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Evaluation of Evapotranspiration Models for Pea (*Pisum Sativum)* in Mid Hill Zone-India

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Abstract:
Efficient irrigation water management requires a good quantification of evapotranspiration. Lysimeter was used to measure actual crop water use and local weather data were used to determine the reference evapotranspiration (ET_o). The K c values determined over the growing seasons varied from 0.5 to 1.15 for pea. The development of regionally based and growth-stage-specific Kc helps in irrigation management and provides precise water applications for this region. Six climatological models were selected for estimating reference crop evapotranspiration on a daily basis. Some of these methods are based on combination theory and others are empirical methods based primarily on solar radiation, temperature and relative humidity. According to results the crop coefficient vary among locations and even among years, depending on soil evaporation (rainfall, irrigation), vapour pressure deficit, solar radiation and reference evapotranspiration (ET_0).

Keywords: Crop coefficient, Crop evapotranspiration, Lysimeter and Reference Evapotranspiration

1.0 Introduction:
Pea is main cash vegetable crops in mid hill zone of Himachal Pradesh, India, efficient irrigation management requires an accurate quantification of evapotranspiration for pea crop. The most common approach to calculate evapotranspiration (ET) has been as the product of reference evapotranspiration by the crop coefficient (Kc), which depends on ground cover and crop characteristics (Allen *et al*., 1998). The reference evapotranspiration play an important role for estimating the crop water requirement. Six climatological methods were selected for estimating reference crop evapotranspiration on a daily basis. Some of these methods are based on combination theory and others are empirical methods based primarily on solar radiation, temperature and relative humidity. Crop coefficients (Kc) were estimated for pea at different stages of growth, based on measured actual ET and the reference crop evapotranspiration estimated by these methods. According to our results the crop coefficient will vary among locations and even among years, depending on soil evaporation (rain-fall, irrigation), vapour pressure deficit, solar radiation and reference evapotranspiration (ET_0).

Determination of actual crop evapotranspiration (ETc) during the growing season has a potential advantage to attain proper irrigation scheduling. Crop coefficient (Kc) is widely used to estimate crop water use and to schedule irrigations. The concept of Kc was introduced by Jensen (1968) and further developed by the other researchers (Doorenbos and Pruitt, 1975, 1977; Allen *et al*., 1998). The methodology was developed to provide growers with a simple ETc prediction tool for guiding irrigation management decisions. One of the earliest equations for estimating ETo involving the use of temperature is the Blaney and Criddle (1962) that was modified by Doorenbos and Pruitt (1977). Although this equation is simple and old, it has been used in recent studies as a temperature based method for estimating ETo in different locations of the world with different climates (Chauhan and Shrivastavt, 2009; Fooladmand and Hmadi, 2009; Benli *et al*., 2010; Horvath *et al*., 2010; Mohawesh, 2010; Razzaghi and Sepaskhah, 2010).

Mohawesh.,O.E.,(2011) investigate daily outputs from eight evapotranspiration models were tested against reference evapotranspiration (ETo) data computed by FAO-56 P-M to assess the accuracy of each model in estimating ETo. Models were compared at eight stations across Jordan. Results show that Hargreaves modified models were the best in light of mean biased error (MBE), root mean square error (RMSE) and mean absolute error (MAE). The purpose of this research was to determine plant water usage or crop evapotranspiration (ETc) and crop coefficients (Kc) for pea grown in the mid hill zone of Himachal Pradesh, India. Irrigation scheduling can then be improved for private consultants and growers to avoid water over use and to more precisely meet the crop water demand to produce greater yields with enhanced water use efficiency.

2.0 Materials and Methods:

The study was conducted at the Dr. Y.S Parmar University of Horticulture and Forestry, Nauni, Solan (HP)- India. Field crop experiments have been conducted nearby the experimental farm of the university from Nov, 2009 to Feb, 2010. University of Horticulture and Forestry is located at location, at 30°50' N latitude and 77°11'30" E longitude and 1260 m above mean sea level and represents the mid-hill zone of Himachal Pradesh. The annual precipitation is 1000-1300 mm, with most rainfall occurring from June-September. The south-west monsoon generally breaks in mid June and the north-east during November-December. The average annual sunshine duration is 2750 hrs. Fig. 1 & 2 shows the precipitation data for the study period.

