IOSR Journal of Engineering (IOSRJEN)
ISSN: 2250-3021 Volume 2, Issue 6 (June 2012), PP 35-42
www.iosrjen.org

Evaluation of Evapotranspiration Estimation Methods and Development of Crop Coefficients for Groundnut Crop

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***ABSTRACT*: -** *Evapotranspiration estimation is essential in the planning, designing and management of an irrigation system. The present study aims to compare various reference evapotranspiration (ET_0) estimation methods and to develop inter-relationships between ET_0 estimated by FAO Penman-Monteith method with those estimated by the other methods. The study also focuses on the comparison of crop coefficients (k_c) recommended by FAO 56 with those computed using the other climatological methods for groundnut crop in the Tirupati region of Andhra Pradesh, India. The evapotranspiration for groundnut crop and other meteorological data observed at the Tirupati Agricultural Research Station were collected from the India Meteorological Department (IMD), Pune. The temperature, radiation, physically and pan evaporation based methods were chosen for comparison in the present study. The results indicated that the Blaney-Criddle, Jensen-Haise and Radiation methods overestimated ET_0 values, Makkink and Pan Evaporation methods underestimated and ET_0 values estimated by Modified Penman, Hargreaves and Priestley-Taylor methods slightly overestimated/ underestimated and were comparable with those computed by Penman-Monteith method(PMM) in the study area. Inter-relationships between PMM and other methods developed may be adopted to get the results in terms of the desired method. The k_c values evolved for various methods followed a similar trend to that of FAO 56 and may be adopted to reasonably estimate ET_c in the region selecting the method based on the data availability.*

KEY WORDS: *Evapotranspiration; empirical methods; inter-relationships; crop coefficient*

I. INTRODUCTION

Evapotranspiration is one of the important phases of hydrologic cycle and its accurate estimation is of paramount importance for water balance studies, irrigation system design, crop yield simulation and water resources planning and management. It is desirable to have a method that estimates reasonably the reference crop evapotranspiration (ET_0). The Penman-Monteith method recommended by UN - FAO and WMO has received widespread acceptance internationally for estimating ET_0. However, the major limitation of the method is that it requires data for a large number of weather parameters, which may not be available for many locations.

Crop ET (ET_c) is computed by multiplying ET_0 with a crop coefficient (k_c) to account for the differences between the grass ET and crop ET. Irrigation planning on a regional scale is performed on the basis of estimated ET_c. Doorenbos and Pruitt (1977) recommended crop coefficients for a number of crops grown under different climatic conditions. However, they emphasized the strong need for local calibration of the coefficients under given climatic conditions.

Tyagi et al. (2000) developed crop coefficients for wheat and sorghum from ET_c measurements and weather data. The relationships between Penman-Monteith method and the other methods were also investigated. Kashyap and Panda (2001) developed regional relationships between lysimeter ET and that estimated by various climatological methods for the Kharagpur region. Irmak et al. (2003) recommended solar radiation and net radiation based ET_0 equations over the other commonly used temperature and radiation based methods by comparing their performance with Penman-Monteith method. Temesgen et al. (2005) compared ET_0 equations and indicated that ET_0 estimated by California Irrigation Management Information System (CIMFIS) Penman equation correlated well with those estimated by standardized Penman – Monteith equation. Alkaeed et al. (2006) compared several ET_0 methods for the Itoshima peninsular area, Japan and concluded that the Thornthwaite method was found to have highly correlated with Penman-Monteith method in the study region. Nandagiri and Kovoor (2006) evaluated the performance of several ET_0 methods in the major climatic regions of India and identified that the FAO – 56 Hargreaves (temperature based) method yielded ET_0 estimates closest to the FAO – 56 Penman-Monteith method in all the climates except the humid one where the Turc (radiation based) method was the best. Demirtas et al. (2007) developed regional relationships between ET and that estimated by various climatological methods and concluded that Penman-Monteith method gives the best results followed by Penman, Radiation and Blaney-Criddle methods. Suleiman and Hoogenboom (2007) made a study to assess the potential improvement that can be achieved by replacing Priestley – Taylor with FAO – 56 Penman-Monteith in Georgia and southern states in a humid climate of mountainous and coastal areas. Mallikarjuna and Aruna Jyothy (2008) evolved the performance of various empirical methods for estimating ET_c for different crops for the Tirupati and Nellore regions of Andhra Pradesh. Xing et al. (2008) evaluated the methods of estimating daily ET_0 and found that the pan evaporation methods generated lower estimation of ET_0 compared to the Penman-Monteith and Priestley – Taylor methods. The study also suggested the Snyder equation to calculate k_{pan} with an acceptable accuracy. Gavilan et al. (2008) compared ASCE and FAO- 56 standardized ET_0 equations and indicated that the ASCE method provided good estimations for inland locations of southern Spain. Crop coefficients for potato crop were also estimated at different stages of growth.

