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ORIGINAL CONTRIBUTION

Crop Coefficients of Some Selected Crops of Andhra Pradesh

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Abstract Precise information on crop coefficients for estimating crop evapotranspiration (ET_c) for regional scale irrigation planning is a major impediment in many regions. Crop coefficients suggested based on lysimeter data by earlier investigators have to be locally calibrated to account for the differences in the crop canopy under given climatic conditions. In the present study crop coefficients were derived based on reference crop evapotranspiration (ET_0) estimated from Penman–Monteith equation and lysimeter measured ET_c for groundnut, paddy, tobacco, sugarcane and castor crops at Tirupati, Nellore, Rajahmundry, Anakapalli and Rajendranagar centers of Andhra Pradesh respectively. Crop coefficients derived were compared with those recommended by FAO-56. The mean crop coefficients at different stages of growth were significantly different from those of FAO-56 curve though a similar trend was observed. A third order polynomial crop coefficient model has therefore been developed as a function of time (days after sowing the crop) for deriving suitable crop coefficients. The crop coefficient models suggested may be adopted to estimate crop evapotranspiration in the study area with reasonable degree of accuracy.

Keywords Reference crop evapotranspiration · Crop coefficient · Crop evapotranspiration · Polynomial model

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Introduction

Accurate estimation of crop water requirement is an important aspect of agricultural planning. The water requirement varies widely from crop to crop and also during the period of growth of individual crops. Water use efficiency which is essentially governed by crop evapotranspiration (ET_c) can be improved by proper irrigation planning, scheduling and decision making on a regional scale based on estimated ET_c, which in turn depends on the crop coefficient (K_c). ET_c is calculated by multiplying reference evapotranspiration (ET_0) with K_c to account for the differences in the crop canopy under given climatic conditions. The FAO-56 [1] reported crop coefficients at different stages of growth for various agricultural crops and suggested the adjustment for different wetting frequencies, climatic, agronomic and water management conditions. However, it has been emphasized in the literature that there is a strong need for local calibration of crop coefficients under given climatic conditions.

The researchers have [2] developed crop coefficients for a number of crops grown under different climatic conditions and suggested the use of these values at locations where local data are not available. However, they emphasized the strong need for local calibration of crop coefficients since the climatic conditions encountered in the field differ from the standard conditions. Earlier, the researchers have worked out on crop coefficient values and crop coefficient curves for different crops [3–5]. The investigators have derived crop coefficient curves as a function of day past planting for different crops using fifth order polynomial [6]. Shah and Edling crop coefficients for rice crop for the vegetative, flowering, and yield formation stages using Penman–Monteith (daily) ET_0 and recommended a second order polynomial to moderately fit to the interval-wise K_c

data [7]. The researchers have developed crop coefficients for wheat and sorghum crops from ET_c measurements and weather data at Karnal and, observed that K_c values for these crops at the four crop growth stages are significantly different from those suggested in UN FAO indicating the need for generating these values at the local/regional level [8]. The values of K_c have been estimated at different stages for potato crop using lysimeter measured ET_c at sub-humid Kharagpur region and compared stage- wise K_c values estimated by various methods [9]. The K_c value at the maturity stage was found to be considerably higher than the corresponding FAO recommended K_c value. It was also observed that the Penman–Monteith method is the best method to estimate daily and stag-wise K_c using the lysimeter measured ET_c. The investigators have [10] estimated K_c in AL- Hassa for the fourth growth stages of wheat crop. Jeetendra Kumar and Singh developed crop. It has been developed by earlier investigators the crop coefficient models for wheat and maize in the Gandak command area in Bihar and a polynomial model was fitted to the K_c values [11]. Alkaeed et al. emphasized the need for local calibration of K_c by indicating the necessary adjustment of K_c to the field conditions under the environmental effects [12]. The researchers have developed crop coefficients and relationships for cotton, sorghum and millet crops [13]. It was also reported that K_c values for cotton crop in the late stage, for sorghum crop in the mid and late stages and for millet crop in all stages were significantly different from FAO suggested K_c values.

