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Determination of Crop Coefficient for Capsicum (*Capsicum annumm L.*) in Eastern Himalayan Region through Field Lysimeter

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ABSTRACT: A Crop coefficient (k_c) was determined for *Capsicum annumm* L. (hot pepper) with the help of UMS-GmBH cylindrical field lysimeter of 30 cm diameter and 120 cm deep and Penman-Monteith FAO-56 model. Penman-Monteith model is the universally adopted standard model for estimation of reference evapo-transpiration (ET_0) based on local weather parameters. Eight other models viz. Modified Penman Method, Hargreaves equation, Samini Hargreaves equation, Thorthwaite equation, Solar Radiation Method, Net Radiation Method, Blaney-Criddle Method and Radiation Method were also used for estimation of ET_0 and compared with Penman-Monteith model to find out the accuracy of prediction with limited weather parameters. Scatter plot and paired t-test were used for comparison. Out of all these models, Blaney-Criddle Method was found to yield similar results as given by Penman-Monteith model. The values of crop evapo-transpiration (ET_c) were varying from 1.11 mm d^{-1} to 3.12 mm d^{-1}. k_c is the ratio of ET_c to ET_0. The highest kc value was obtained during the maximum vegetative growth in 8th week after transplantation. The crop-coefficients for three growth stages *viz.* initial, mid and maturity were found to be 0.33, 0.64 and 0.30, respectively.

Key words: Crop-coefficient, evapo-transpiration, crop evapo-transpiration, lysimeter

Capsicum annumm L. (hot pepper) is a high value crop growing all over the world. Irrigation is a standard practice in hot pepper production (Wein, 1998). Water requirement of pepper varies from 600 mm to 1250 mm per growth cycle and it depends on region, climate and variety (Doorenbos and Kassam, 1979). The water requirement can be estimated by using different models from simple empirical equations to complex models. Some mechanistic models are also available to estimate the water requirement by utilizing soil, plant and climatic data. Mechanistic models require crop-specific growth parameters, which are not readily available for all crops and conditions (Hodges & Ritchie, 1991; Annandale *et al.,* 1999) and hence difficult to use at field levels.

Evapo-transpiration (ET) is a representation of the evaporation demand of atmosphere, independent of crop growth and management factors (Allen *et al.,* 1998). Evapo-transpiration is the simultaneous process of transfer of water to the atmosphere by transpiration and evaporation in a soil system (Allen *et al.,* 1998; Mavi and Tupper, 2004). It is an important parameter for climatological and hydrological studies, as well as for irrigation planning and management (Sentelhas *et al.,* 2010) as a major component of the agriculture water budget. Since it is difficult to separate evaporation and transpiration during crop growth, they are often expressed in one term ET.

Allen *et al.* (2005a) reported that the FAO Penman-Monteith (FAO PM) method had been considered as a universal standard to estimate ET called as reference ET (ET_0) and it incorporates physiological and aerodynamic parameters at location specific observation (Allen *et al.,* 1990; Allen and Pruitt, 1991; Lopez-Urrea *et al.,* 2006). It provides consistent ET_0 in many regions and climate. This method has been accepted worldwide as a good estimator and comparable to other methods especially for daily computations (e.g. Pereira and Pruitt, 2004; Cai *et al.,* 2007; Stokle *et al.,* 2004; Harmsen, 2003; Mohan and Arumugam, 1996; Itensifu *et al.,* 2003; Li *et al.,* 2003; Tyagi *et al.,* 2000; Chiew *et al.,* 1995). In other words, transpiration slowly supplants evaporation as Crop Evapo-transpiration (ET_c) increases. Soil water availability encourages plant growth and subsequent increases in ET_0. However, deficient soil water can induce plant wilting or death (Brady, 1990).

Study on ET_0 was conducted by Tyagi *et al.* (2000) on rice (monsoon) using regression statistics between Penman-Monteith and different methods where there was better agreement between Penman Monteith and FAO Blaney-Cridle (FB-C) along with FAO-24 (FAO Irrigation and Drainage Paper No. 24) corrected Penman followed by other methods and the higher value was estimate by FAO-24 corrected Penman. Another study was done on high lands of Eastern Ghats of Orissa, where comparison of some empirical methods for estimation of ET_0 was conducted to evaluate the best method for estimation of ET_0. Results indicated that FAO-56 (FAO Irrigation and Drainage Paper No. 56) was best in estimation of ET_0 throughout the year and Hargreaves equation being more consistent among temperature based equations (Lenka *et al.,* 2009).