The present study reports the performance evaluation of commonly used ET_0 estimation methods based on their accuracy of estimation and development of inter-relationships between the Penman-Monteith and the other climatological methods. It also presents the comparison of monthly crop coefficients estimated by various methods based on measured lysimeter ET_c for groundnut crop for the Tirupati region of Andhra Pradesh.

II. MATERIALS AND METHODS

The Tirupati region located in Chittoor district of Andhra Pradesh, India with global coordinates of 13^0 05’ N latitude and 79^0 05' E longitudes has been chosen as the study area. The meteorological data at the regional centre for the period 1990-1998 were collected from IMD, Pune. The monthly mean climatic parameters at the station are given in Table 1. The details of the methods selected for the present study are presented in Table 2.

TABLE-1 MONTHLY MEAN OF WEATHER DATA OF THE STUDY AREA

Month	Pan evaporation (mm)	Sunshine hours (%)	Vapor pressure (%)		Wind speed (kmph)	Relative humidity (%)		Temperature (^{0}C)	
			Max.	Min.		Max.	Min.	Max.	Min.
Jul	5.85	4.02	19.32	18.49	10.52	70.37	50.23	34.18	25.10
Aug	6.02	4.96	19.28	18.39	10.15	71.52	51.34	33.67	25.01
Sep	5.36	5.70	20.01	19.09	6.82	74.61	53.77	33.56	24.24
Oct	3.85	5.30	20.72	19.80	4.81	82.89	63.64	31.53	22.65
Nov	3.37	5.50	19.84	19.27	5.47	83.81	67.63	29.55	21.43

TABLE-2 DETAILS OF VARIOUS EVAPOTRANSPIRATION ESTIMATION METHODS

Method	Equation	Input data	
		Primary	Secondary
Temperature based			
1.FAO-24 Blaney-CriddleMethod(BCM)	$ET_0 = a + b\,[p\,(0.46T + 8.13)]$ Where $a = 0.0043\,(RH_{min}) - n/N - 1.41$ $b = 0.82 - 0.0041\,(RH_{min}) + 1.07\,(n/N) + 0.066\,(u_d) - 0.006\,(RH_{min})\,(n/N) - 0.0006\,(RH_{min})\,(u_d)$	T_{max}, T_{min}	RH_{min}, n, u_2, u_d/u_n
2.Jensen-Haise Method (JHM)	$ET_0{}^1 = R_s\,(0.025\,T_{mean} + 0.08)$	T_{max}, T_{min}, n	---
3.FAO-56 Hargreaves Method (HRM)	$ET_0 = 0.0023\,R_a\,(T_{mean} + 17.8) \times (TD)^{0.5}$	T_{max}, T_{min}, n	---
Radiation based			
1.Priestley-Taylor Method (PTM)		T_{max}, T_{min}, n	---