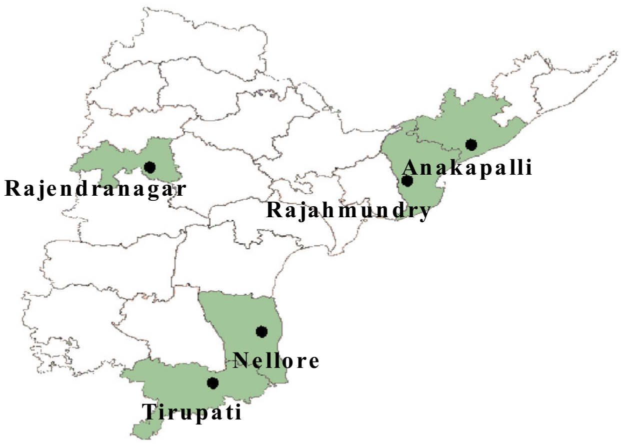


Fig. 1 Location map of the meteorological centers in Andhra Pradesh

The present study compares the crop coefficients computed using ET_0, estimated from Penman–Monteith equation and, lysimeter measured ET_c with those recommended

Table 1 Brief description of the meteorological centers

Meteorological center	Longitude (^{0}E)	Latitude (^{0}N)	Altitude, m	Mean daily relative humidity, %	Mean daily temperature, °C	Mean daily wind velocity, kmph	Mean daily sunshine hours, h	Mean daily vapour pressure, mm of Hg	Mean annual rainfall, mm
Tirupati	79°05′	13°05′	161.0	59.5	28.2	7.9	6.8	17.6	1100
Nellore	79°59′	14°22′	19.0	77.3	25.6	6.3	7.3	20.3	1170
Rajahmundry	81° 46′	17°00′	14.0	70.9	27.8	6.3	7.1	20.4	1160
Anakapalli	83°01′	17°38′	25.0	71.9	27.9	4.6	7.1	20.6	1190
Rajendranagar	78°23′	17°19′	536.0	61.8	26.2	7.3	8.0	14.9	920

Table 2 Crop details and period of data

Meteorological center	Crop	Crop varieties	Crop season	Crop period, days	Period of data	Training period	Testing period
Tirupati	Groundnut	KDR3, TMV2, JL24, K134, TPT1	July–Nov	130	1992–1998	1992–1996	1997–1998
Nellore	Paddy	BULKH/9, NLR9672, NLR9674, NLR27999, IR50, NLR33635, NLR9673	Sep–Jan	140	1983, 1987, 1988, 1994, 1996, 1997, 2002	1983, 1987, 1988, 1994, 1996	1997, 2002
Rajahmundry	Tobacco	JAYASHRE, NLS5, HEMA, MULTIPLE, 1158	Nov–Mar	110	1990–1998	1990–1995	1996–1998
Anakapalli	Sugarcane	CO419, CO7602	Mar–Feb	320	1981–1986	1981–1984	1985–1986
Rajendranagar	Castor	ARUNA	Jun–Nov	135	1978–1993	1978–1988	1989–1993

