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Determination of Crop Water Requirement and Crop Coefficient at Different Growth Stages of Tomato by Using Weighing Type Lysimeter in Raichur Region

Shrikant [a++*], G. V. Srinivasa Reddy [b#], M. S. Ayyanagoudar [b†], B. Maheshwara Babu [a‡], M. Y. Ajayakumar [c^] and M. K. Meena [d##]

[a] *Department of Soil and Water Engineering, College of Agricultural Engineering, CAE, UAS, Raichur, India.*
[b] *Department of Irrigation and Drainage Engineering, College of Agricultural Engineering, CAE, UAS, Raichur, India.*
[c] *Department of Agronomy, MARS, UAS, Raichur, India.*
[d] *Department of Crop Physiology, College of Agriculture Raichur, UAS, Raichur, India.*

Authors' contributions

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

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[++] *Ph.D. Scholar;*
[#] *Associate Professor;*
[†] *Professor and Head;*
[‡] *Professor;*
[^] *Scientist;*
[##] *Assistant Professor;*
**Corresponding author: E-mail: shrikanth035981@gmail.com;*

ABSTRACT

The water requirement for any cropping system is important consideration for designing and managing irrigation systems. Water requirement of crops varies substantially over the growing season mainly due to variation in crop cover and climatic conditions. For estimating crop water requirement of tomato crop, we have taken field experiment in weighing lysimeter for three seasons *rabi* - (7th September 2021 to 5th January 2022); Summer - (15th January 2022 to 15th May 2022) and *Kharif* - (6th June 2022 to 4th October 2022). The crop water requirement helps us to develop the crop coefficients for various growth stages (initial, development, mid and late season) for particular climatic conditions. Further, with exact crop coefficients derived from weighing type lysimeter will be helpful for determining water requirement. The results showed that the crop evapotranspiration (ET_c) for initial, development, mid-season and late-season being 22.76, 110.71, 173.47 and 68.71 mm, respectively. With respect to crop coefficient (K_c), it is estimated to be 0.38, 0.64, 1.12 and 0.66 for initial, development, mid-season and late season stages, respectively during *rabi* season. The crop evapotranspiration (ET_c) for initial, development, mid-season and late-season being 26.53, 164.76, 235.56 and 121.51 mm, respectively. With respect to crop coefficient (K_c), it is estimated to be 0.56, 0.87, 1.22 and 0.78 for initial, development, mid-season and late season stages, respectively during summer season. The crop evapotranspiration (ET_c) for initial, development, mid-season and late-season being 32.31, 131.38, 173.51 and 60.13 mm, respectively. With respect to K_c, it is estimated to be 0.36, 0.77, 1.13 and 0.74 for initial, development, mid-season and late season stages respectively during *kharif* season. The measured Kc values were significantly different from the FAO-56 reported values. Therefore, local calibration of crop coefficients is an essential for efficient irrigation water management and precise water applications.

Keywords: Crop water requirement; crop coefficient; weighing lysimeter; irrigation scheduling.

1. INTRODUCTION

"Proper irrigation scheduling and efficient irrigation water management are crucial for the sustainability of irrigated agriculture. Globally, water is considered as a precious element for the agricultural sector. Water being a scarce resource, it is necessary to use judiciously and manage this natural resource scientifically to sustain life on earth" [1]. Irrigation is the major consumer of water in the country and therefore water used for irrigation must be prudently managed to ensure high efficiency.

Tomato (*Solanum Lycopersicum* Mill, Family: Solanaceae) is one of the major and widely grown staple vegetable crop in both tropics and sub-tropics of the world and ranks second in importance among vegetables. It is said to be a native of tropical America from where it has spread to other parts of the world in the sixteenth century. It is an important source of minerals and vitamin A and C. It is also known as 'Red Gold' and has high potential for developing value added products like soup, juice, pickle, ketchup and powder through processing. It is also important for its edible fruits that can be consumed either directly as a raw vegetable in a sandwich or as cooked foods.

Crop water requirement is the important key for proper planning and structure of the irrigation system of any crop. Crop water requirements is the depth of water needed to meet the water loss through evapotranspiration of a disease-free crop growing in large fields under non-restrictive soil conditions including soil water and fertility and achieving full production potential under the given growing environment." Crop Water Requirement (CWR) is based on the type of crop, stage of the crop, soil type, climatic conditions and evapotranspiration demand. Accurate quantification of crop water requirements of any crop is essential for irrigation scheduling and water management. The crop water requirement (CWR) also can be determined from reference evapotranspiration using crop coefficients (K_c).