2.FAO-24Radiation Method (RAM) 3.MakkinkMethod (MKM)	$ET_0 = 1.26\frac{\Delta}{\Delta+\gamma}(R_n - G)$ $ET_0 = c\,(W.R_s)$ Where $c = 1.066 - 0.00128\,RH_{mean} + 0.045\,u_d - 0.0002\,RH_{mean}\,u_d + 0.0000315\,(RH_{mean})^2 - 0.00103\,(u_d)^2$ $ET_0 = 0.65\frac{\Delta}{\Delta+\gamma}R_s$	T_{max}, T_{min}, n T_{max}, T_{min}, n	RH_{max}, RH_{min}, u_2, u_d/u_n ---
Physically based 1.FAO-24 Modified-Penman Method (MPM) 2.FAO-56 Penman-Montieth Method (PMM)	$ET_0 =$ $C\left[\frac{\Delta}{\Delta+\gamma}R_n + \frac{\gamma}{\Delta+\gamma}(0.27)(1.0+0.01U_2)(e_s - e_a)\right]$ Where $C = 0.68 + 0.0028\,(RH_{max}) + 0.018\,(R_s) - 0.068\,(u_d) + 0.013\,(u_d/u_n) + 0.0097\,(u_d)(u_d/u_n) + 0.000043\,(RH_{max})\,(R_s)\,(u_d)$ $ET_0 = \frac{0.408\Delta^1(R_n^1 - G^1) + \gamma^1\frac{900}{T_{mean}+273}u_2(e_s^1 - e_a^1)}{\Delta^1 + \gamma^1(1+0.34u_2)}$	T_{max}, T_{min}, RH_{max}, RH_{min}, n T_{max}, T_{min}, RH_{max}, RH_{min}, u_2, n	u_2, u_d/u_n ---
Pan Evaporation based 1.FAO-56 Pan Evaporation Method (PEM) 2.Christiansen Method (CSM)	$ET_0 = K_p\,E_{pan}$ where $K_p = 0.108 - 0.0286\,u_2 + 0.0422\ln(FET) + 0.1434\ln(RH_{mean}) - 0.000631\,[\ln(FET)]^2\ln(RH_{mean})$ $ET_0 = 0.473\,R_a\,C_T\,C_W\,C_H\,C_S\,C_E\,C_M$ where $C_T = 0.393 + 0.5592\,(T/T_m) + 0.04756\,(T/T_m)^2$ $C_W = 0.708 + 0.3276\,(U_2/U_{2m}) - 0.036\,(U_2/U_{2m})^2$ $C_H = 1.25 - 0.212(RH/RH_m) - 0.038(RH/RH_m)^5$ $C_S = 0.542 + 0.64\,(s_p/s_{pm}) - 0.4992\,(s_p/s_{pm})^2 + 0.3174\,(s_p/s_{pm})^3$ $C_E = 0.970 + 0.030(E/E_m)$ C_M = ranges from 0.9 to 1.1depending on the latitude	E_{pan} ---	FET, RH_{max}, RH_{min}, u_2 T_{max}, T_{min}, u_2, RH_{max}, RH_{min}, n, E

III. RESULTS AND DISCUSSION

The mean monthly ET_0 values estimated by various methods are compared with those estimated by FAO 56 PMM as shown in Fig 1. The percent deviations of mean monthly ET_0 values with respect to PMM are presented in Table 3. The positive deviation represents overestimation and negative deviation represents underestimation of ET_0.

The BCM, RAM and JHM overestimated average monthly ET_0 during monsoon period in the study area. The percent deviation has increased as the monsoon progresses. The MKM, PEM and MPM underestimated average monthly ET_0 and the deviation decreased mostly as the monsoon advances. The HRM and PTM slightly underestimated during south-west monsoon and overestimated during north-east monsoon. This may be due to the fact that apart from radiation, temperature difference and the corresponding vapour pressure influence more during the period. The CSM followed a similar trend with relatively large percent deviation.

The comparison of monthly ET_0 values estimated by various methods with those of PMM is presented in Fig.2. Linear regression analysis has been carried out to derive interrelationships between PMM and other methods as presented in Table 4. All the methods except CSM correlated well with PMM during the crop period for the study region. These relationships, therefore, may be adopted to estimate ET_0 by the methods for which meteorological data are available to get reasonable estimation in terms of the desired method.

Monthly crop coefficients (k_c) were computed for groundnut crop based on the lysimeter measured ET_c and, ET_0 estimated by various methods as presented in Table 5. Comparison of these k_c values with those recommended by FAO 56 as shown in Fig 3 indicates that all the climatological methods except MKM, PTM, PEM and CSM underestimated during the crop period. The PTM and CSM gave reasonably good estimation during south-west monsoon period and the MKM during north-east monsoon. PEM consistently slightly overestimated k_c during the crop period.

From the results of the study, it may be observed that HRM, PTM and MPM may be used to estimate ET_0 as the values are close to PMM. The PEM may be adopted to estimate ET_c with the k_c values recommended by FAO 56. Further, the suitable method depending upon the availability of data may be selected with the corresponding k_c values suggested to reasonably estimate ET_c for groundnut crop in the study area.