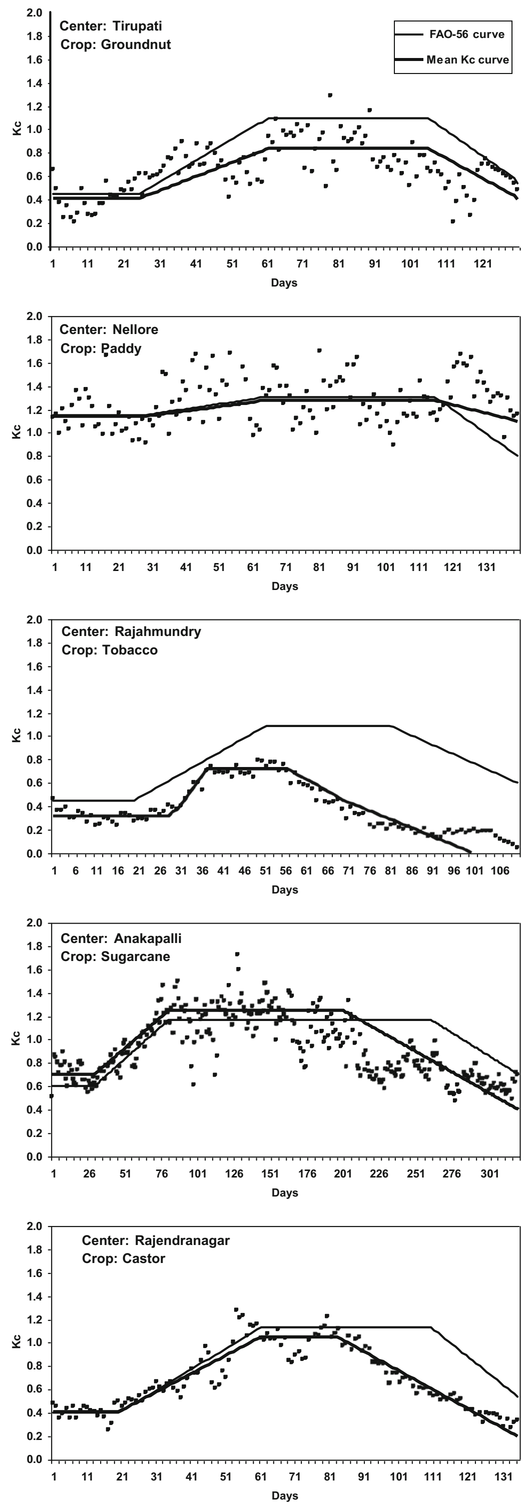


Fig. 2 Comparison of K_c curve derived from PMM ET_0 and lysimeter measured ET_c with that of FAO-56 curve

by FAO-56. It also attempts to develop crop coefficient models for different crops in the study area for estimating ET_c with reasonable degree of accuracy.

Materials and Methods

The lysimeter measured ET_c and the climatic data during the crop period at Tirupati (Rayalaseema region), Nellore, Rajahmundry and Anakapalli (Coastal region) and Rajendranagar (Telangana region) meteorological centers in Andhra Pradesh collected from the India Meteorological Department (IMD), Pune, India were used in the data analysis and model development. The data was divided into training and testing sets for the purpose of model development and its verification respectively. The closeness of the statistical structure in terms of mean, variance and skewness of the calibration and validation data sets was ensured while making the division. The location of the meteorological centers is shown in Fig. 1 and a brief description of these centers is presented in Table 1. The crop details and the period of data collected are given in Table 2.

The crop coefficients for various crops were calculated as the ratio of lysimeter measured ET_c to ET_0 estimated from Penman–Monteith equation and compared with the adjusted K_c values. The adjusted FAO-56 K_c curve was constructed with mean values at different crop growth stages after suitably modifying the table values of crop coefficients for average wetting events and climatic conditions using the following expressions.

$$K_{c\ ini} = K_{c\ ini\ (FAO)} + [(I - 10)/(40 - 10)] \times \left[K_{c\ ini\ (heavy\ wetting)} - K_{c\ ini\ (light\ wetting)}\right]$$

$$K_{c\ mid} = K_{c\ mid\ (FAO)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)](h/3)^{0.3}$$

$$K_{c\ end} = K_{c\ end\ (FAO)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)](h/3)^{0.3}$$

A polynomial K_c model as a function of x (number of days from sowing of the crop) is expressed as:

$$K_c = C_1x + C_2x + C_3x^2 + \ldots$$

where C_1, C_2, C_3,… are empirical constants.

The K_c models were developed using calibration data set and verified using validation data set. The performance of K_c models is verified by comparing ET_c computed from ET_0 estimated from Penman–Monteith equation and K_c, calculated using the models developed with that of lysimeter measured ET_c using the validation data set. The validity of the models is evaluated based on numerical and graphical performance indicators. The numerical performance indicators include correlation coefficient, RMSE [14], and efficiency coefficient [15]. The scatter and comparison plots are graphical indicators.

