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Estimation of Crop-coefficients and Evapotranspiration of Field Pea (*Pisum sativum* L.) Using Lysimeter and Empirical Models under Temperate Climate

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

During Rabi 2020-21, a field experiment was conducted at SKUAST-K, Shalimar, India, focusing on field Pea (*Pisum sativum* L.). The aim of this study was to determine the water requirement and single crop coefficient (K_c) of pea using a lysimeter setup. Four empirical models were employed to

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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 Penman Monteith crop evapotranspiration model for estimating crop evapotranspiration in temperate regions.

Keywords: Crop evapotranspiration; drainage type lysimeter; crop coefficient; pea.

1. 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 [1]. 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. 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 [2].

Research indicates that gaining a better understanding of actual crop water requirements through modern technologies can lead to save at least 50% of irrigation water [3]. Numerous studies have explored various evapotranspiration models in different locations. For instance, Dehghani Sanij et al. [4] assessed four ET_0 models in Karaj, Iran; Bormann [5] investigated 18 PET models in the German climate; Nag et al. [6] examined 14 models in India; Djaman et al. [7] studied 16 ET_0 models in the Senegal River Valley; and Muniandy et al. [8] 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 [9]. However, some researchers have also used simpler empirical models like Hargreaves-Somani, Turc, 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 [10]. 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 [11]. 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 evapotranspiration of field pea using four reference evapotranspiration models.

2. 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 and 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 experimental site is characterized by temperate climate, experiencing moderately hot summers and extremely cold winters, with the majority of precipitation occurring as snow during winter. Summer temperature typically ranges from 30°C to 35°C, while winter temperatures can drop as low as -10°C. The annual rainfall was approximately 710 mm, relative humidity was

70% and average number of sunshine periods was 4 hours per day during the study period.

2.1 Monthly Climatic Parameters of the Study area

The monthly meteorological parameters during pea crop growing season of the experiment

i.e. November 2020 to May 2021 is presented in Table 1.

2.2 Crop Duration

The pea seeds were sown on 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 2.

The values of K_c vary with different crop growth stages from 0.50 to 1.10 during initial, development, mid and end stages, respectively as recommended by Allen [12].

A lysimeter was set up in the experimental field to monitor the water inflow and outflow within the crop root zone throughout the growing period. However, certain fluxes like subsurface flow and deep percolation are challenging to accurately assess crop evapotranspiration (ET_c) over short time frames. Consequently the soil water balance method typically provides estimates of ET_c over longer durations [9].

The inflow and outflow variables required in the water balance equation were measured in the lysimeter set-up. The inflow is the sum of precipitation and applied irrigation water and outflow consists of 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 lysimeter. The crop evapotranspiration was computed using the following water balance equation:

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

where, ΔS is the change of storage in the root zone (mm), P is precipitation (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 were conducted in a lysimeter, horizontal seepage (HS) was zero and as the soil was not fully filled in the lysimeter, surface runoff (R) was negligible. Therefore, the water balance equation for the lysimeter set-up was:

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

ΔS was calculated using the initial and final moisture content readings over required time duration. Precipitation (R) data was taken from the meteorological observatory of Agromet Field Unit, SKUAST-K, Shalimar. ET was estimated using FAO-Penman-Monteith equation [9]. I was measured by calibrated hosepipe.

Table 1. Monthly meteorological parameters

Month	Temperature (°C)		Relative Humidity (%)		Sunshine durations (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

Table 2. Duration of crop growth period and crop coefficient (K_c) of 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

The evapotranspiration rate from a well-watered reference surface is known as the reference crop evapotranspiration or ET_0. Table 3 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 was calculated using local climatic data and modified crop coefficient values.

The concept of crop coefficient (K_c) was first introduced by Jensen in 1968 and further developed by other researchers such as Jensen [13], Doorenbos and Pruitt [14], Doorenbos and Pruitt [15], and Jensen (2011). Determination of K_c value is essential as it represents the crop-specific water use, enabling accurate estimation of irrigation requirements. To accommodate different growth stages of crops under diverse climatic conditions, Doorenbos and Pruitt [15] suggested about the calculation of 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 [9]. Therefore, the modified FAO values of crop coefficients for different ET_0 models. Specifically, the crop coefficient for the initial stage was denoted as K_c ini, while the coefficients for the mid-season and end stages were referred to as K_c mid and K_c end, respectively.