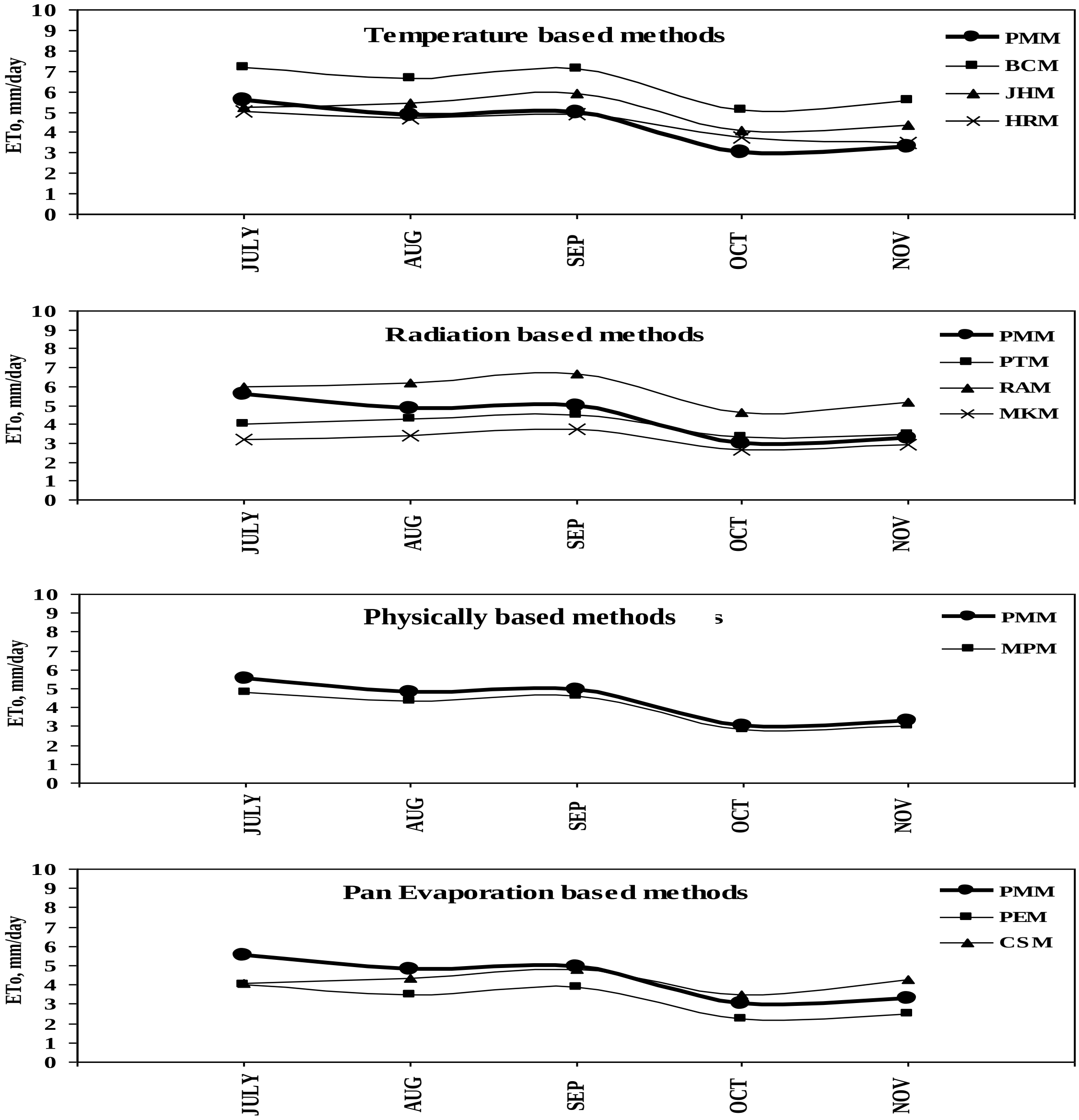

FIG.1 COMPARISON OF AVERAGE MONTHLY ET_0 VALUES ESTIMATED BY VARIOUS METHODS WITHPMM

TABLE-3 PERCENT DEVIATIONS OF AVERAGE MONTHLY ET_0 VALUES ESTIMATED BY VARIOUS METHODS WITH PMM

Method / Month	BCM	JHM	HRM	PTM	RAM	MKM	MPM	PEM	CSM
Jul	30.0	-6.1	-8.9	-27.3	8.1	-42.0	-13.9	-28.1	-25.9
Aug	37.9	12.7	-1.9	-11.4	28.3	-29.1	-9.4	-27.8	-10.3
Sep	43.4	19.7	-1.0	-9.4	34.6	-24.9	-6.2	-22.2	-2.8
Oct	69.6	36.2	25.4	10.0	52.7	-10.7	-5.7	-25.4	16.8
Nov	71.1	34.0	6.4	5.8	58.1	-9.8	-6.6	-23.0	31.0