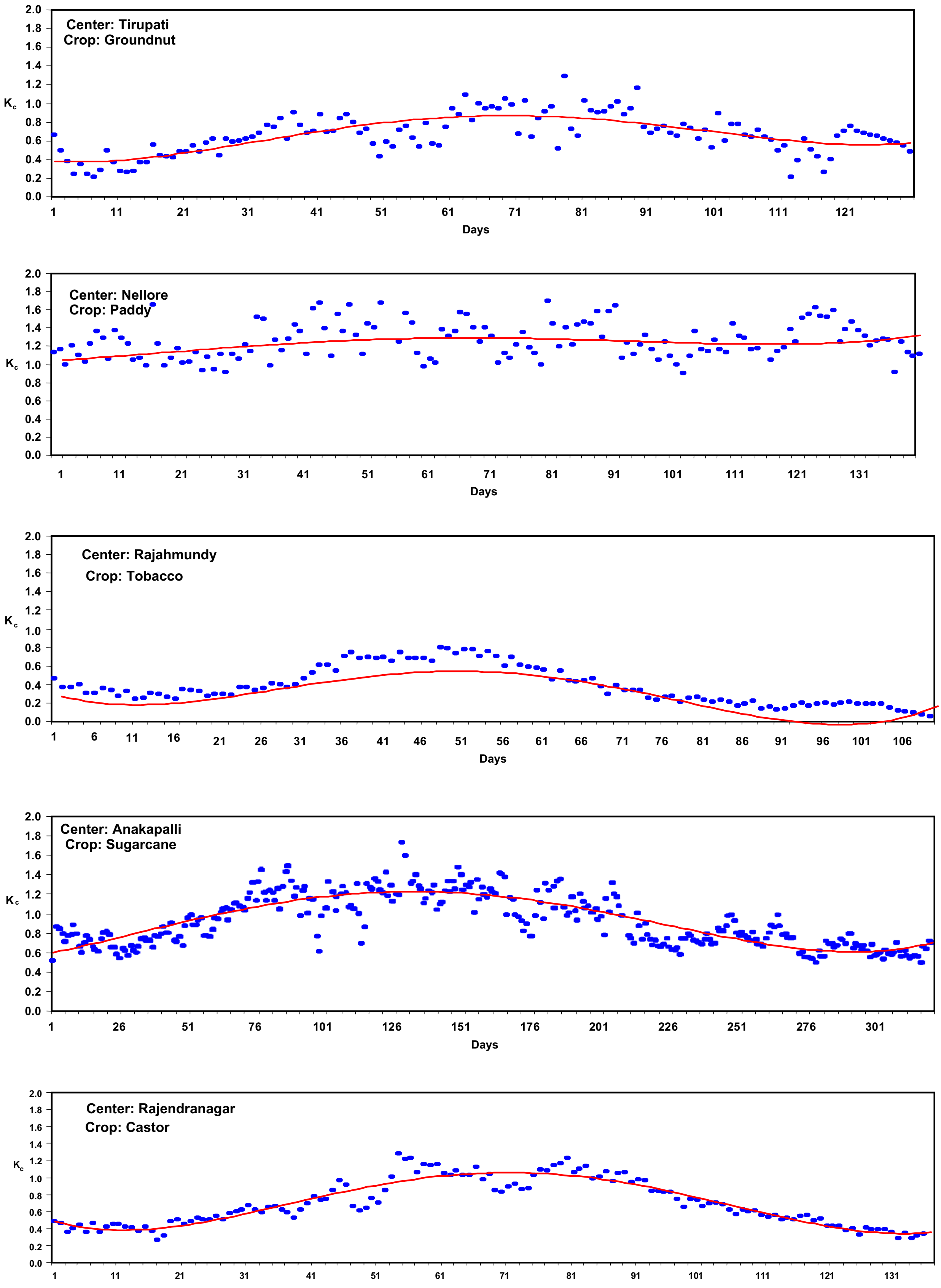


Fig. 3 Variation of daily K_c values

Results and Discussion

The daily crop coefficients calculated at different stages of growth were compared with mean adjusted values as recommended in FAO-56 manual by fitting the mean curve with the trend similar to the one recommended in FAO-56 as shown in Fig. 2. It may be noted that the table values suggested in FAO-56 were adjusted to the climatic conditions and wetting frequencies of the study area for the construction of the FAO-56 K_c curve. The variation of K_c at different stages of crop growth (Fig. 2) indicates that FAO-56 mostly overestimates daily K_c values at all stages of groundnut crop at Tirupati and of tobacco crop at Rajahmundry. It almost coincides with the proposed mean daily K_c curve of castor crop at Rajendranagar at initial and development growth stages but overestimates at mid and late stages. It underestimates at initial, development and mid stages and overestimates at late stage of sugarcane crop at Anakapalli. It almost coincides with mean daily K_c at all stages of paddy crop at Nellore. A significant deviation of the curve (Fig. 2) at most of the stages of crop growth of crops selected for the present study from that suggested by FAO-56 may be due to different agronomic, soil, climate and water management conditions. This suggests the need for the development of K_c models at the centers in order to reasonably estimate ET_c in the study area.