The actual crop water use depends on climatic factors, crop type and crop growth stage. While ET_0 provides the climatic influence on crop water use, the effect of crop type and management is addressed by ET_c. Factors affecting ET_c such as ground cover, canopy properties and aerodynamic resistance for a crop are different from the factors affecting reference crop (grass or alfalfa); therefore, ET_c differs from ET_0. The characteristics that distinguish field crops from the reference crop are integrated into a crop factor or crop coefficient (kc) (Allen *et al.,* 1998; Allen *et al.,* 2000). kc is used to determine the actual water use for any crop in conjunction with ET_0.

$$ET_c = k_c \, X \, ET_0$$

In general, it is difficult to determine the ET_c as a residual from water balance computation, so k_c based approach is primary for predicting water consumption from irrigation projects (Burt *et al.,* 1997; Molden and Sakthivadivel 1999; Droogers and Bastiaanssen 2002).

Crop coefficients (k_c) are properties of plants used in predicting evapo-transpiration (ET). It varies by crop, stage of growth of the crop, and by some cultural practices. Crop coefficients are crop and crop variety specific and also location specific. Doorenbos and Pruitt (1977) recommended the values of crop coefficients at different stages of growth i.e. initial, crop development, mid season and maturity under different RH and Wind Speed conditions. The kc values recommended by FAO-24 (Doorenbos and Pruitt, 1977) were used in worldwide to estimate actual evapo-transpiration based on the local weather parameters in absence of derived crop coefficients. But if crop duration and morphology do not match, the actual values differ considerably from the tabulated values. Addition of more crops were done in the list of FAO-56 by Allen *et al.* (1998). They recommended the values for broad climatic conditions indicating maximum height of the crops for use of specific sets of crop coefficients.

The initial period is defined in FAO-24 (Doorenbos and Pruitt 1977) and in FAO-56 (Allen *et al.,* 1998) for annual crops as the period between the planting date and the date of approximately 10% ground cover. This period represents conditions when the soil is effectively bare. If the soil surface is wet during this period, the evaporation rate may be relatively large. As the soil surface dries, hydraulic conditions change and evaporation decreases. The mean crop coefficients (k_c) during this period are termed as the crop coefficient for the initial period kc ini. A value for k_c ini is required for constructing a "singular" crop coefficient curve for a growing season that incorporates impacts of wetting frequency on k_c. FAO-56 included a "dual" k_c method in addition to the singular method that simulates impacts of evaporation separately (Allen *et al.,* 2005b). However, the singular k_c method is often applied for general planning studies and regional analyses and thus, accurate and representative k_c ini values are needed.

kc as a function of time does not take into account environmental and management factors that influence the rate of canopy development (Grattan *et al.,* 1998). Therefore, most researchers have reported k_c as a function of days after transplanting (DAT) which helps to reference kc on crop development stage (Allen *et al.,* 1998; Tyagi *et al.,* 2000; Kashyap and Panda, 2001; Sepashkah and Andam, 2001).

Allen *et al.* (1998) recommended the evaluation of crop coefficient values in local climate conditions by observed data using lysimeter when the accuracy is highly concerned. Shab and Edling (2000) used the water balance equation in paddy field and Penman-Monteith equation for the calculation of ET_C and estimated the value of k_c for paddy rice in Louisiana to be 1.39, 1.51 and 1.43 for initial, mid-season and late season stage, respectively.

Vu *et al.* (2005) reported that the estimation of cumulative ET_C in paddy rice by FAO-56 using the recommended k_c value resulted in estimation error up to 17% from the observed values. Also, ET_C may exhibit considerable variability between rice varieties. The recommended values of k_c-ini in FAO-56 method are appropriate if reliable atmospheric data are available. However, the k_c -mid was found to be the sensitive parameter affecting ET_C estimation and the careful calibration according to the regional conditions and varieties seemed to be required for the accurate prediction. Considering the effect of random errors, FAO-56 method is more reliable when calculating cumulative ET_C longer than 7 days of period. Sahoo *et al.* (2009) reported that the average crop co-efficient values for 3 stages of sunflower namely for growing stage, mid-stage and late stage were found to be 0.7, 1.1 and 0.77 and the crop-evapotranspiration for these 3 stages were 2.62, 3.53 and 3.01 mm d^{-1}, respectively. The experiment was conducted at the research farm of CSWCRTI, Research Centre, Udhagamadhalan, Tamil Nadu, India using weighing type-lysimeter. The area receives an annual rainfall of 1228 mm and the mean monthly maximum and minimum temperatures are 22.1^0C and 8.5^0C occurring in April and January, respectively. Reference crop evapotranspiration (ET_0) for the growing period was worked out by FAO-Penman-Monteith (FAO 56-PM) equation using daily meteorological data.