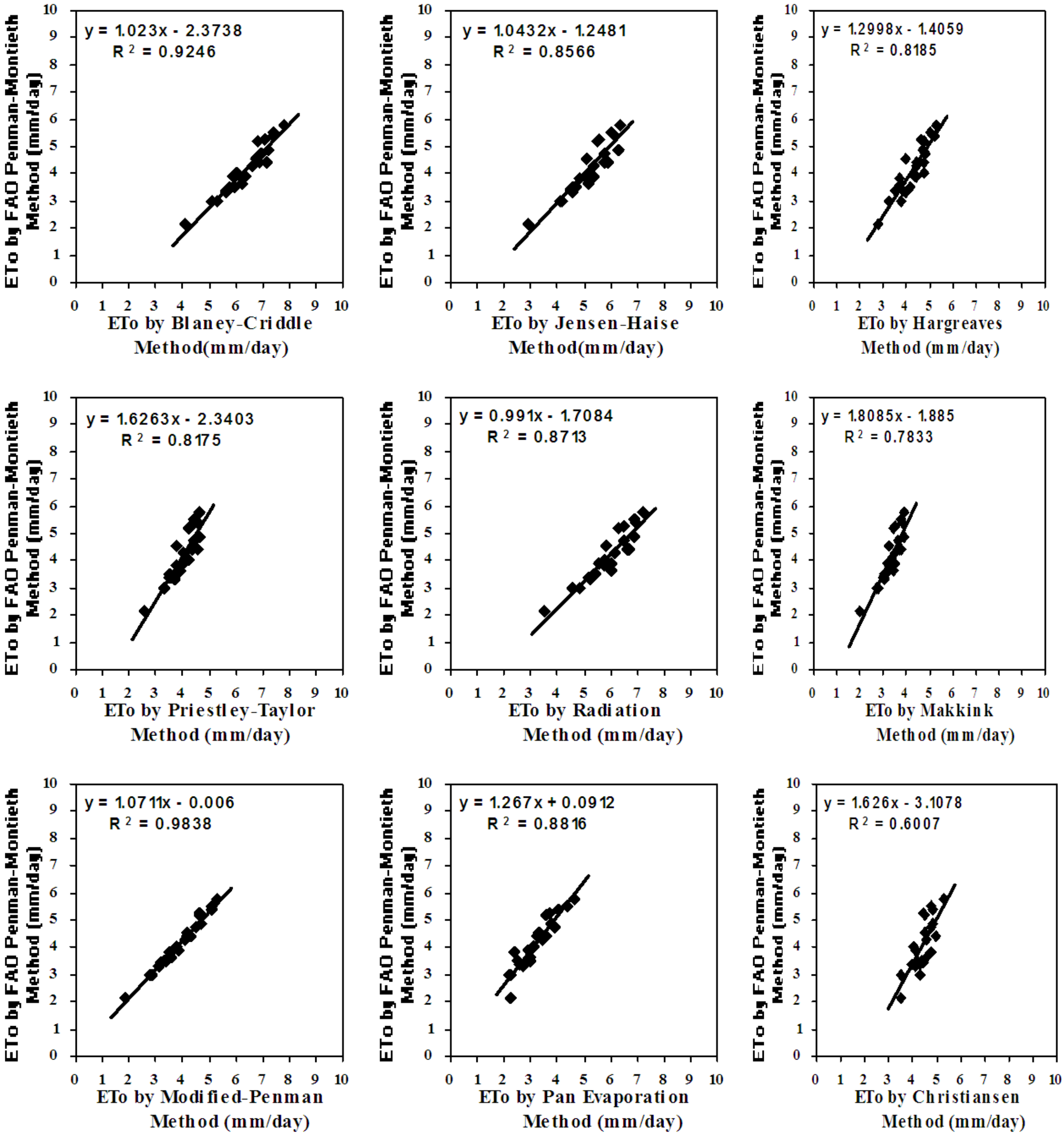

FIG.2 COMPARISON OF MONTHLY ET_0 ESTIMATED BY VARIOUS METHODS WITH THAT ESTIMATED BY PMM

TABLE-4 INTERRELATIONSHIPS BETWEEN VARIOUS EMPIRICAL METHODS AND PMM

S.No	Conversion equation	R^2	RMSE (mm/day)
1	PMM = 1.0230 BCM – 2.3738	0.925	1.2
2	PMM = 1.0432 JHM – 1.2481	0.857	1.1
3	PMM = 1.2998 HRM – 1.4069	0.819	0.5
4	PMM = 1.6263 PTM – 2.3403	0.818	0.5
5	PMM = 0.9910 RAM – 1.7084	0.871	1.8
6	PMM = 1.8085 MKM – 1.8850	0.783	1.0
7	PMM = 1.0711 MPM – 0.0060	0.984	0.3
8	PMM = 1.2670 PEM + 0.0912	0.882	1.1
9	PMM = 1.6260 CSM – 3.1078	0.601	0.7

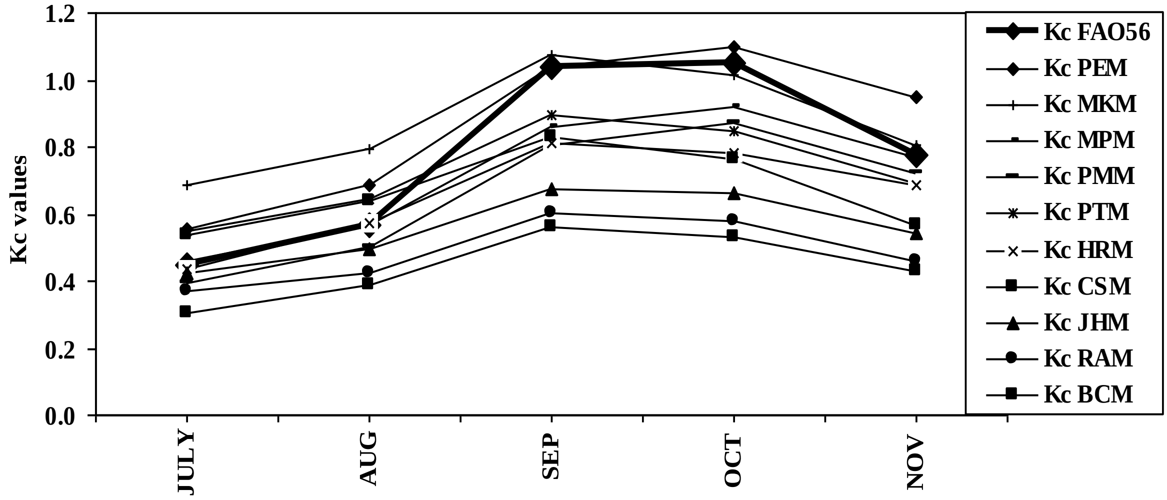

FIG.3 COMPARISON OF MONTHLY CROP COEFFICIENTS (k_c) ESTIMATED FROM MEASURED ET_C WITH THOSE RECOMMENDED BY FAO 56

TABLE-5 VALUES OF AVERAGE MONTHLY CROP COEFFICIENTS (k_c)

Month	k_c values									
	FAO56	BCM	JHM	HRM	PTM	RAM	MKM	MPM	PMM	PEM	CSM
Jul	0.5	0.31	0.42	0.44	0.55	0.37	0.68	0.46	0.40	0.55	0.54
Aug	0.6	0.39	0.49	0.57	0.65	0.43	0.79	0.57	0.50	0.69	0.64
Sep	1.0	0.56	0.68	0.81	0.89	0.60	1.08	0.86	0.81	1.04	0.83
Oct	1.1	0.53	0.66	0.78	0.85	0.58	1.01	0.92	0.87	1.10	0.76
Nov	0.8	0.43	0.54	0.69	0.69	0.46	0.81	0.77	0.72	0.95	0.57

IV. CONCLUSIONS

The HRM, PTM and MPM are the alternative methods to PMM for the good estimate of ET_0 for the Tirupati region of Andhra Pradesh, India. The inter-relationships developed between the evapotranspiration methods and PMM may be adopted depending upon the data availability to estimate ET_0 in terms of the desired method. The k_c values computed based on the PEM are comparable with those recommended by FAO 56. The other climatological methods adopted in the present study with corresponding k_c values suggested may also be used to reasonably estimate ET_c.