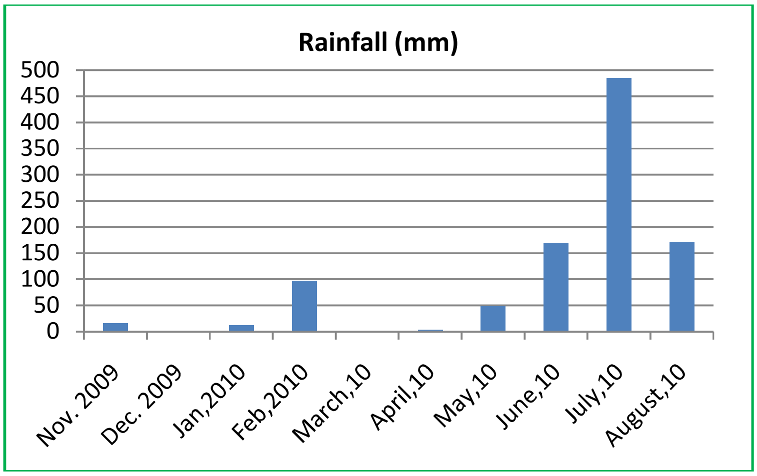

Fig. 1: Precipitation Of Study Area for Year 2009-10

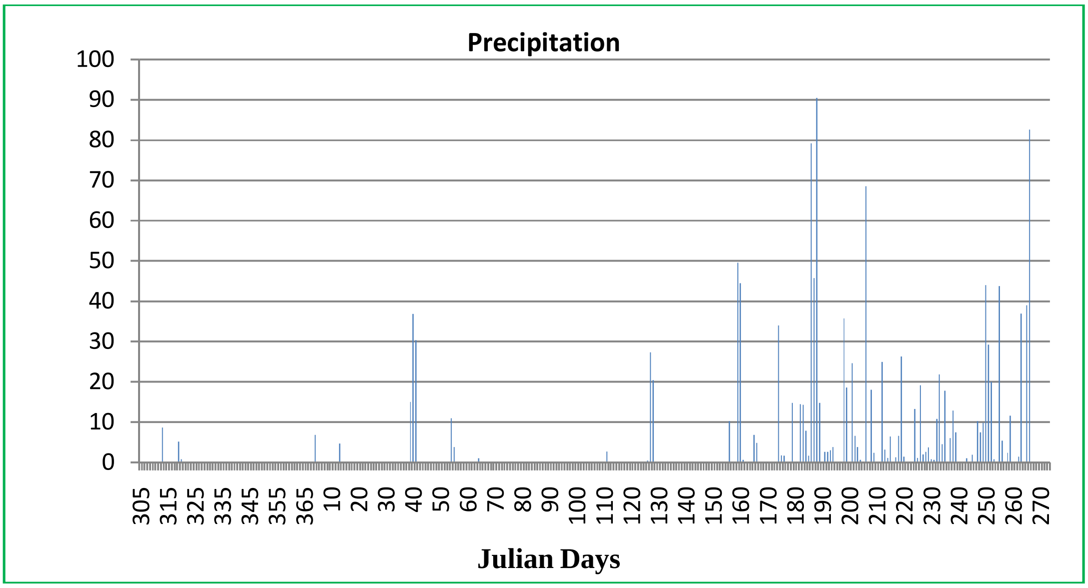

Fig 2: Precipitation of Study Area for Year 2009-10

2.1 Reference Evapotranspiration Computation:

Evapotranspiration is a complex phenomenon and depends on several climatological factors, such as temperature, humidity, wind speed, radiation, and type and growth stage of crop. Required climatic variables have been monitored at the Meteorological station at Dr Y. S Parmar University of Horticulture and Forestry, Solan. Reference evapotranspiration (ET_0) has been computed by six climate-based ET_0 estimation methods. The six different methods, corresponding equations and the required meteorological data for each of the methods are given in Table 1. ET_0 for the corresponding duration has been used, while carrying out the evaluation of the ET_0 methodologies, in estimating crop evapotranspiration. Fig. 3 shows the weekly average daily ET_0 (mm/day) calculated using the six reference evapotranspiration models.