Materials and Methods

Experimental site

The experiment was conducted during 2013 and 2014 growing seasons at a 100 m^2 experimental farm located at Central Agricultural University, Barapani, Meghalaya (25.680 N latitude 91.930 E longitude, 951 m above mean sea level). The soil at the experimental area is sandy loam to clay loam (texture with 62.9% sand, 21.6% clay, and 15.2% silt) with 1.35 (g cm^{-3}) and slightly acidic in nature. The minimum and maximum temperatures ranges from 3°C to 14°C and 28°C to 33°C, respectively with average annual precipitation of 2000 mm.

Table 1 : Soil chemical properties of experimental field

pH	OC %	CEC	Exchangeable acidity	N (kg/ha)	P (kg/ha)	K (kg/ha)
5.2	0.82	1.3	1.4	257 .1	15.1	155.7

Moisture characteristics of soil

The moisture characteristics of the soil in the experimental site was determined with the help of Pressure Pate Apparatus in order to ascertain the water holding capacity and soil moisture at field capacity level. Soil moisture at different suctions and at different depth of soil has been given in the Table 2. The moisture content of the soil varies from 12 to 44% at different suction. The soil moisture characteristics curve is also given in Figure 1.

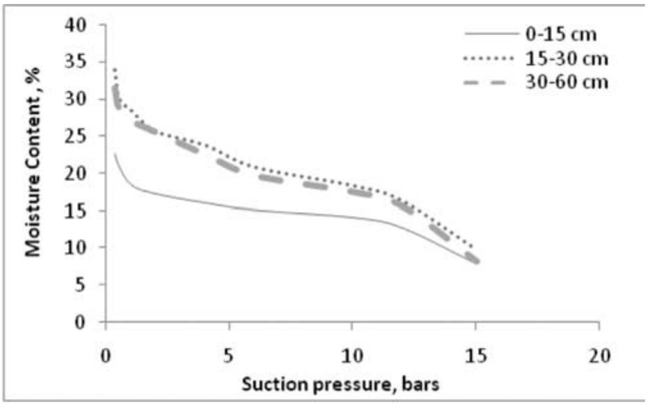

Fig. 1 : Soil moisture characteristics curve of the experimental site

Description of Weather station, Lysimeter and Tensiometer

An automatic weather station (Davis Vintage Pro-2) was installed within the area for collecting real time weather data. The standard weather data (rainfall; maximum and minimum temperature, morning and afternoon RH, wind speed and sun shine hours) were collected for the experiment at daily intervals. The operation of the lysimeter and weather station was automatic and data were allowed to be stored in the data logger. Two weighing type of lysimeters (UMS-GmBH) were installed within crop area of the experimental field. Lysimeter isolates a volume of soil to a given depth and includes a percolating water sampling system at its bottom. The UMS-GmBH lysimeters is consists of a metallic cylinder which is inserted into the soil by cutting or pressing. Once the whole cylinder is inserted, entire soil column is lifted and the bottom of the cylinder is sealed with a cover fixed with a ceramic plate. Then the lysimeter placed on a sensitive load cell. Generally different dimensions of lysimeters are available for various research works. Present lysimeter is a cylindrical lysimeter with 30 cm diameter and 120 cm soil column inserted in it. The soil is not disturbed across the profile only except negligible shearing along the cutting plane of the lysimeter wall. Five moisture sensors (EC5), Tensiometer (T4) and vacuum cup (SK20) were fixed on the wall of the lysimeter at different depth (10 cm, 30 cm, 55 cm, 80cm and 115 cm) for collecting leachate under suction. EC5 measures dielectric constant of the soil in order to find the volumetric water content. T4 Tensiometer is a precision tensiometer developed for outdoor monitoring works. Here only ceramic cup is filled with water for highest accuracy. VS Pro Vacuum system is also fitted to create constant vacuum condition at suction of -400 hPa to drain our excess water from the soil profile. SK20 vacuum cup is a simple ceramic cup with removable shaft. It is mainly suitable for continuous and discontinuous extraction. All the sensors including the load cell is connected to a data logger for continuous data collection at pre-determined interval. The gravitational water or the leachate is taken out through the vacuum cups and collected in the bottles kept in a buried chamber. The ceramic plate at the bottom of lysimeter is also connected to the vacuum pump to collect the excess water beyond field capacity. The lysimeter cylinder fitted with all the sensors and vacuum cups then inserted in a PVC casing and buried in the field.