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NOTATION

a, b	: calibration factors
BCM	: Blaney-Criddle Method
c	: adjustment factor
C	: correction or calibration factor
C_E	: elevation coefficient
C_H	: humidity coefficient
C_M	: monthly coefficient
Cs	: sunshine coefficient
C_T	: temperature coefficient
$C_T^{\,1}$	: constant (JHM)
C_W	: wind velocity coefficient
E	: elevation, m
E_m	: mean elevation of stations considered, m
E_{pan}	: pan evaporation, mm day^{-1}
ET_0	: grass reference crop evapotranspiration, mm day^{-1}
$ET_0^{\,1}$	: alfalfa reference crop evapotranspiration, mm day^{-1}
ET_c	: actual crop evapotranspiration, mm day^{-1}
e_a	: mean actual vapour pressure, mbar
$e_a^{\,1}$	: actual vapour pressure, kP_a
e_2	: vapour pressure of the month with the mean maximum temperature, mbar
e_1	: vapour pressure of the month with the mean minimum temperature, mbar
e_s	: mean saturation vapour pressure at daily mean air temperature, mbar
$e_s^{\,1}$	: saturation vapour pressure, kP_a
FET	: fetch distance, m
G	: soil heat flux density, mm day^{-1}
G^1	: soil heat flux density, MJ m^{-2} day^{-1}
H_n	: relative humidity at noon, %
H_{nm}	: mean relative humidity at noon over the period considered, %

HRM	: Hargreaves Method
JHM	: Jensen-Haise Method
K_p	: pan coefficient
k_c	: crop coefficient
MKM	: Makkink Method
MPM	: Modified-Penman Method
n	: actual duration of sunshine in a day, hour
N	: maximum possible sunshine duration in a day (daylight hours), hour
p	: mean daily percentage of total annual sunshine hours
P	: vapour pressure, mb
PEM	: Pan Evaporation Method
PTM	: Priestly-Taylor Method
R_a	: extraterrestrial radiation, mm/day
R_a^1	: extra terrestrial radiation, MJ m^{-2} day^{-1}
RH_{max}	: maximum relative humidity, %
RH_{min}	: minimum relative humidity, %
RH	: mean relative Humidity, %
RH_m	: mean of mean relative Humidity over the period considered, %
R_n	: net solar radiation, mm day^{-1}
R_n^1	: net solar radiation, MJ m^{-2} day^{-1}
R_s	: global solar radiation, mm/day
R_s^1	: solar radiation reaching the earth, MJ m^{-2} day^{-1}
R_{ns}	: incoming net shortwave radiation, MJ m^{-2} day^{-1}
R_{nl}	: outgoing net long wave radiation, MJ m^{-2} day^{-1}
R_{so}	: clear sky solar radiation, MJ m^{-2} day^{-1}
s_p	: relative sunshine duration, n/N
s_{pm}	: mean relative sunshine duration over the period considered
T	: mean daily temperature, ^0C
T_m	: mean daily temperature over the period considered, ^0C
T_{max}, T_{min} & T_{mean}	: maximum, minimum and mean daily temperatures respectively, ^0C
TD	: difference between maximum and minimum daily temperatures, ^0C
T_x	: constant (JHM)
u_d, u_n	: day and night time wind speeds respectively, m/s
u_z, u_2	: wind speed measured at height z m and 2m respectively, m s^{-1}
U_2	: wind speed measured at height 2m, km day^{-1}
U_{2m}	: mean wind speed measured at height 2m over the period, km day^{-1}
W	: weighting factor
z	: height of wind measurement, m
Δ	: slope of saturation vapour pressure curve, mb $^0C^{-1}$
Δ^1	: slope of saturation vapour pressure curve, kPa $^0C^{-1}$
Υ	: Psychrometric constant, mb $^0C^{-1}$
Υ^1	: psychrometric constant, kPa $^0C^{-1}$