET_0).

Table 1: Various models used for computing ET_0

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Model	Formula	Reference
Priestley-Taylor	$ET_0=\alpha+\frac{\Delta}{\Delta+\gamma}(R_n-G)$	Shuttleworth W J, 1992
Penman-Monteith	$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_S - e_a)}{\Delta + \gamma(1 + 0.34\,U_2)}$	Allen *et al.*, 1998
FAO Pan-Evaporation	$ETO = E_{pan} \times K_p$	Allen *et al.*, 1998
Hargreaves-Samani	$ET_0= 0.0023\ (T_{max} – T_{min})\ \sqrt{(Tmean + 17.8)}R_a$	Hargreaves and Somani, 1985
Blaney-Criddle	$E_0 = P\ (0.46T+8)$	Allen and Pruitt, 1986

RESULTS AND DISCUSSION:

Plant moisture depletion from the root zone is primarily influenced by the daily crop evapotranspiration values. The amount of moisture taken up from the root zone corresponds to the crop evapotranspiration. The variability in the moisture content within the effective root zone is largely indicative of ~~the~~ crop evapotranspiration (Evans *et al*. 1996). The estimated crop evapotranspiration is obtained through a specific model, which is the product of two factors, K_c (crop coefficient) and ET_0 (reference evapotranspiration). The model predicts the crop evapotranspiration for a given period. Figure 1 illustrates the reference evapotranspiration values calculated using different models over ~~the course of~~ one year.

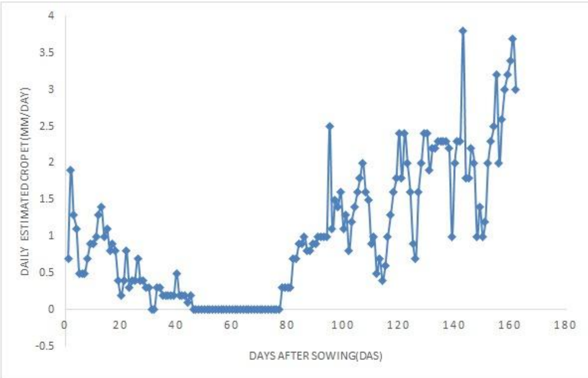

Figure 1. Reference evapotranspiration values were calculated using different models over the course of one year.

Monthly climatic parameters of the study area

The monthly meteorological parameters during the pea crop growing season of the experiment i.e. November 2020 to May 2021 are presented in Table 2.

Table 2. Monthly meteorological parameters

Month	Temperature (°C)		Relative humidity (%)		Sunshine duration (hrs)	Rainfall (mm)	Wind speed (Km/hr)
	Maximum	Minimum	RH_1	RH_2			
Nov	13.7	-1.15	83.1	64.8	2.9	6.14	0.59
Dec	9.4	-3.2	90.3	69.5	2.6	15.0	0.4
Jan	5.8	-5.87	91.5	73.4	1.6	24.6	0.2
Feb	12.6	-0.87	86.7	60.6	4.5	4.58	0.62
Mar	15.0	3.78	81.2	60.7	3.8	15.6	1.62
Apr	18.7	5.3	75.1	48.4	4.9	17.5	1.7
May	24.5	9.4	79.6	54.8	6.2	5.34	2

Crop duration

The pea seeds were sown on the 20th of November 2020 and it took 180 days to reach maturity and harvesting stages. The crop duration was divided into four stages as shown in Table 3.

The values of K_c vary with different crop growth stages from 0.50 to 1.10 during the initial, development, mid, and end stages respectively as recommended by FAO.

Table 3. Duration of the crop growth period and crop coefficient (K_c) of the pea crop

Crop stages	Crop duration	K_c value
Initial stage	35	0.50
Development stage	45	0.80
Mid-season stage	70	1.15
End-season stage	30	1.10

Evaluation of stage-wise ET_o using different empirical methods

The stage wise mean reference evapotranspiration at different pea crop growth stages was calculated at the experimental field of COAE&T, Shalimar using different empirical methods and it is presented in Table 4. The variation in reference evapotranspiration (ET_0) of the same sample during each stage by different methods of determination was because of the various climatic factors that the particular procedure considers. Similar results about variation in ET_0 values by different methods were reported by Ahmad *et al.*, (2017).