Table 2 : Soil moisture at different suction as determined with pressure plate apparatus

Depth (cm)	0.33 bar	0.5 bar	1 bar	2 bar	4 bar	6 bar	10 bar	12 bar	15 bar
0-15	22.58	20.91	18.41	17.23	16.03	15.1	14.11	12.71	7.92
15-30	33.98	30.21	28.5	25.69	23.83	20.88	18.38	16.32	9.82
30-60	31.47	28.76	27.08	25.53	22.51	19.71	17.52	15.59	8.25

Crop coefficient

Derivation of crop coefficient for capsicum was carried out by two steps.

Firstly, estimation of reference evapo-transpiration (ET_0) by nine different methods including Penman Monteith method (Allen *et al.,* 1998) as a standard model was done using real time weather data viz. Maximum & Minimum temperature, Relative Humidity, Wind Speed and Net Radiation as collected in the Automatic Weather Station installed in the field. Eight other popular methods (Modified Penman Method, Hargreaves equation, Samini Hargreaves equation, Thorthwaite equation, Solar Radiation Method, Net Radiation Method, Blaney-Criddle Method and Radiation Method) were used for estimation of ET_0 and compared with Penman Monteith Method which was considered as standard method. Statistical tools such as scatter plots and paired t test were used to assess applicability of these methods in any situation where all the weather parameters may not be available. The FAO Penman-Monteith equation was used for ET_0 estimation (as given in FAO-56, Eq.1):-

$$ET_0 = \frac{0.408\,\Delta\,(Rn - G) + \gamma\left\{\frac{900}{T+273}\right\} * u_2(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34u_2)} \quad \text{............1}$$

Wher

ET_0	Reference evapo-transpiration [mm d^{-1}],
Rn	Net radiation at the crop surface [MJ m^{-2} d^{-1}],
G	Soil heat flux density [MJ m^{-2} d^{-1}],
T	Mean daily air temperature at 1 m height [^{0}C],
u_2	Wind speed at 2 m height [ms^{-1}],
e_s	Saturation vapour pressure [kPa],
e_a	Actual vapour pressure [kPa],
e_s-e_a	Saturation vapour pressure deficit [kPa],
Δ	Slope vapour pressure [kPa $^0C^{-1}$],
γ	Psychrometric constant [kPa $^0C^{-1}$].

The actual evapo-transpiration (ET_c) was then calculated from the soil moisture value from lysimeter as recorded with EC5 sensors and load cell data taken on daily basis using water balance approach. The ratio between the actual evapo-transpiration (ET_c) to the reference evapo-transpiration (ET_0) gave the Crop Coefficient (k_c).

$$k_c = ET_0 / ET_c$$

Table 3 : Calculated average weekly ET_0 for capsicum

Date	Average weekly ET_0 (mm d^{-1})								
	PMM	**MPM**	**HE**	**SHE**	**TE**	**SRM**	**NRM**	**BCM**	**RM**
15.10.13	3.43	6.68	9.26	8.47	11.68	1.11	4.53	4.69	13.36
22.10.13	3.33	6.41	7.65	7.58	11.68	1.08	3.82	4.64	12.77
29.10.13	3.33	6.14	6.38	6.86	11.68	0.91	3.36	4.38	12.56
05.11.13	3.13	5.60	7.65	7.22	21.44	0.75	3.85	4.02	11.00
12.11.13	2.80	4.83	7.75	7.97	27.68	0.70	4.63	3.91	9.23
19.11.13	2.84	4.88	7.69	9.31	27.68	0.61	4.29	3.78	9.66
26.11.13	2.96	5.07	6.58	6.15	27.68	0.57	3.39	3.78	10.34
03.12.13	2.90	5.03	6.59	6.22	23.08	0.68	3.21	3.83	10.04
10.12.13	2.89	4.97	6.11	5.49	19.73	0.62	3.15	3.68	9.83
17.12.13	2.37	4.15	5.59	5.50	19.73	0.38	3.17	3.35	7.56
24.12.13	2.43	4.12	5.25	4.90	19.73	0.27	2.46	3.20	7.33
31.12.13	3.19	5.18	5.03	4.96	19.73	0.37	2.50	3.33	7.01