To estimate crop evapotranspiration (ET) for irrigation planning, the crop coefficient (K_c), which is the ratio of crop evapotranspiration to reference evapotranspiration, is needed. The crop coefficient value represents crop-specific water use and is required for accurate estimation of irrigation requirement of different crops grown under different climatic conditions. These values are commonly used in places where local data are not available. Therefore, it is felt that the crop coefficients must be determined under different climatic conditions.

2. MATERIALS AND METHODS

The analysis was carried out for the Raichur region. It is situated in the North-Eastern Dry zone (Zone 2) of Karnataka at 16° 15′ N latitude and 77° 20′ E longitude with an average elevation of 407 meters (1335 feet) above the mean sea level and it lies in semi-arid climatic condition. The district has a total geographical area of 8,383 sq km. The major part of the year remains dry and hot. In the month of May, it experiences the highest temperature while the lowest temperature is experienced in December.

The average annual rainfall of the area is 722.32 mm. December is the coldest month with the mean maximum temperature of 29.9^{0}C and the mean minimum temperature of 15.3^{0}C. The nights are generally cool in the season, but the day temperature sometimes reaches 35 to 38^{0}C. May is the hottest month; with the mean maximum temperature being 39.9^{0}C. Day temperature shows a slight increase in October. From November, both day and night temperature gradually decreases till December. The mean maximum relative humidity (RH) was noticed during the August and September months (83 per cent) whereas the mean minimum RH was noticed during March month (24 per cent).

2.1 FAO 56 Penman Monteith Model

The FAO 56 Penman-Monteith model is recommended as the sole of standard model. It is a model with a strong likelihood of correctly predicting evapotranspiration in a wide range of locations and climates [2]. It can be calculated by using the following formula:

$$PET = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_a - e_d)}{\Delta + \gamma(1 + 0.34U_2)}$$

Where,

PET = Potential evapotranspiration (mm d^{-1})
R_n = Net radiation at crop surface (MJ m^{-2} d^{-1})
G = Soil heat flux (MJ m^{-2} d^{-1})
T = Average temperature at 2 m height (^{o}C)
U_2 = Wind speed measured at 2 m height (m s^{-1})
(e_a - e_d) = Vapour pressure deficit for measurement at 2 m height (kPa)
Δ = Slope vapour pressure curve (kPa ^{o}C^{-1})
γ = Psychrometric constant (kPa ^{o}C^{-1})

2.2 Transplanting of Tomato

Tomato variety Syngenta T0-1057 was chosen for this study to estimate crop evapotranspiration in the lysimeter. Transplanting was done for three seasons viz., *rabi* 2021-22 summer-2022 and *kharif*-2022 on 7st September, January 15 and June 6 respectively. Transplanting was done in the weighing lysimeter as well as the area around the lysimeter. In the lysimeter, six plants were transplanted at a spacing of 75 x 45 cm. the overall views of crop development at several stages of growth, intial, development, mid and late seasons in a lysimeter bin and outside a field was depicted in plate 1.

Plate 1. The overall view of the weighing lysimeter with tomato crop

2.3 Crop Coefficients

The measured crop coefficients (K_c) for all the sel ected crops under study were calculated using th e following relation:

$$K_C = \frac{ET_C}{ET_0}$$

In which ET_c is the actual crop evapotranspiration (mm day^{-1}) measured from weighing lysimeter and ET_o is the reference evapotranspiration (mm day^{-1}) measured from FAO 56 Penman Monteith method.

The crop coefficient varies according to crop type, growth stages and varying local climatic conditions. Hence, stage wise crop coefficients derived from FAO 56 was modified as per the climatic parameters of Raichur for tomato crop by following the standard procedure and guidelines suggested by Allen et al. [2] using FAO-56 curve method [3]. The FAO-56 curve method was based on the estimated value of the crop coefficients.