Table 4. Mean Reference evapotranspiration at different stages using different empirical methods

Stages	Penman-Monteith (mm/day)	Hargreaves (mm/day)	Blaney-Criddle (mm/day)	Open pan (mm/day)
Initial	1.43	1.19	1.04	1.24
Development	1.35	1.09	0.87	1.15
Mid-stage	2.74	2.59	2.44	2.60
End-stage	4.59	4.54	4.38	4.51

The mean Crop evapotranspiration (ET_c) at different stages of the pea crop growing season was calculated by different empirical methods by multiplying the reference evapotranspiration with crop coefficients recommended in FAO. Also, crop evapotranspiration was calculated by lysimeter using a water balance equation at each crop growth stage. The stage wise mean crop evapotranspiration of pea crop growing season is shown in Table 5. Similar results about variation in ET_c, values by different methods were reported by Ahmad *et al.*, (2017).

Table 5. Mean Crop evapotranspiration (ET_c) by using Lysimeter and different empirical methods at different stages

Stages	Penman-Monteith (mm/day)	Hargreaves (mm/day)	Blaney-Criddle (mm/day)	Open Pan (mm/day)	Lysimeter (mm/day)
Initial	0.71	0.59	0.52	0.62	0.66
Development	1.08	0.87	0.69	0.95	1.01
Mid-stage	3.15	2.97	2.80	2.99	3.11
End-stage	5.04	4.99	4.81	4.96	4.97

Regression analysis between Crop evapotranspiration (ET_c) by Lysimeter and by different empirical methods

To show a more clear and convincing picture of analysis a single linear regression ~~(y = mx + c)~~ or commonly called straight line equation is used for each of the estimations in all stages. In the graphical representation, the X-axis was crop evapotranspiration (ET_{Obs}) by the lysimeter method and the Y-axis was crop evapotranspiration by a particular method that we selected.

Agreement between the calculated (ET_{Cal}) and observed evapotranspiration (ET_{Obs}) values were quantitatively evaluated using the Nash Sutcliffe efficiency (NSE), the ratio of the root mean square error to the standard deviation of measured data (RSR), and root mean square error (RMSE). Based on the above statistical evaluation the performance of the different empirical methods in the estimation of crop evapotranspiration for each crop stage varied from 'Good to Very Good'. The comparison of calculated evapotranspiration (ET_{Cal}) by empirical methods and observed evapotranspiration (ET_{Obs}) values using a lysimeter during each growth stage was rated graphically from Fig. 2 to Fig. 5.

During the analysis of results, it was found that the Penman-Monteith method has a close relationship with the lysimeter method. The RMSE, RSR, and NSE values indicated that the Penman-Monteith method performed 'Very Good' in estimating the evapotranspiration of pea crops during each crop growth stage. With ~~the~~ reference to the data, it was concluded that the Penman-Monteith method of determination of reference evapotranspiration would be adopted as the best method. The RMSE, NSE, and RSR values indicated that the Hargreaves method performed "Very Good" in estimating the evapotranspiration of pea crops during the initial, development, mid, and End stages. Hargreaves method can be the

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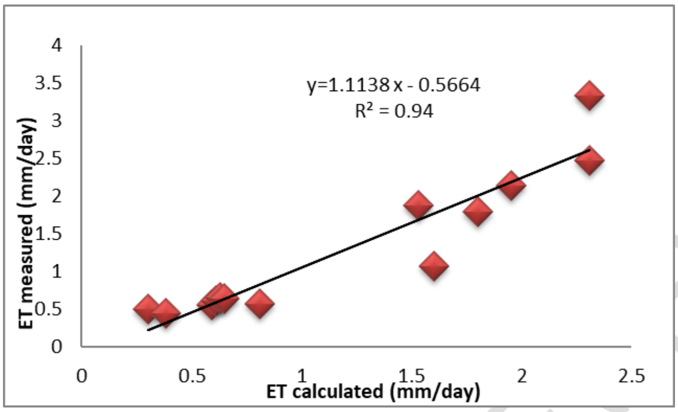

