Journal of AgriSearch, 12 (3) : 169-175
An Open Access International Peer Reviewed Quaterly

ISSN : 2348-8808 (Print), 2348-8867 (Online)
https://doi.org/10.21921/jas.v12i03.15247

Assessment of Crop Coefficients for Tomato in Temperate Region of Kashmir

Zubair Ahmad Mir[1], Yogesh Pandey[2*], Sushmita M Dadhich[3] and Nuzhat Bint Nazir[4]

ABSTRACT

A field experiment was conducted at SKUAST-K, Shalimar using a drainage-type lysimeter to determine the water requirement and crop coefficients (single and dual) for tomato (Solanum lycopersicum L.) under temperate conditions. Reference evapotranspiration (ET_0) during different crop growth stages was estimated using four empirical models and compared to actual crop evapotranspiration (ETc) measured via the lysimeter. Model performance was assessed using statistical indicators including Nash–Sutcliffe Efficiency (NSE), root mean square error (RMSE), and correlation coefficient (r). Results indicated a "Satisfactory" to "Very Good" agreement between computed and observed ETc values. A Z-test revealed no statistically significant differences at the 5% level between lysimeter-measured ETc and values estimated by the four models, affirming their applicability. Among these, the FAO Penman-Monteith model showed the closest agreement with lysimeter data, with R^2 values of 0.88, 0.93, 0.91, and 0.92 across initial, development, mid, and late stages, respectively. The single crop coefficient (Kc) values determined were 0.54 (initial), 0.85 (development), 1.04 (mid-season), and 0.62 (late). Dual crop coefficients [Kcb (basal crop coefficient) + Ke (soil evaporation)] were 0.52, 0.83, 1.01, and 0.59, respectively. These findings underscore the lysimeter's effectiveness for calibrating ecohydrological crop evapotranspiration models and provide critical data for efficient irrigation planning in the temperate regions of Kashmir.

Keywords: Reference evapotranspiration models, Crop coefficient, Drainage-type lysimeter, Tomato

ARTICLE INFO

Received on	:	06/07/2025
Accepted on	:	09/09/2025
Published online	:	30/09/2025

INTRODUCTION

Precise estimation of actual evapotranspiration (ET) is vital for sustainable agricultural management, particularly in arid and semi-arid regions where water availability is a limiting factor. Efficient irrigation scheduling and optimal water use depend on precise ET estimates. It is also crucial for agricultural planning, water resource management, and climate change studies. The degree of vulnerability of crops to climate variability depends mainly on the growth stages of the crop at the time of weather aberration. However, direct ET measurement through field methods like lysimeters is often expensive, labour-intensive, and time-consuming. Weighing lysimeters, for example, require sophisticated equipment and meticulous monitoring of physical parameters and soil water balance (Howell et al., 1991). Despite these limitations, such direct methods are considered highly accurate and are used to validate indirect estimation techniques. Indirect methods commonly estimate crop evapotranspiration (ETc) by multiplying reference evapotranspiration (ETo) with a crop coefficient (Kc). Several empirical and semi-empirical models have been developed for estimating ETo using meteorological variables. These include (a) radiation-based models such as Thornthwaite (1948) and Doorenbos and Pruitt (1975), (b) temperature-based models such as Hargreaves and Samani (1985), and (c) combination-based models such as the FAO-56 Penman–Monteith (Allen et al., 1998). Each model has strengths and weaknesses and their accuracy varies significantly across different climatic zones. Numerous studies have evaluated these models under various climatic conditions. Djaman et al. (2015) studied 16 models in the Senegal River Valley; and Muniandy et al. (2016) assessed 26 models in Malaysia. These evaluations reinforce the importance of regional calibration and validation of ET models to improve accuracy.

India's water scarcity issues amplify the urgency of accurate ET estimation. With just 2.4% of the world's land and 4% of its water resources, India supports 16% of the global human population and 20% of the cattle population. The country's total utilizable surface and groundwater resources are estimated at 690 and 396 billion cubic meters (BCM), respectively. The per capita water availability has decreased

[1,4]M. Tech. Scholar, Division of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, SKUAST-K, Shalimar
[2]Associate Professor, Division of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, SKUAST-K, Srinagar
[3]Associate Professor, Division of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, SKUAST-J, Jammu.
*Corresponding Author E-mail: ypandey@skuastkashssmir.ac.in

from 2309 m³ in 1991 to 1902 m³ in 2001 and is projected to decline further to 1401 m³ in 2025 and 1191 m³ by 2050 (Kumar et al., 2005). These figures highlight the critical need for water-efficient agricultural practices and resource planning. To achieve maximum yield and minimize soil moisture stress, it is advisable to adjust the irrigation interval according to the crop's growth stage. This ensures that water availability is optimized and doesn't limit yield potential (Pandey et al., 2023). One effective method to improve irrigation efficiency is through the estimation of crop water requirements using the crop coefficient (Kc) approach. The Kc method involves multiplying ETo by a crop-specific coefficient that accounts for crop physiology, growth stage, local climate, and management practices (Allen et al., 1998). Wright (1982) emphasized that Kc values are influenced by various factors including irrigation frequency, soil type, weather conditions, and agronomic practices. Kang et al. (2003) also noted that Kc values are location-specific and can vary significantly with local climate and soil characteristics.