The total duration of tomato crop was divided into four growth stages (initial, developmental, mid-season and late-season). The length of each growth stages were 15, 40, 40 and 25 days for initial, development, mid-season and late season stages, respectively [4]. The initial stage refers to the germination and early growth stage when the soil surface is not or is hardly covered by the crop (ground cover <10%). The crop development stage is the stage from the end of the initial stage to attainment of effective full groundcover (groundcover 70-80%). The mid-season stage is the stage from the attainment of effective full groundcover to the start of maturity, as indicated for example by discolouring or falling of leaves. At this stage, K_c will reach its maximum value. The late season stage runs from the start of maturity to harvest or full senescence. The calculation of K_c and ET_o was presumed to end when the crop was harvested, dried out naturally, reached senescence or experienced leaf drop.

2.4 Crop Water Requirement

The amount of water required to compensate for the evapotranspiration loss from the cropped field is defined as crop water requirement. Crop water requirements encompass the total amount of water used in evapotranspiration process. Out of the total evapotranspiration, evaporation account for about 10 per cent and plant transpiration for the remaining 90 percent. The crop evapotranspiration differs distinctly from the reference evapotranspiration (ET_o) as the ground cover, canopy properties and aerodynamic resistance of the crop is different from grass. The difference in evaporation and transpiration between both surfaces was combined into single coefficient K_c. In the present study, crop coefficient approach was used for computation of crop water requirements [5].

The crop water requirement of selected crop was computed by following equation:

$$ET_C = K_C \times ET_O$$

Where,

ET_c = Crop evapotranspiration, (mm day^{-1})
K_c = Crop coefficient
ET_o= Reference crop evapotranspiration (mm day^{-1})

The daily ET_c computed were summed for different growth stages of crop and total seasonal crop water was determined for tomato crop. The total duration of tomato crop was divided into four growth stages (initial, developmental, mid-season and late-season).

3. RESULTS AND DISCUSSION

3.1 Reference Evapotranspiration (ET_o)

Values of reference crop evapotranspiration through the growth stages of tomato during the *rabi*, summer and *kharif* season were shown in Table 1. “The values of ET_o through growth season indicate that it is lowest with the beginning of the season and increased till development stage during the *rabi*, summer and *kharif* season” [6]. Which was attributed to the variability of climatologically factors during the growing season. The total reference evapotranspiration value were 491.89, 585.49 and 495.41 mm during the *rabi*, summer and *kharif* season respectively.

The crop evapotranspiration (ET_c) exceeded ET_o only at the mid-season stage, whereas in the rest stages ET_o is higher than ET_c during *rabi*, summer and *kharif* season as shown in the Fig. 1a, b and c [7]. “This indicates that during the mid-season stage, the crop water demand is high because of the fully developed crop canopies and high evaporative demand to flower, fruit formation and filling” [6].

The seasonal crop evapotranspiration (ET_c) of tomato planted during the *rabi* season was 375.65 mm (Table 1) with the crop evapotranspiration (ET_c) for initial, development, mid-season and late-season being 22.76, 110.71, 173.47 and 68.71 mm, respectively. With respect to crop coefficient (K_c), it is estimated to be 0.38, 0.64, 1.12 and 0.66 for initial, development, mid-season and late season stages, respectively, the crop coefficient (K_c) values increased from initial value of 0.38 to midseason value of 1.12 and decreased during late-season crop coefficient (K_c) value was found to be 0.66.

Meanwhile The seasonal crop evapotranspiration (ET_c) of tomato planted during the summer season was 548.36 mm (Table 1) with the crop evapotranspiration (ET_c) for initial, development, mid-season and late-season being 26.53, 164.76, 235.56 and 121.51 mm, respectively. With respect to crop coefficient (K_c), it is estimated to be 0.56, 0.87, 1.22 and 0.78 for initial, development, mid-season and late season stages, respectively, the crop coefficient (K_c) values increased from initial value of 0.56 to midseason value of 1.22 and the late- season crop coefficient (K_c) value was found to be 0.78 [8,3].

Similarly the seasonal crop evapotranspiration (ET_c) of tomato planted during the *kharif* season was 397.33 mm with the crop evapotranspiration (ET_c) for initial, development, mid-season and late-season being 32.31, 131.38, 173.51 and 60.13 mm, respectively. With respect to crop coefficient (K_c), it is estimated to be 0.36, 0.77, 1.13 and 0.74 for initial, development, mid-season and late season stages, respectively, the crop coefficient (K_c) values increased from initial value of 0.36 to midseason value of 1.13 and late- season crop coefficient (K_c) value was found to be 0.74.