2.2 Crop Coefficient:

The concept of *Kc* was introduced by Jensen (1968) and further developed by the other researchers (Doorenbos and Pruitt, 1975, 1977; Burman *et al.*, 1980a, Allen *et al.*, 1998). The crop coefficient is the ratio of the actual crop evapotranspiration (*ETc*) to reference crop evapotranspiration (*ETo*) and it integrates the effects of characteristics that distinguish field crops. Reference evapotranspiration is a measure of evaporative demand, while the crop coefficient accounts for crop characteristics and management practices (e.g., frequency of soil wetness). It is specific for each vegetative surface and it evolves in function of the development stage of the crop considered. Evapotranspiration varies in the course of the season because morphological and eco-physiological characteristics of the crop do change over time.

FAO- 56 has reported the both *Kc* and *Kcb* values corresponding at the three grown stages for the different crops. The *Kc* is affected by all the factors that influence soil water status, for instance, the irrigation method and frequency (Doorenbos and Pruitt, 1977; Wright, 1982), the weather factors, the soil characteristics and the agronomic techniques that affect crop growth (Tarantino and Onofrii, 1991; Cavazza, 1991; Annandale and Stockle, 1994). Consequently, the crop coefficient values reported in the literature can vary even significantly from the actual ones if growing conditions differ from those where the said coefficients were experimentally obtained (Tarantino and Onofrii, 1991). FAO suggested general trend of the crop coefficient was given (Fig. 4).

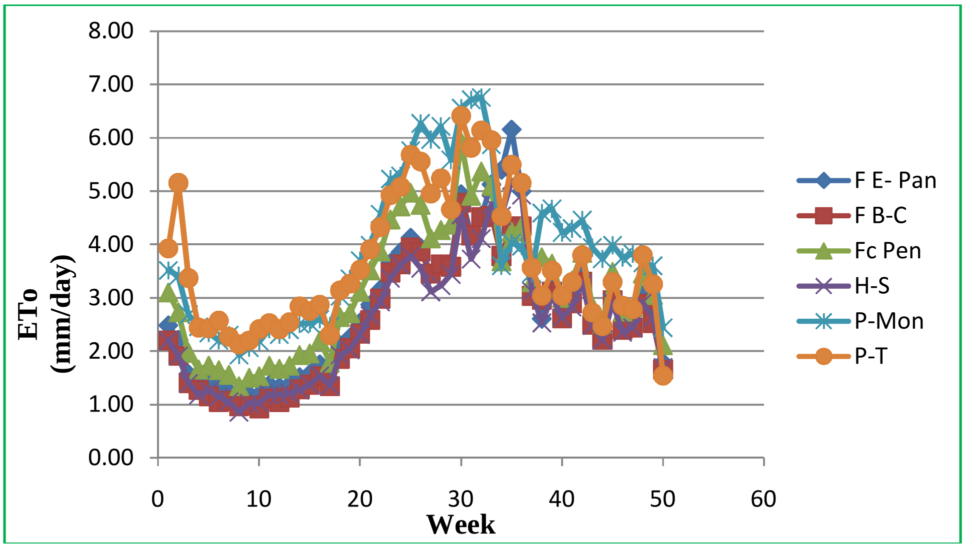

Fig. 3: Weekly ET_0 estimates for study area, based on different models (Nov. 1, 2009 - Sep 30, 2010)