To estimate evapotranspiration accurately, it is essential to develop crop coefficients (Kc) for different models (Pandey et al., 2023). According to Allen et al. (1998), there are two methods to determine crop coefficients: single and dual crop coefficient approaches. The single Kc method combines crop transpiration and soil evaporation into one coefficient. The dual Kc method separates evapotranspiration into basal crop coefficient (Kcb), representing transpiration under non-stressed conditions, and the soil evaporation coefficient (Ke), accounting for evaporation from the soil surface. Allen et al. (2011) highlighted that the dual approach provides greater accuracy, especially in quantifying the effects of irrigation or precipitation-induced soil wetting and practices like mulching. Evaporation of water from the soil plays a significant role in the soil water balance, particularly during early growth stages or in fallow fields. Methods for estimating evaporation include micrometeorological, water balance, and lysimetric approaches (Naidu and Majhi, 2019). Lysimeters either weighing or non-weighing types are essential tools for directly measuring ETc. Drainage-type lysimeters estimate ETc by measuring the volume of water added and lost from the system, providing a reliable yet practical alternative for field-scale studies. Because ETc varies with crop type, canopy cover, and environmental conditions, accurate local estimation of Kc is vital for efficient irrigation scheduling and water use planning (Jagtap and Jones, 1989).

MATERIALS AND METHODS

A field experiment was conducted at the experimental farm of the College of Agricultural Engineering and Technology (COAE&T), Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar during kharif 2022.

Metrological Observations

The metrological data during tomato growth period were acquired from the Agro metrology field unit (AMFU) observatory, SKUAST-K, Shalimar. The mean monthly meteorological observations recorded during the entire crop growth period are graphically represented in Fig 1. The climatic data made it clear that during the crop growth period, the mean maximum temperature was 28.0°C and the mean lowest temperature was 14.78°C. Throughout the entire crop growth season, 14.7 mm of rain on average were observed. During the crop growth period, there were 6.04 hours of sunshine per day on average, with a relative humidity of 77.4%.

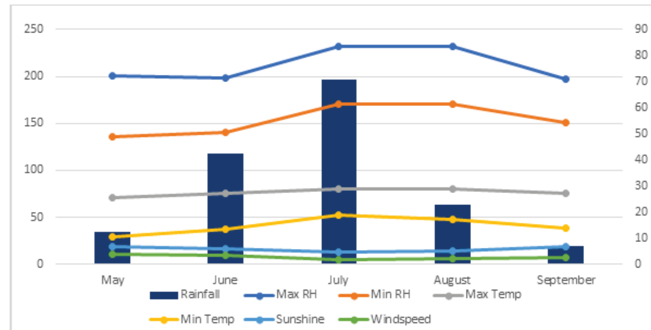

Fig. 1: Monthly metrological data from May to September 2022

Design and Lysimeter Description

The ease of fabrication, simple installation, low maintenance, and low cost were also important parameters in the design of the lysimeter. The use of readily available materials and components helped to keep costs low, and a simple design allowed fabrication with common tools.

Drainage type lysimeter was used for the study with the following dimensions:

Length = 72 cm

Breadth = 62 cm

Height = 51cm

Installation of the Lysimeter

The installation was completed by inserting the lysimeter into the hole created and filling it with the removed dirt. The tank was placed in the hole that had been dug and lowered into it. To make sure the tank was level on the bottom of the hole, it was examined. A mesh fabric measuring approximately 0.20 mm was positioned at the bottom of the lysimeter, upon the hole that had been drilled, to serve as a filtering mechanism and restrict the movement of items from the soil into the drain pipe. The mesh cloth was first laid over the hole to form the filter, then gravel, and finally sand. The earth was then refilled into the tank to the level it had been excavated from. A freeboard of approximately 5 cm from the ground surface was permitted in the installation. A 15-litre bucket was used as the reception vessel, and it was positioned in a nearby hole to collect the percolated water. An initial test was performed to determine the lysimeter's capacity to contain water without leaking. This was accomplished by adding water to the tank and watching it for a few hours.