“The crop evapotranspiration (ET_c) is low in initial and followed in late-stage during the *rabi*, summer and *kharif* season, which was due to low canopy cover in the initial stage and cessation of leaf growth in the late-stage” [9]. “The average crop coefficient (K_c) value was low at the initial stage and high at the mid season stage during *rabi*, summer and *kharif* season. K_c values for mid season in most crops are generally higher than those observed in other development stage” [10,11]. “During the mid-season stage, the highest value of K_c is obtained due to the crop attained peak value of leaf area index and maximum canopy cover, which leads to increase crop evapotranspiration” [7]. The K_c tends to decline at a point after a full cover up to late or harvest stage during *rabi*, summer and *kharif* season.

A comparison was carried out between the crop coefficient (K_c) values measured by lysimeter (K_c Lysimeter) and recommended by FAO 56. The crop coefficient (K_c) curve for tomato developed in this study followed a similar trend with the estimated K_c curve by FAO 56, where K_c is small at the beginning of the season and increases as the plant grows until it reaches a maximum value at crop maturity and decline in harvest during the *rabi*, summer and *kharif* season.

“The crop coefficient (K_c) values obtained from the lysimeter during the *rabi* season are underestimated at initial, development and late growth stage and almost similar during the mid season stage as compared to crop coefficient (K_c) values recommended by FAO 56” (Fig. 2a) [12].

The crop coefficient (K_c) values obtained from the lysimeter during the summer season are overestimated at initial, development and mid season stages and almost similar during late growth stage as compared to crop coefficient (K_c) values recommended by FAO 56 (Fig. 2b).

“The crop coefficient (K_c) values obtained from the lysimeter during the *kharif* season are slightly underestimated at initial, development and late season stages and slightly overestimated during the mid growth stage as compared to crop coefficient (K_c) values recommended by FAO 56” (Fig. 2c) [13].

3.2 The Crop Coefficient and Water Requirement for Tomato Crop at Raichur Region for All Seasons (*Rabi*, Summer and *Kharif*)

The compiled crop coefficients and water requirement for tomato crop for Raichur climatological conditions are depicted in Table. 1. From results it revealed that, the variations in crop coefficients were observed across all crop growth stages and different crop growing season (*rabi*, Summer and *kharif*). The average crop coefficients (K_c) values were observed to be low (0.38 during *rabi*; 0.56 during summer and 0.36

during *kharif*) during initial crop growth stages and highest during mid season (1.12 during *rabi*; 1.22 during summer and 1.13 during *kharif*) stages. It was clearly observed (Table. 1) that, the crop coefficients (K_c) were high during summer season followed by *kharif* and *rabi* season for all crop growth stages (initial, development, mid and late) expect *kharif* season during initial stage [14]. Similarly, the seasonal water requirement for tomato crop was observed to be high during summer (548.36 mm) followed by *kharif* (397.33 mm) and *rabi* season (375.64 mm) at Raichur climatic conditions.