The variation of K_c with time during crop period is shown in Fig. 3. Differences in leaf anatomy, stomata characteristics, aerodynamic properties and albedo caused ET_c of different crops to differ under the same climatic conditions. It may be observed from these plots that K_c values showed an increasing trend with the advancement in the crop growth up to physiological development and after that started declining. A dual third order polynomial model each for raising and falling trends of K_c curve was therefore fitted to the data as presented in Table 3.

It may be noted that the variation of K_c with crop canopy and other crop parameters is not dealt with in the present study because of limited crop data available. However, the empirical coefficients in the model may, to a certain extent, implicitly take care of the effect of various crop parameters for the commonly grown crops and their varieties in the study area. The ET_c has been estimated using K_c values obtained from these models and compared with ET_c measured. Figures 4 and 5 respectively present the scatter diagrams and comparison plots between measured ET_c and estimated ET_c. The performance indicators in the ET_c estimates are given in Table 4. The values of R^2 and EC indicate that ET_c values estimated using the K_c models developed are fairly good. The RMSE found is also low. The slope (m) and intercept (c) respectively close to one and zero of scatter plots and, closeness of computed ET_c with ET_c measured in the comparison plots, indicate the satisfactory performance of the models. Therefore, the K_c models proposed may be adopted in the reasonable ET_c estimation for the crops commonly grown in the study area.

Conclusion

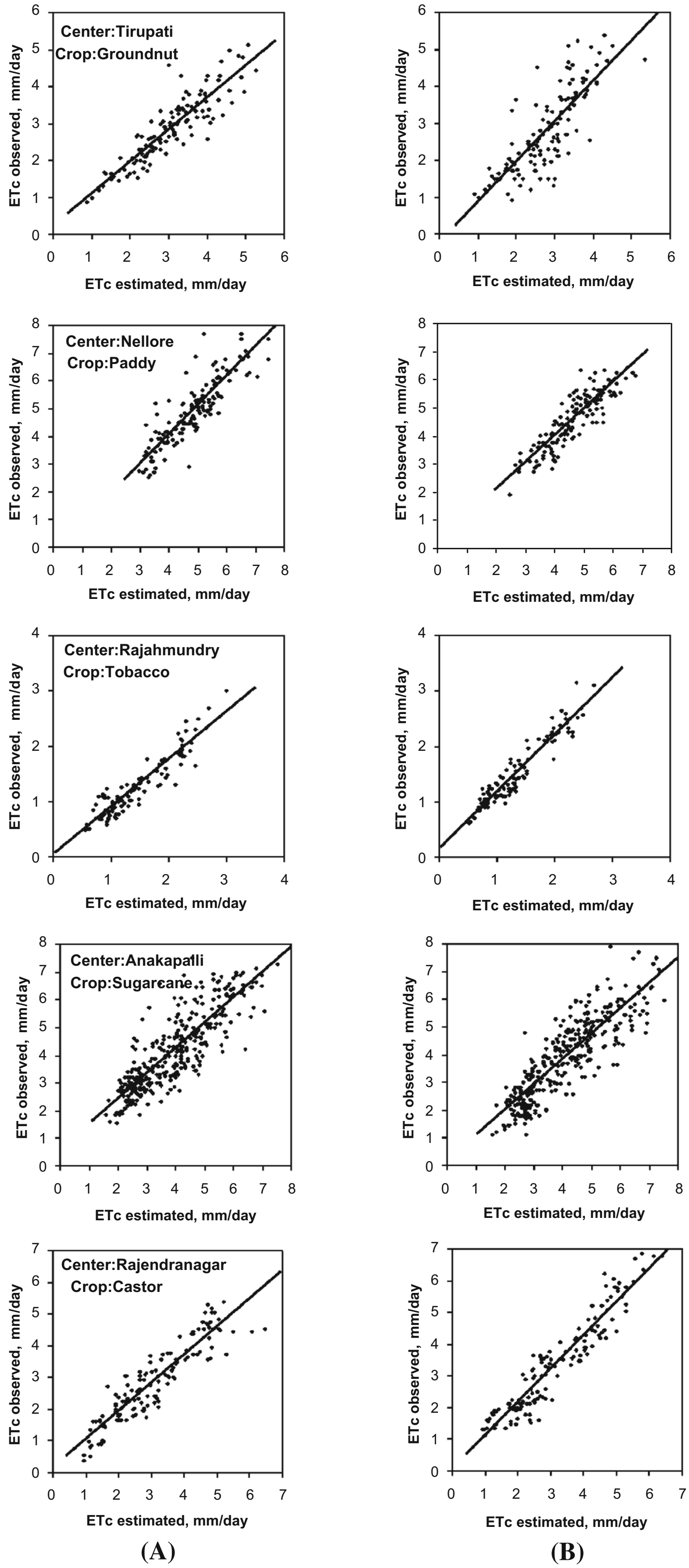
The crop coefficient values, computed for various crops using lysimeter measured ET_c and, Penman–Montieth ET_0 were compared with adjusted K_c values suggested in FAO-56 manual. These values deviated significantly from the adjusted FAO-56 values. A third order polynomial model has been developed to determine K_c values at different stages of growth for the crops commonly grown in the