[PMM- Penman-Monteith Methods MPM- Modified Penman Method, HE- Hargreaves equation, SHE- Samini Hargreaves equation, TE- Thorthwaite equation, SRM- Solar Radiation Method, NRM- Net Radiation Method, BCM- Blaney-Criddle Method , RM- Radiation Method]

Results and Discussion

Reference Evapo-transpiration

The calculated average weekly reference evapo-transpiration by nine different methods was given in Table 3. Daily trend of estimated ET_0 reflected a wide range from 2.06 mm to 4.75 mm (Figure 2) by Penman Monteith method with a mean value of 2.96 mm. Weekly average ET_0 of 3.5 mm d^{-1} was observed during 1st four Weeks After Transplanting (WAT) and less than 3 mm d^{-1} during 5th to 12th WAT and 3.19 mm d^{-1} during 12th WAT. In the entire crop growth period, total ET_0 loss amounts 249.30 mm. Variation in ET_0 loss was influenced by the three most important weather variables namely net radiation received, wind speed and mean air temperature.

In comparison to the results of Penman-Monteith methods, closer values were obtained through Net Radiation method and Blaney-Criddle Method where the minimum and maximum values of ET_0 were 2.50 mm d^{-1}, 4.63 mm d^{-1} and 3.20 mm d^{-1}, 4.69 mm d^{-1}, respectively. All other methods yielded ET_0 values much higher than that obtained with Penman-Monteith method. Temesgen *et al.* (1999) indicated that high humidity conditions may result in an overestimation of ET_0 by the Hargreaves method whereas the conditions with high wind speed may result in the underestimation of ET_0. Reference evapo-transpiration calculated by Thornthwaite method was found to be consistently higher since from the 1st week after transplanting till the end of the plant growth period as temperature is the only input parameter available. However, the differences in the ET_0 estimates using these methods provided a significant range of uncertainty (Othoman *et al.,* 2006). Reference evapo-transpiration by Samini Hargreaves equation gave over-estimation during the initial growing period. Hargreaves Samini method consistently overestimated by as much as 20% giving the worst estimates among all other tested methods (Alexandris *et al.,* 2008). Similar behavior of Hargreaves equation under humid conditions was reported by Jensen *et al.* (1997), Droogers and Allen (2002), Temesgen *et al.* (2005) and Garcia *et al.* (2004). Lower reference ET was observed in Solar Radiation method as compared to other methods.

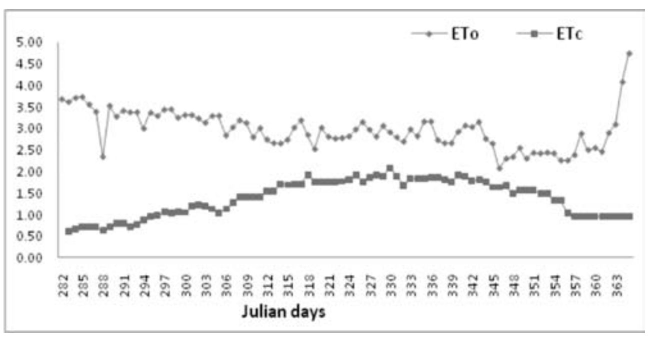

Fig. 2 : Reference ET_0 by penman monteith method and crop evapo-transpiration of capsicum (2013)

The linear regression statistics as obtained from scatter plots revealed that Modified Penman, Solar Radiation method, Net Radiation method, Balney Criddle method and Radiation methods had given statistically significant R^2 values with different slopes and intercepts given in Table 4. From October 9th to December 31st (rabi season), better agreement was observed between Penman Monteith and Blaney Criddle and Net solar radiation methods followed by other methods. The values of R^2 suggested that Blaney Criddle Method and Net radiation Method for estimation of ET_0 were similar to Penman Monteith Method in sub humid tropical climate during rabi season. The paired t-statistics have however reaffirmed that only Blaney-Criddle and Net Radiation methods were capable of estimating the ET_0 which were comparable to Penman-Monteith equation. Hence, it could be inferred that with the availability of temperature and radiation data in this hilly region Blaney-Cridle and Net radiation methods were applicable for estimating the ET_0 with some degrees of accuracy.