In order to precisely evaluate various methods, a quantitative assessment procedure was employed, incorporating error statistics as proposed by Ambrose and Roesch [16]. The error statistics used for this evaluation include 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. [17].

$$RMSE = \sqrt{\frac{1}{n} \sum n\, i = 1\, (ETobs - ETcal)^2}$$

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

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

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)

Table 3. Various models used for computing ET_0

Model	Formula	Reference
Priestley-Taylor	$ET_0 = \alpha + \frac{\Delta}{\Delta+\gamma}(R_n - G)$	Shuttleworth W J [18]
Penman-Montei th	$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2(e_S - e_a)}{\Delta + \gamma(1 + 0.34\, U_2)}$	Allen et al. [9]
FAO Pan-Evaporatio n	$ET_0 = E_{pan} \times K_p$	Allen et al. [9]
Hargreaves-Sa mani	$ET_0 = 0.0023\, (T_{max} - T_{min}) \sqrt{(Tmean + 17.8)}\, R_a$	Hargreaves and Somani [19]
Blaney-Criddle	$E_0 = P\,(0.46T+8)$	Allen and Pruitt [20]

3. RESULTS AND DISCUSSION

3.1 Evaluation of Stage-wise ET_0 Using Different Empirical Methods

The stage wise calculated mean reference evapotranspiration (ET_0) at different pea crop growth stages is presented in Table 4. It was observed that ET_0 was highest in the end stage of Penman Monteith method i.e., 0.87 mm/day. Also, the values of ET_0 obtained by the Penman Monteith method were higher as compared to other methods. Variation in ET_0 at each growth stage under different methods was because of the use of various climatic factors. Similar results pertaining to variation in ET_0 values by different methods was reported by Ahmad et al. [21].

Table 4. ET_0 at different growth stage

Stages	Penman-Monteit h (mm/day)	Hargreaves (mm/day)	Blaney-Criddl e (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

Table 5. Mean Crop evapotranspiration (ET_c) at different growth stages

Stages	Penman-Monteith (mm/day)	Hargreaves (mm/day)	Blaney-Criddl e (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

The mean crop evapotranspiration (ET_c) at different stages of pea crop growing season was calculated by different empirical methods by multiplying the reference evapotranspiration with crop coefficients recommended by FAO. The stage wise mean crop evapotranspiration of pea crop growing season is shown in Table 5. It was observed that the value of ET_c was very less during the initial stage of growing period due to the absence of leaves and it gradually increased with increase in the crop canopy. Similar results pertaining to variation in ET_c, values by different methods was reported by Ahmad et al*.* [21].

3.2 Relationship between Crop Evapotranspiration (ET_c) by Lysimeter and by Different Empirical Methods

The relationship between calculated evapotranspiration by empirical methods and observed evapotranspiration using lysimeter during each growth stage is presented in Fig. 1 to Fig. 4.

With the course of analysis of result, it is found that Penman-Monteith method has a close relationship with lysimeter method having RMSE (0.20), RSR (0.02), and NSE (0.99) for initial stage, RMSE (0.23), RSR (0.04) and NSE (0.98) for development stage, RMSE (0.10), RSR (0.05) and NSE (0.97) for mid-stage and RMSE (0.24), RSR (0.03) and NSE (0.98) for end stage. This indicated that the Penman-Monteith method performed ‘Very Good’ in estimating the evapotranspiration of pea crop during each crop growth stage. With the reference from the data it was concluded that the Penman-Monteith method of determination of reference evapotranspiration would be adopted as best method. The RMSE, NSE and RSR values indicated that the Hargreaves method performed “Very Good” in estimating the evapotranspiration of pea crop during initial, development, mid and End stage. Hargreaves method can be the best substitute in similar results pertaining to the performance evaluation of different empirical methods [22].