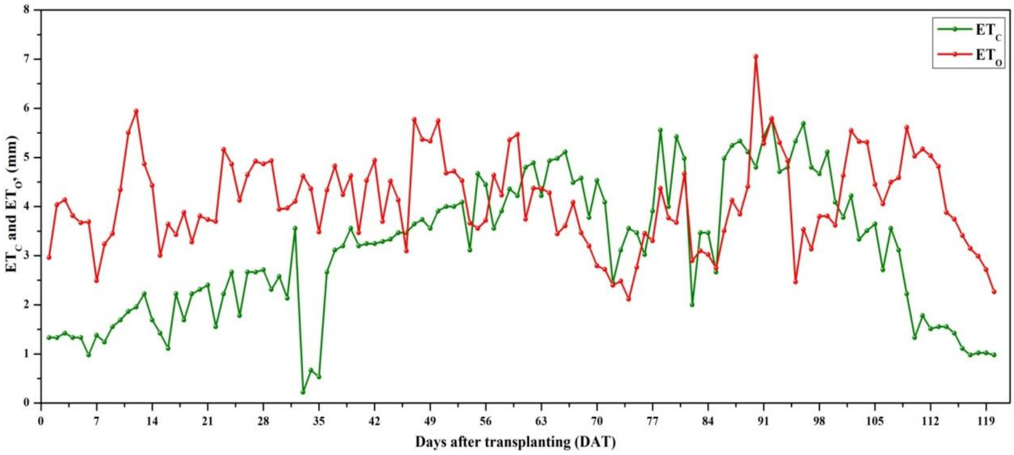

Fig. 1a. Daily ET_c and ET_o of tomato crop during *rabi* season

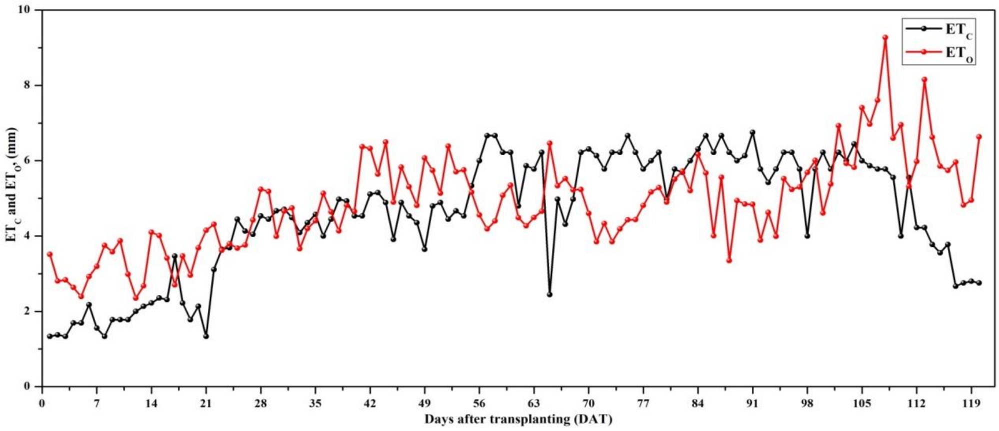

Fig. 1b. Daily ET_c and ET_o of tomato crop during summer season

Table 1. Average crop evapotranspiration, reference crop evapotranspiration and crop coefficient values of tomato during *rabi,* summerand *Kharif* season (2021-2022)

Tomato	Growth stages				Seasonal	
(*Rabi Season*)	**Initial**	**Development**	**Mid**	**Late**	**ET_o (mm)**	**ET_c (mm)**
ET_o (mm/stage)	59.58	173.24	154.98	104.09	491.89	375.65
ET_c (mm/stage)	22.76	110.71	173.47	68.71		
K_c lysimeter	0.38	0.64	1.12	0.66		
Tomato (Summer Season)						
ET_o (mm/stage)	47.63	189.10	193.00	155.76	585.49	548.36
ET_c (mm/stage)	26.53	164.76	235.56	121.51		
K_c lysimeter	0.56	0.87	1.22	0.78		
Tomato (*Kharif* Season)						
ET_o (mm/stage)	90.52	170.21	153.58	81.10	495.41	397.33
ET_c (mm/stage)	32.31	131.38	173.51	60.13		
K_c lysimeter	0.36	0.77	1.13	0.74		