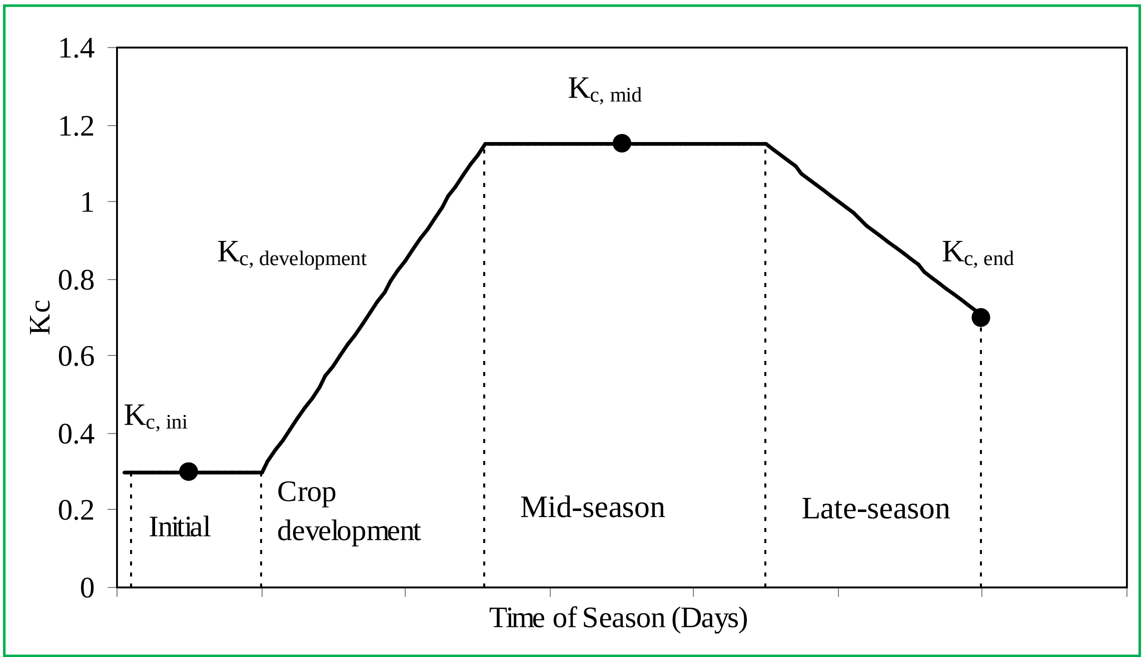

Fig 4: FAO Suggested General Crop Coefficient Curve (Allen *Et Al.*, 1998)

Table 1: Soil Properties at Different Depth

Soil depth (cm)	Bulk density (kg/m^3)	Gravel (%)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture	Particle density (kg/m^3)	Hydraulic conductivity (cm/ mint)
0-15	1.21	24.55	8.89	33.71	40.0	17.40	Silt	2.50	0.24
15-30	1.23	35.0	19.6	27.8	31.2	21.4	Loam	2.45	0.22
30-60	1.30	40.40	20.23	18.97	35.20	25.60	Silt	2.54	0.16
60-90	1.31	36.0	22.14	18.86	32.6	26.4	Silt clay loam	2.51	0.15
90-120	1.35	20.0	24.85	14.75	36.40	24.0	Silt clay loam	2.48	0.17
120-150	1.42	52.0	22.26	26.14	31.2	20.4	Silt	2.46	0.18
				COV	3.05		SD	0.569	

It is assumed that the different environmental conditions between regions allow variation in variety selection and crop developmental stage which affect *Kc* (Allen *et al.*, 1998).

2.3 Soil Characteristics:

Representative soil samples have been obtained from the 0-0.3 m, 0.3-0.6 m, 0.6-0.9 m, and 0.9-1.20 m depths, in the experimental site for testing the soil obtained through grain size and hydrometer analysis reveal that the soil profile up to 1.2 m is different in texture and consider two layers on the basis of soil properties Table 1.

3.0 Results and Discussions:

3.1 Comparison of Estimated Crop Evapotranspiration and Observed Value by Different Methods:

The estimated evapotranspiration value determine by six different model (Table 2) and actual crop evapotranspiration (ET) measured by lysimeter water balance method. Though, FAO Penman Monteith method gives most accurate result and less deviation than actual crop evapotranspiration values. Fig. 5 and 6 shows the estimated ET value and observed value of pea properties. The cumulative particle size curves.