Table 4 : Regression statistics between penman monteith and different methods of ET_0 estimation

Variables	MPM	HE	SHE	TE	SRM	NRM	BCM	RM
Regression line slope (m)	0.60	0.38	0.40	0.02	5.47	0.72	0.72	0.29
Regression line intercept (c)	-0.01	0.02	0.02	0.05	0.15	0.01	0.01	0.00
Coefficient of determination (R^2)	0.99	0.86	0.75	0.12	0.59	0.96	0.96	0.90
Daily t-test value (p = 0.05) n=84	38.30	29.10	21.30	23.80	-53.60	5.70	18.30	32.80

[PMM- Penman-Monteith Methods MPM- Modified Penman Method, HE- Hargreaves equation, SHE- Samini Hargreaves equation, TE- Thorthwaite equation, SRM- Solar Radiation Method, NRM- Net Radiation Method, BCM- Blaney-Criddle Method , RM- Radiation Method]

Crop evapo-transpiration

The net solar radiation during the growing season was 774.96 MJm^{-2}. The values of ET_c were varying from 1.11 mm to 3.12 mm d^{-1}. The average weekly ET_c (mm d^{-1}) of capsicum increased from 0.67 to 1.89 mm d^{-1} during 1-6th WAT and thereafter decreased to 0.97 mm d^{-1}. The highest values of weekly average ET_c i.e. 1.89 was obtained during the period of maximum vegetative growth (6 WAT). The crop evapotranspiration took place right from the first week after transplanting which gradually increased till the crop entered into reproductive stage (6th to 9th week after transplanting). Towrads the end, the crop canopy started wilting due to very low temperature during December upto 7^0C. There was gradual reduction in ET_c from 1.82 to 0.97 mm d^{-1} during 9-12th WAT. The total seasonal ET_c during the cropping season was 114.81 mm. The weekly avearage ET_c as calculated by lysimeter are given in Table 5.

Table 5 : Average weekly ET_c by lysimeter for Capsicum (mm d^{-1})

Date	15.10.13	22.10.13	29.10.13	05.11.13	12.11.13	19.11.13	26.11.13	03.12.13	10.12.13	17.12.13	24.12.13	31.12.13
ET_c	0.7	0.8	1.1	1.23	1.58	1.78	1.89	1.84	1.82	1.6	1.23	0.97

Crop coefficient

Crop coefficient (k_c) values of capsicum was obtained from crop evapo-transpiration measured by lysimeter divided by reference ET calculated by different methods.

In the present experiment, k_c values were estimated on daily and weekly basis. To generate k_c curves, k_c values for the entire crop duration calculated and expressed in terms of three stages of growth namely k_c ini (transplanting to flowering), k_c mid (flowering to crop development), k_c end (crop development to harvesting).

Table 6 : Crop coefficient (k_c) values for capsicum

	k_c								
Date	**PMM**	**MPM**	**HE**	**SHE**	**TE**	**SRM**	**NRM**	**BCM**	**RM**
15.10.13	0.20	0.10	0.07	0.08	0.06	0.60	0.14	0.14	0.05
22.10.13	0.24	0.12	0.10	0.11	0.07	0.74	0.17	0.17	0.06
29.10.13	0.33	0.18	0.17	0.16	0.09	1.21	0.25	0.25	0.09
05.11.13	0.39	0.22	0.16	0.17	0.06	1.65	0.31	0.31	0.11
12.11.13	0.56	0.33	0.20	0.20	0.06	2.24	0.40	0.40	0.17
19.11.13	0.63	0.37	0.23	0.19	0.06	2.90	0.47	0.47	0.18
26.11.13	0.64	0.37	0.29	0.31	0.07	3.30	0.50	0.50	0.18
03.12.13	0.63	0.37	0.28	0.30	0.08	2.72	0.48	0.48	0.18
10.12.13	0.63	0.37	0.30	0.33	0.09	2.94	0.49	0.49	0.19
17.12.13	0.67	0.38	0.29	0.29	0.08	4.18	0.48	0.48	0.21
24.12.13	0.51	0.30	0.23	0.25	0.06	4.47	0.38	0.38	0.17
31.12.13	0.30	0.19	0.19	0.20	0.05	2.61	0.29	0.29	0.14

[PMM- Penman-Monteith Methods MPM- Modified Penman Method, HE- Hargreaves equation, SHE- Samini Hargreaves equation, TE- Thorthwaite equation, SRM- Solar Radiation Method, NRM- Net Radiation Method, BCM- Blaney-Criddle Method , RM- Radiation Method]