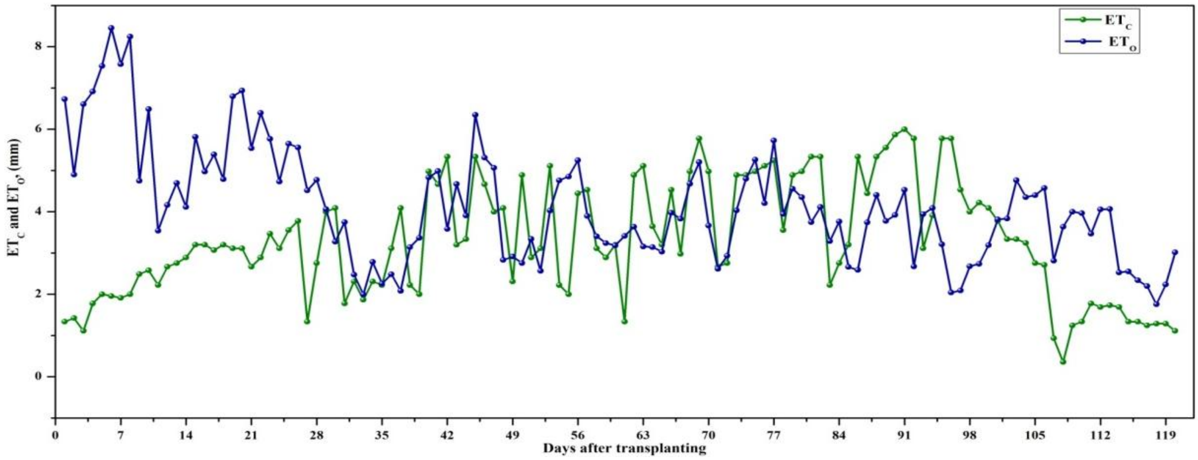

Fig. 1c. Daily ET_c and ET_o of tomato crop during *kharif* season

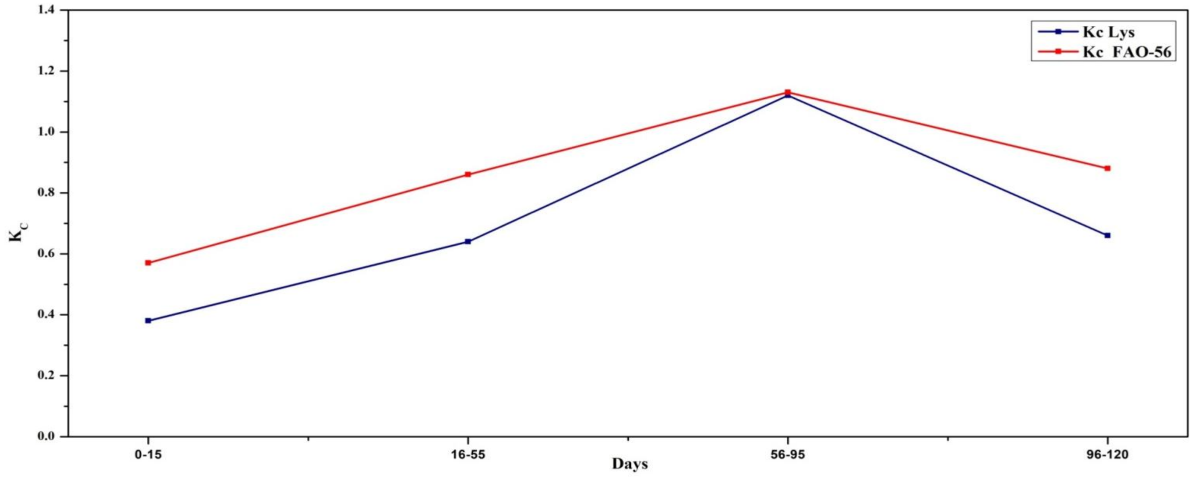

Fig. 2a. Crop coefficients recommended by FAO56 for the crop (K_c FAO) and determined by lysimeter (K_c Lys) during *rabi* season

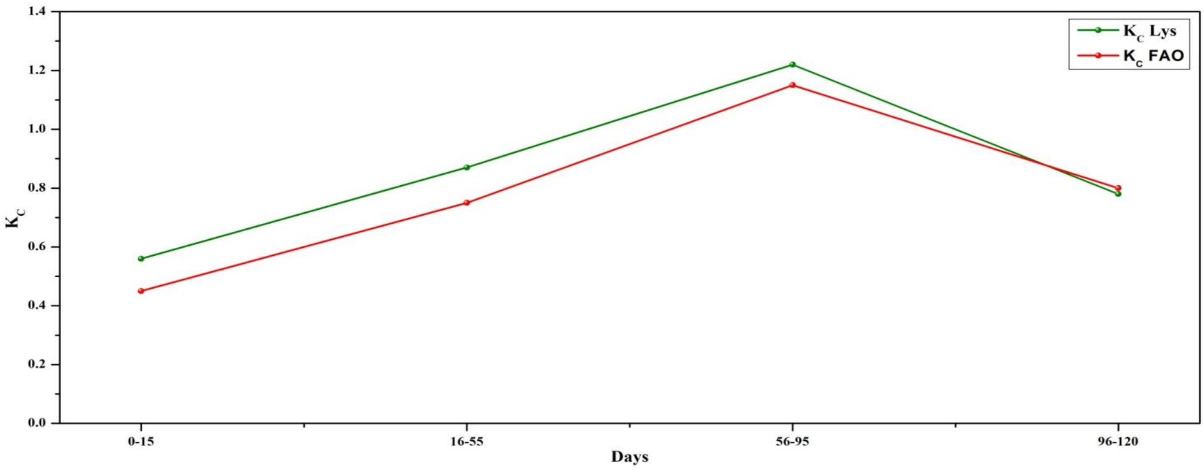

Fig. 2b. Crop coefficients recommended by FAO56 for the crop (K_c FAO) and determined by lysimeter (K_c Lys) during summer season