Table 2: Reference Evapotranspiration Estimation Methods

Sr. No.	Method of ET_0 Estimation	Equations Used	Basic Reference	Required Meteorological Data
1.	FAO-24 corrected Penman (c = 1), (F c P-Mon)	$ET_0 = c\left[\frac{\Delta}{\Delta+\gamma}(R_n - G) + \frac{\gamma}{\Delta+\gamma}2.7W_f(e_a - e_d)\right]$	Doorenbos and Pruit, (1977)	Net radiation, vapour pressure and wind velocity
2.	Priestley-Taylor (P-T)	$ET_0 = \alpha\frac{\Delta}{\Delta+\gamma}(Rn - G)$	Shuttleworth, (1992)	Net radiation, soil heat flux and vapour pressure deficit
3.	FAO-24 Blaney-Criddle, (F B-C)	$ET_0 = a + b\left[p\left(0.46\bar{T} + 8.13\right)\right]$	Doorenbos and Pruit, (1977)	Annual day time hours, temperature and wind velocity
4.	Hargreaves-Samani (H-S)	$ET_0 = 0.0135(KT)(R_a)(TD^{1/2})(TC+17.8)$ $KT = 0.00185(TD)^2 - 0.0433TD + 0.4023$	Hargreaves and Samani, (1982, 85)	Net radiation, min/max temperature
5.	FAO Pan Evaporation (F E-Pan)	$ET_0 = K_p\ E_{pan}$	Allen *et al.*, (1998)	Pan evaporation
6	Penman Monteith* (P-Mon)	$ET_0 = \dfrac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$	Allen *et al.*, (1998)	Vapour pressure, radiation flux, wind velocity, soil heat flux, temperature