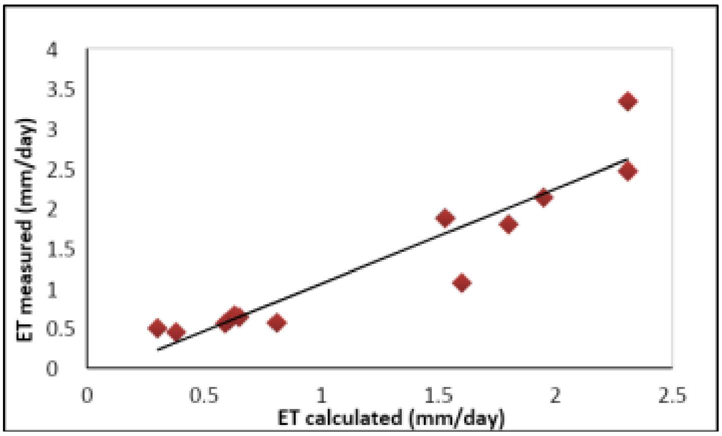

Fig. 1. ET_c Lysimeter versus ET_c by Penman-Monteith method

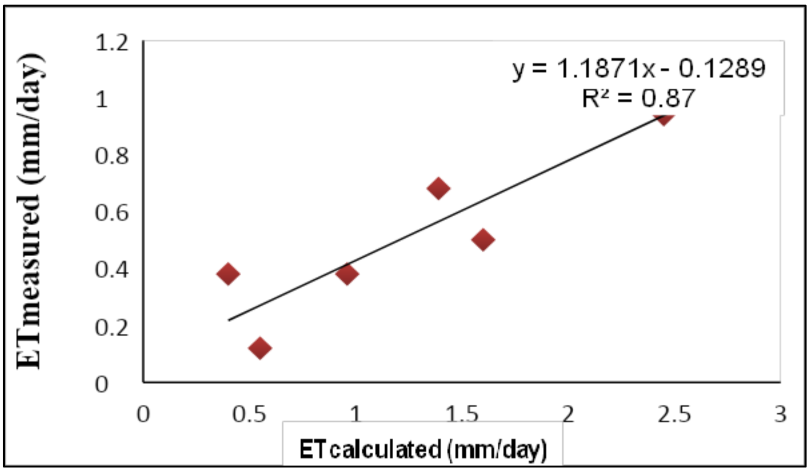

Fig. 2. ET_c Lysimeter versus ET_c by Hargreaves method

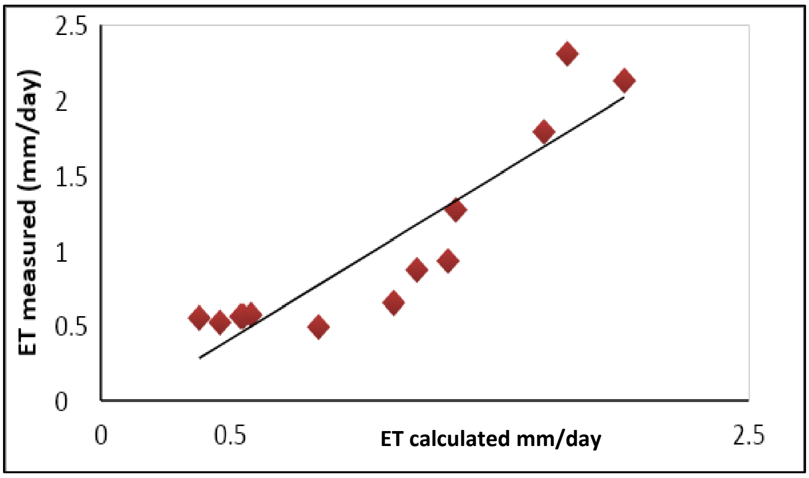

Fig. 3. ET_c lysimeter versus ET_c by Blaney-criddle method

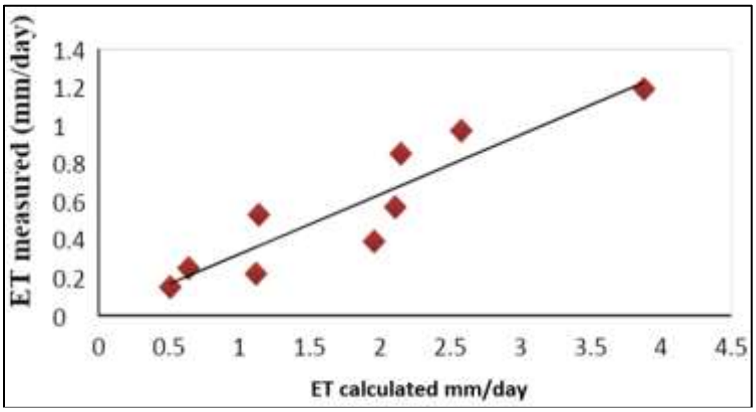

Fig. 4. ET_c Lysimeter versus ET_c by Open pan method

4. CONCLUSION

Determination of daily crop evapotranspiration at different growth stages of pea crop was undertaken in this study using 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 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 for better yields with enhanced water use efficiency, crop water management practices are essential.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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