Fig.2. ET_c Lysimeter versus ET_c by Penman-Monteith method

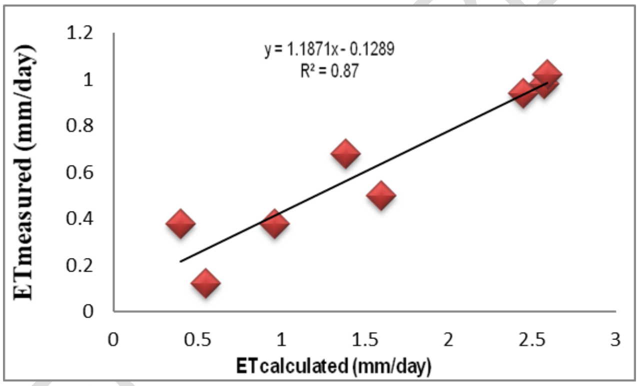

Fig 3. ET_c Lysimeter versus ET_c by Hargreaves method

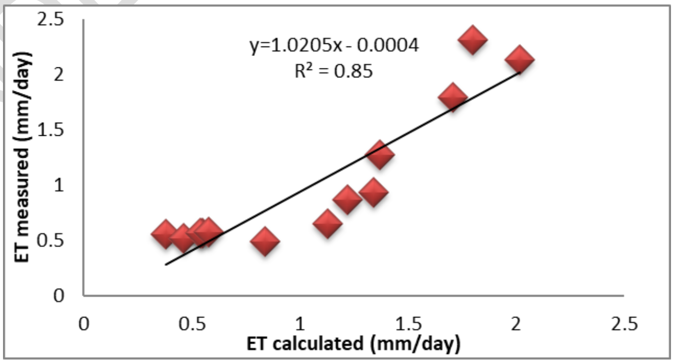

Fig. 4. ET_c lysimeter versus ET_c by Blaney-criddle method

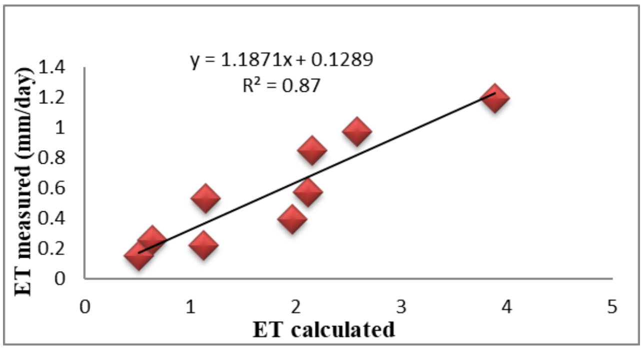

Fig. 5. ET_c Lysimeter versus ET_c by Open pan method

Conclusion

Spatio-temporal variability of rainfall events coupled with their irregularity and amount received during crop growing seasons is a major concern for enhancing agricultural production in temperate regions of India. Such situation requires the provision of irrigation facilities for enhancing agricultural production in the region. Moreover, under irrigated conditions, efforts should be made to apply a judicious amount of water which lowers the cost of production and saves the valuable water resources of the country for enhancing irrigation water use efficiency. To accomplish this, proper irrigation schedules need to be devised, proclaimed, and adopted by the stakeholders ~~for enhancing~~ to enhance ~~the~~ water productivity. It is observed that about 99% of the water uptake by plants from soil is lost as evapotranspiration. Therefore, the determination of daily crop evapotranspiration at different crop growth stages of pea crop was undertaken in this study using a non-weighing drainage type field lysimeter which is the direct method of estimating evapotranspiration. Penman-Monteith and three other models viz., Hargreaves, Blaney-Criddle, and Open Pan methods were used for the estimation of reference evapotranspiration (ET_0). FAO Penman-Monteith Model has been found to perform better than other reference evapotranspiration (ET_0) models in predicting crop evapotranspiration (ET_c). The total crop evapotranspiration from the lysimeter study during the crop growing period was 230.4 mm. ~~In order~~ To minimize the loss of water and to precisely meet the crop water demand to produce greater yields with enhanced water use efficiency crop water management practices are essential.

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