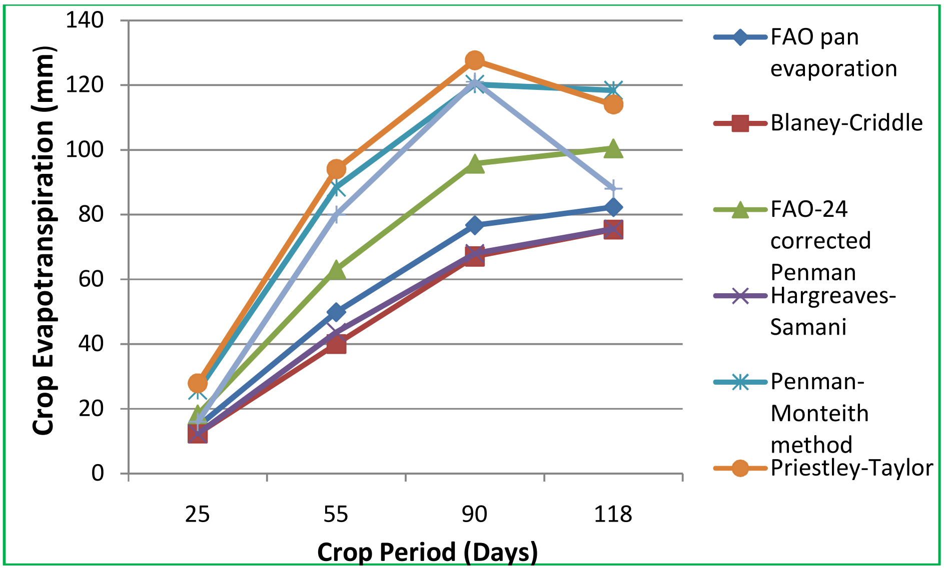

Fig 5: Observed and Computed Stage Wise Crop Evapotranspiration for Pea

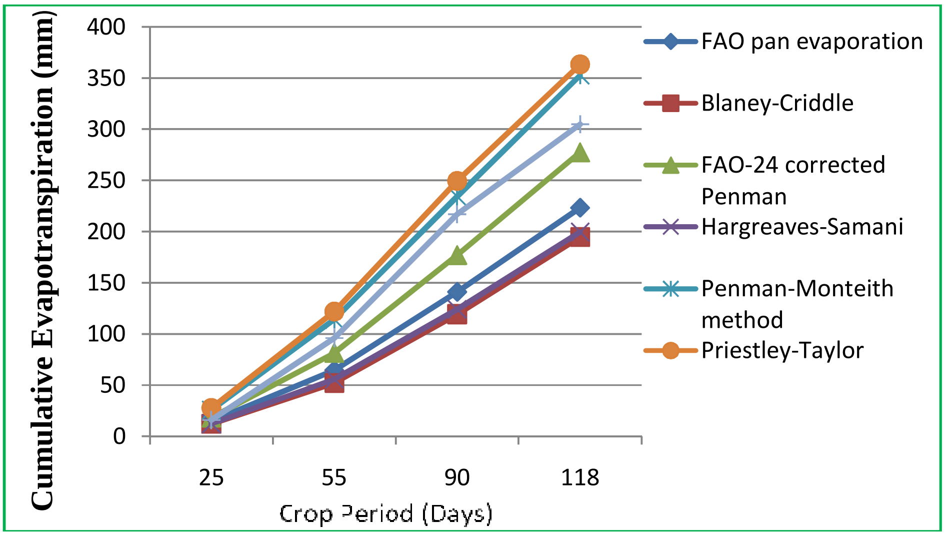

Fig 6: Observed and Computed Cumulative Crop Evapotranspiration for Pea

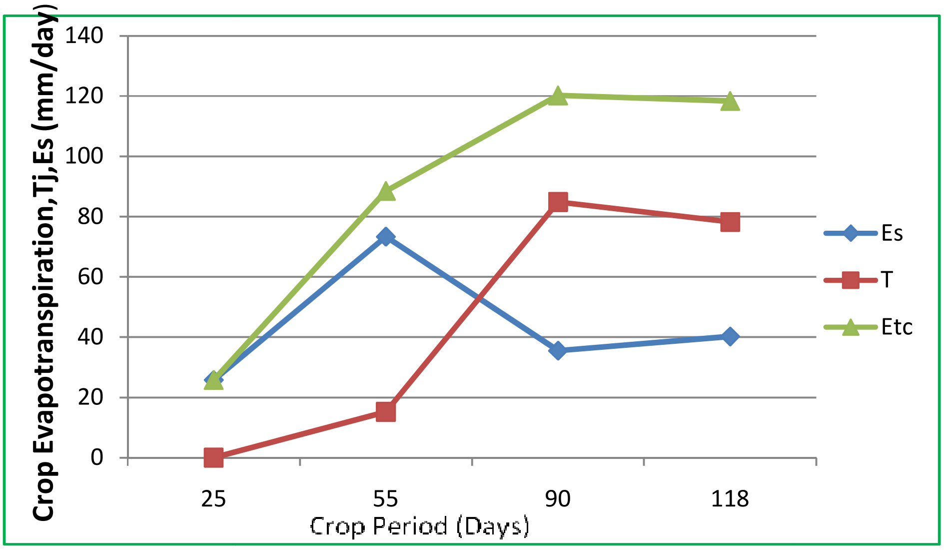

Fig 7: Daily Crop Evapotranspiration, Transpiration and Evaporation for Pea

Table 3: Modified values of FAO recommended crop coefficients for actual field conditions for Pea

Crop Coefficients								
$K_{c\ ini}$			$K_{c\ mid}$			$K_{c\ end}$		
FAO Value	**Parameters**	**Modified value**	**FAO Value**	**Modifying Parameters**	**Modified value**	**FAO Value**	**Modifying Parameters**	**Modified value**
0.47	Wetting frequency 8days Avg. ET_0 5 mm/day	0.50	1.32	u_2 = 0.57 ms^{-1} RH_{min} = 67.1 H = 1.787 m	1. 35	1.10	u_2 = 0.58 ms^{-1} RH_{min} = 60.1 H = 1.11 m	1.15

3.2 Statistical Analysis Procedure:

To accurately evaluate the methods, the study follows a quantitative assessment procedure, which involves the use of error statistics (Ambrose and Roesch, 1982) calculated as:

$$R^2 = 1 - \frac{\sum_{i}^{n} (y_i - \hat{y}_i)^2}{\sum_{i}^{n} (y_i - \bar{y})^2} \quad (1)$$