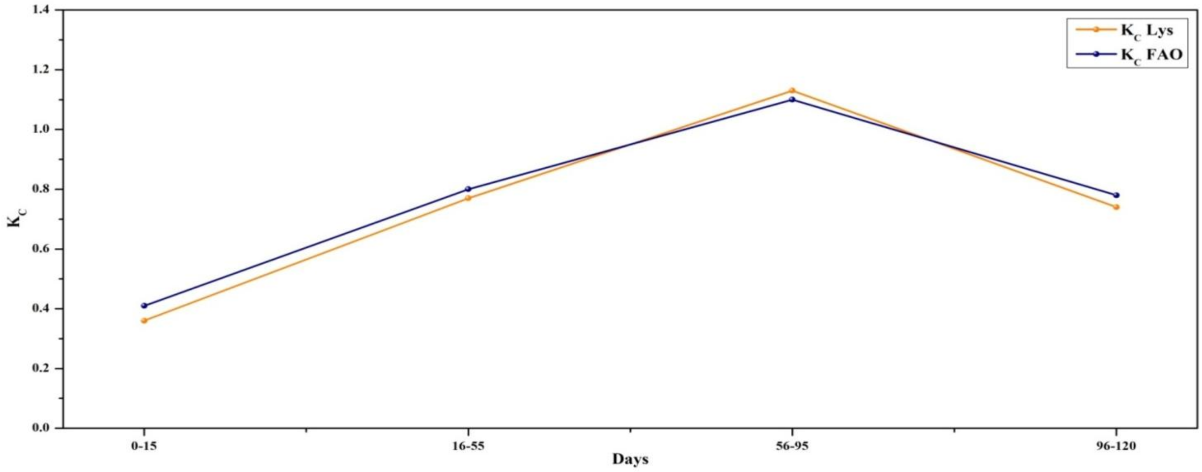

Fig. 2c. Crop coefficients recommended by FAO-56 for the crop (Kc FAO) and determined by lysimeter (Kc Lys) during *kharif* season

4. CONCLUSION

The present study was conducted with the objective of determining the crop evapotranspiration (ET_c) and crop coefficient (K_c) values by weighing lysimeters and compares them with the values estimated by the FAO-56 method at the different stages of development of tomato plants at Raichur, Karnataka.

The results showed that the seasonal crop evapotranspiration (ET_c) of tomato were 375.65, 548.36 and 397.33 mm during the *rabi*, summer and *kharif* season respectively. The total reference evapotranspiration value were 491.89, 585.49 and 495.41 mm during the *rabi*, summer and *kharif* season respectively. The average K_c values of tomato planted during the *rabi* cropping season were 0.38, 0.64, 1.12 and 0.66 for initial, development, mid-season and late season stages, respectively. Meanwhile the K_c values of tomato planted during the summer cropping season were 0.56, 0.87, 1.22 and 0.78 for the respective growth stage. Similarly the K_c values of tomato planted during the *kharif* cropping season were 0.36, 0.77, 1.13 and 0.74 for the respective growth stage.

The estimated values of crop coefficients for tomato differ considerably during the *rabi* season underestimated at initial, development and late growth stage and almost similar during the mid season stage. Meanwhile during summer season, overestimated at initial, development and mid season stages and almost similar during late growth stage. Similarly for *kharif* season, slightly underestimated at initial, development and late season stages and slightly overestimated during the mid growth stage as compared to crop coefficient (K_c) values recommended by FAO 56. Therefore, local calibration of crop coefficients is essential for agricultural planning and efficient irrigation water management for the cultivation of tomato in the Raichur and other similar semi-arid climates.

The seasonal water requirement for tomato crop was observed to be high during summer (548.36 mm) followed by *kharif* (397.33 mm) and *rabi* season (375.64 mm) for tomato crop at Raichur climatic conditions.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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