Table 3 Polynomial regression K_c models

Meteorological center	Crop	Regression equation
Tirupati	Groundnut	$K_c = -1E-06\ x^3 + 7E-05\ x^2 + 0.0081\ x + 0.3104\ (1 \le x \le 80)$
		$K_c = 4E-06\ x^3 - 8.9E-04\ x^2 + 0.0449\ x + 1.0847\ (x > 80)$
Nellore	Paddy	$K_c = -5E-06\ x^3 + 0.0007\ x^2 - 0.0193\ x + 1.2513\ (1 \le x \le 60)$
		$K_c = -7E-07\ x^3 + 2.16E-04\ x^2 - 0.02026\ x + 1.8615\ (x > 60)$
Rajahmundry	Tobacco	$K_c = -2E-05\ x^3 + 0.0018\ x^2 - 0.0378\ x + 0.4897\ (1 \le x \le 50)$
		$K_c = -5E-06\ x^3 + 0.00145\ x^2 - 0.1445\ x + 5.0947\ (x > 50)$
Anakapalli	Sugarcane	$K_c = -6E-07\ x^3 + 0.0001\ x^2 - 0.0007\ x + 0.6832\ (1 \le x \le 150)$
		$K_c = -6E-07\ x^3 + 0.00037\ x^2 - 0.0712\ x + 5.0632\ (x > 150)$
Rajendranagar	Castor	$K_c = -9E-06\ x^3 + 0.001\ x^2 - 0.0212\ x + 0.5032\ (1 \le x \le 70)$
		$K_c = 1E-05\ x^3 - 0.0032\ x^2 + 0.3181\ x - 9.0549\ (x > 70)$

x number of days after sowing of the crop

Fig. 4 Scatter plots of daily ET_c observed with ET_c estimated. **A** Training period, **B** testing period