Results revealed that average weekly k_c values at different stages of growth vary at different magnitude. Crop coefficients increased from 0.20 to 0.67 based on Penman Monteith mthod, 0.10 to 0.38 (Modified Penman Method), 0.07 to 0.30 (Hargreaves Method), 0.08 to 0.33 (Samini Hargreaves Method), 0.06 to 0.09 (Thornthwaite Method), 0.60 to 4.47 (Solar Radiation Method), 0.14 to 0.50 (Net Radiation Method), 0.14 to 0.50 (Blaney Criddle Method), 0.50 to 0.21(Radiation Method), respectively. During the first growth stage which covered the period from transplanting to the end of the 3rd week after transplanting (WAT), k_c value was 0.33 considered as kc ini for capsicum. During the crop development stage (4 - 10th) WAT, k_c value increased to 0.67 (k_c mid) and then decreased to 0.30 (k_c end). The maximum crop coefficient of 0.67 and 4.47 by Penman Monteith method and Solar radiation method were calculated during 10th and 11th WAT, respectively.

The computed k_c values by Penman Monteith method during initial, mid and end stage were 0.33, 0.67 and 0.30 respectively and these values estimated by Net Radiation method and Blaney Criddle methods were 0.31, 0.50 and 0.29 and 0.31, 0.50 and 0.28 in respective stages. The estimated k_c values calculated by Penman Monteith Method and Net Radiation method and Blaney Criddle methods during all the stages were closer to the values. The k_c values during the crop growth stage increased slowly after certain period of time period. Crop coefficient increased rapidly from 0.20 to 0.33, 0.33 to .64 and 0.64 to 0.30 by Penman Monteith method in capsicum season in which crop development stage starting from 3rd to 7th WAT (Fig. 5). The maximum values of crop coefficients were also estimated during the 7th week after transplanting mainly because of the higher canopy.