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

$$\text{ARE} = \frac{\sum_{i=1}^{n} (\hat{y}_i - y_i))}{n|\bar{y}_i|} \quad (3)$$

Where R^2 is coefficient of determination, SEE is standard error estimate and ARE is the average relative discrepancy, subscript i denotes the i^{th} point in the root zone, where moisture content is measured. y_i = Field measured soil moisture content, $\hat{y}_i$ = simulated soil moisture content based on individual method ET_c estimates, $\bar{\hat{y}}$ = average of $\hat{y}_i$, $\bar{y}$ is the average of y_i and n = total number of observation points. A value of R^2 close to the unity indicates a high degree of association between the observed and simulated values, SEE provides a measure of deviation between computed and observed moisture contents, whereas ARE statistics quantify the extent to which, the computed values overestimate (positive ARE) or underestimate (negative ARE) the measured values. The details of statistical comparison are shown in Table 4.

It can be observed from the Table 4, that ET_c estimated from ET_0 methods; P-T, H-S and F E-Pan show large deviation in terms of error statistics values, from the observed values, for pea crops. It can be postulated from the above analysis that, FAO-Penman Monteith method estimated ET_c, gives the most optimal estimate of the crop water requirement in mid hill climatic region. Hence FAO P-Mon model is recommended for estimation of CWR and crop coefficient development (calibration) for pea in the study area.

Table 4: **Statistical Summary of the Comparison between Observed and Different ET_0 Estimation Models Based Stage-Wise Crop (Pea) Evapotranspiration**

Statistical Terms	Reference Evapotranspiration Method					
	P-Mon	Fc- Pen	P-T	F B-C	H-S	F E-Pan
COD	0.83	0.81	0.79	0.47	0.50	0.50
SEE (mm)	21.7	29.03	31.32	26.17	37.16	30.8
ARE (%)	6.66	-9.00	19.17	-36.16	-34.59	-26.75

Employing a suitable ET_0 model for ET_c estimation will give optimal daily Crop water requirement (CWR). Availability of optimal daily CWR is an effective tool to work out the optimum schedule of irrigation. An improved irrigation schedule, results in enhanced water use efficiency and hence irrigation water saving. Thorough investigations on influence of ET_0 models on irrigation schedule are further suggested. Accumulated ETc estimates for crop growing season ranged from 400 to 430 mm for pea. Seasonal Kc values varied from 0.5 to 1.15 for pea. Growth stage- specific Kc values were determined based on the Kc curves that represent the distribution of Kc over time throughout the season (Wright, 1982). Our results showed that Kc values can be different from one region to the other

4.0 Conclusions:

The process of crop evapotranspiration estimation in different stages is depends on reference evapotranspiration model used for computation of crop evapotranspiration. FAO recommended stage wise crop coefficients for pea, are used to check the accuracy of different reference evapotranspiration models in predicting crop water requirement in mid hill region. Following conclusions are drawn from the present study:

1. Different reference evapotranspiration models result in predicting different crop water requirement, when used in combination with literature based or locally calibrated crop coefficients. This postulates the influence of reference evapotranspiration model on crop coefficient calibration.
2. FAO Penman-Monteith Model (FAO P-Mon), has been found to perform better than other reference evapotranspiration models in predicting crop evapotranspiration.
3. The average crop coefficient computed basing on combination theory to calculate reference

evapotranspiration is correctly estimated compared with empirical methods.
4. The development of regionally based Kc helps tremendously in irrigation management and furthermore provides precise water applications in those areas
5. Irrigation scheduling can be improved for private consultants and growers to avoid water over use and to more precisely meet the crop water demand to produce greater yields with enhanced water use efficiency. These results indicate the use of no adequate method to estimate reference evapotranspiration allowed overestimating or underestimating the water requirements. So it is desirable to have a method that estimates the (ET_0) consistently well.

5.0 Acknowledgements:

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