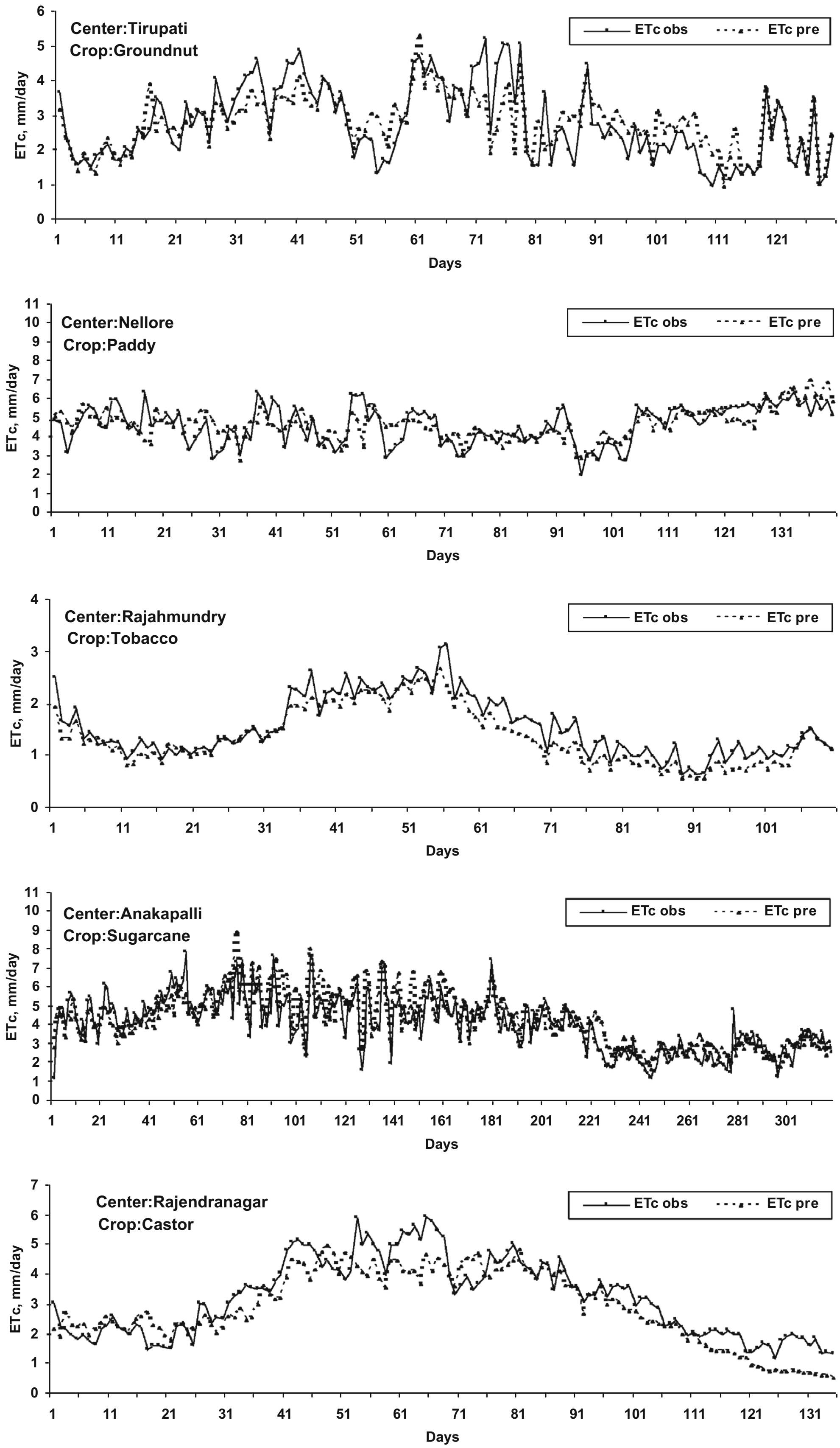


Fig. 5 Comparison of daily ET_c observed with ET_c estimated during testing period

Table 4 Performance indicators

Meteorological center	Crop	m		c		R^2		RMSE, mm		EC, %	
		Training	Testing	Training	Testing	Training	Testing	Training	Testing	Training	Testing
Tirupati	Groundnut	0.8605	1.0916	0.2470	−0.4425	0.8150	0.8043	0.40	0.46	81.50	80.43
Nellore	Paddy	1.0212	0.9854	−0.1063	0.1362	0.8354	0.8323	0.46	0.47	83.54	83.23
Rajahmundry	Tobacco	0.8656	1.0273	0.0213	0.1576	0.8748	0.9135	0.20	0.17	87.48	91.35
Anakapalli	Sugarcane	0.9878	0.9942	0.0812	0.1015	0.8845	0.8932	0.27	0.25	88.45	89.32
Rajendranagar	Castor	0.8887	1.0554	0.1177	0.0307	0.8392	0.8972	0.48	0.47	83.92	89.72

study area. The ET_c values computed using K_c estimated from the models proposed are comparable with those lysimeter measured ET_c. The K_c models proposed for different crops in the study area may therefore be adopted in the ET_c estimates with reasonable degree of accuracy.

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