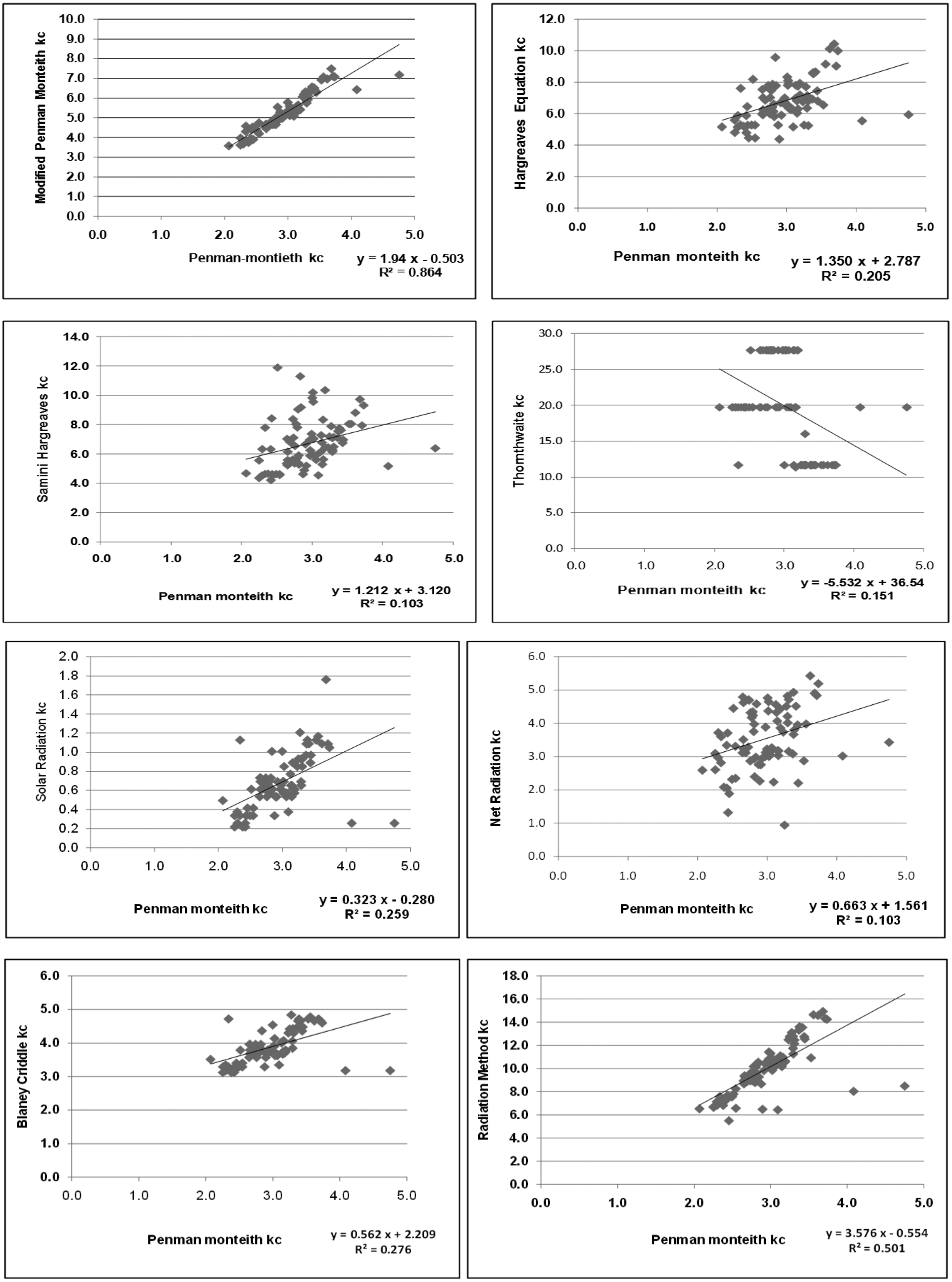

Fig. 3 : Comparison of daily kc values by eight different methods with penman monteith method for capsicum (n=84)

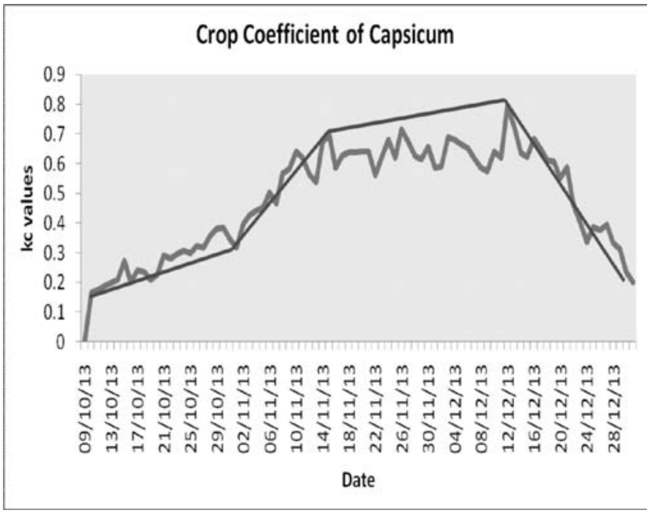

Fig. 4 : Daily crop coefficient of capsicum using penman monteith method

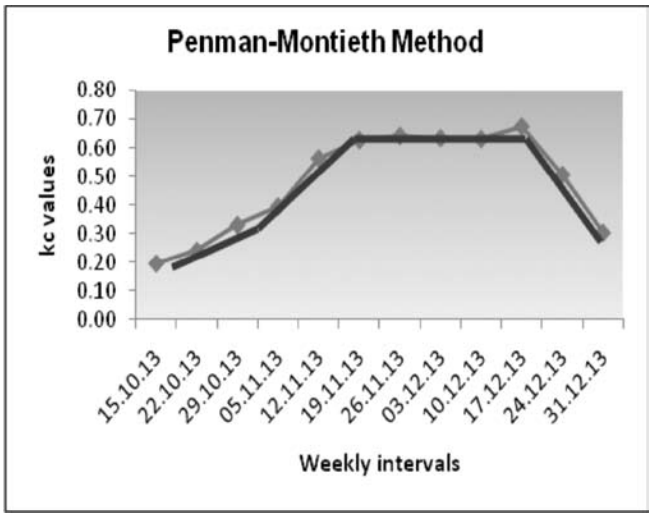

Fig. 5 : Weekly crop coefficient of capsicum using penman monteith method

Conclusions

Overall results indicate that some of the simpler empirical equations compared reasonably well with the Penman Monteith method while several other methods produced ET_0 estimates which significantly differ from those obtained by Penman Monteith method. Based on regression, among all the methods Blaney Criddle and Net Radiation method give better result. The difference between ET_c and ET_0 by different methods during initial and final stage of capsicum proved that ET_0 increased more than ET_c. But in middle stages, ET_c decreased more than ET_0 in all the methods except Solar Radiation method. It is due to increased foliage in the middle stage, the computed values of ET_c were more than ET_0.

The kc, ini, kc, mid and kc, end values were 0.33, 0.64 and 0.3, respectively which were lower than the standard k_c values as reported by the FAO-56 Penman-Montieth method (Doorenbos and Kassam, 1979; Doorenbos and Pruitt,1977; Pruitt,1986; Wright,1981,1982) for similar crops. This might be due to crop variety and type of crop in the present experiment.

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