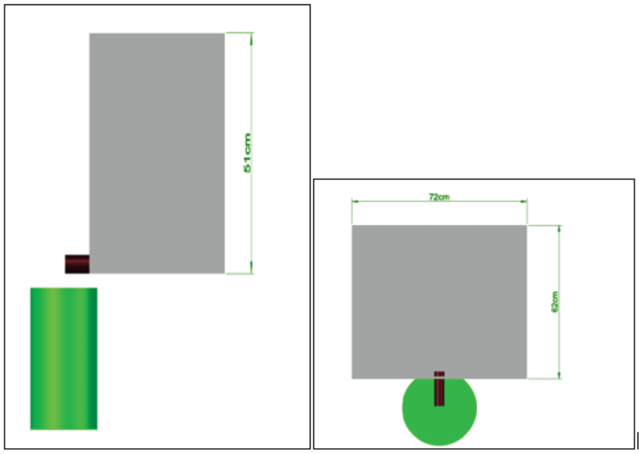

Fig. 2: Isometric view, side view and top view of drainage lysimeter

Determination of Reference Evapotranspiration

The reference evapotranspiration (ETo) was calculated by using different methods i.e, FAO Penman-Monteith method, Hargreaves Method, Blaney Criddle Method and FAO-24 open pan (1977) Method and is given as;

Penman-Monteith method

$$ET_O = \frac{0.408\Delta\,(Rn - G) + V\frac{900}{Tmean+273} + u2\,(es - ea)}{\Delta + V(1+0.34u2)}$$

Where,

ET_O = reference evapotranspiration (mm/day),
R_n = net radiation at the crop surface ($MJ/m^2/day$),
G = soil heat flux density ($MJ/m^2/day$),
T = mean daily air temperature at 2m height (°C),
u_2 = wind speed at 2m height (m/s),
e_s = saturation vapour pressure (kPa),
e_a = actual vapour pressure (kPa),
e_s-e_a = vapour pressure deficit (kPa),
Δ = slope of saturation vapour pressure curve (kPa/°C),
γ = psychrometric constant (kPa/°C).

Hargreaves Method: The following equation will be used in this method:

ETO = 0.0023(Tm+17.8) (Tmax-Tmin)0.5Ra

Where,

ETO = reference crop evapotranspiration (mm day-1)
Tm = daily mean temperature (°C)
Tmax = daily maximum temperature (°C)
Tmin = daily minimum temperature (°C)
Ra = extra-terrestrial radiation (MJ m2 day-1)

Blaney Criddle Method: Using Blaney Criddle Method PET can be expressed as follows:

ETo = P (0.46T+8)

Where,

ETo = reference crop evapotranspiration (mm day-1)
P = monthly percent of total daytime hours of the year
T= m ean monthly air temperature (°C)

FAO-24 open pan (1977) Method: PET can be estimated from pan evaporation as:

$$ET_O = E_{pan} \times K_p$$

Where,

ETo = reference crop evapotranspiration (mm day-1)
Epan = pan evaporation (mm day-1)
Kp = pan coefficient

Estimation of Single Crop Coefficient

Crop coefficient is defined as the ratio of actual crop evapotranspiration to the reference evapotranspiration. In single crop coefficient approach, the effect of both actual crop transpiration and soil evaporation are integrated into a single crop coefficient

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

Estimation of Dual Crop Coefficient

In dual crop coefficient approach, the basal crop coefficient (Kcb) and the soil evaporation coefficient (Ke) will be estimated separately. The basal crop coefficient (Kcb) is defined as the ratio of crop evapotranspiration to reference evapotranspiration (i.e. ETc/ET0) when the soil surface is dry, but transpiration is occurring at a potential rate and water is not a limiting factor in the root zone. In dual crop coefficient approach, the Kc is the sum of Kcb and Ke given by:

Kc = Kcb + Ke

Crop Evapotranspiration Estimation (ETC)

Using CROPWAT 8.0 software (based on Penman- Monteith method) reference evapotranspiration was estimated for respective crop duration. The stage- wise values of KC for different crops were obtained from FAO drainage paper number 56. Thus, ETC was calculated from following equation.

ETC = KC× ETo

Where,

ETC = Crop evapotranspiration (mm),
KC = Crop coefficient,
ETO = Reference crop evapotranspiration (mm).

Statistical Analysis

Various empirical techniques and the lysimeter technique will be assessed using a variety of model evaluation statistics, including the Nash Sutcliffe efficiency (NSE), the root mean square error (RMSE), and the coefficient of correlation (r).

RESULTS AND DISCUSSION

Stage Wise Mean Reference Evapotranspiration (Eto) at Shalimar Using Different Methods

The stage wise mean reference evapotranspiration was found using different empirical methods and it is presented in Fig. 3. It was found that the PET was found to be highest in development stage of Penman Monteith method i.e. 3.75 mm/day and lowest in late stage of Hargreaves method i.e. 2.68 mm/day. The result from Penman Monteith was found to be 3.52 mm/day, 3.75 mm/day, 3.40 mm/day and 3.15 mm/day. For initial, development, mid and late stages, respectively. The result from Modified Hargreaves was found to be 3.18 mm/day, 3.36 mm/day, 2.88 mm/day and 2.68 mm/day for initial, development, mid and late stages, respectively. The result from Blaney Criddle was found to be 3.71 mm/day, 3.56 mm/day, 3.06 mm/day and 3.01 mm/day and from open pan method ETo was found to be 3.65 mm/day, 3.14 mm/day, 2.86 mm/day and 3.12 mm/day for initial, development, mid and late stages, respectively.

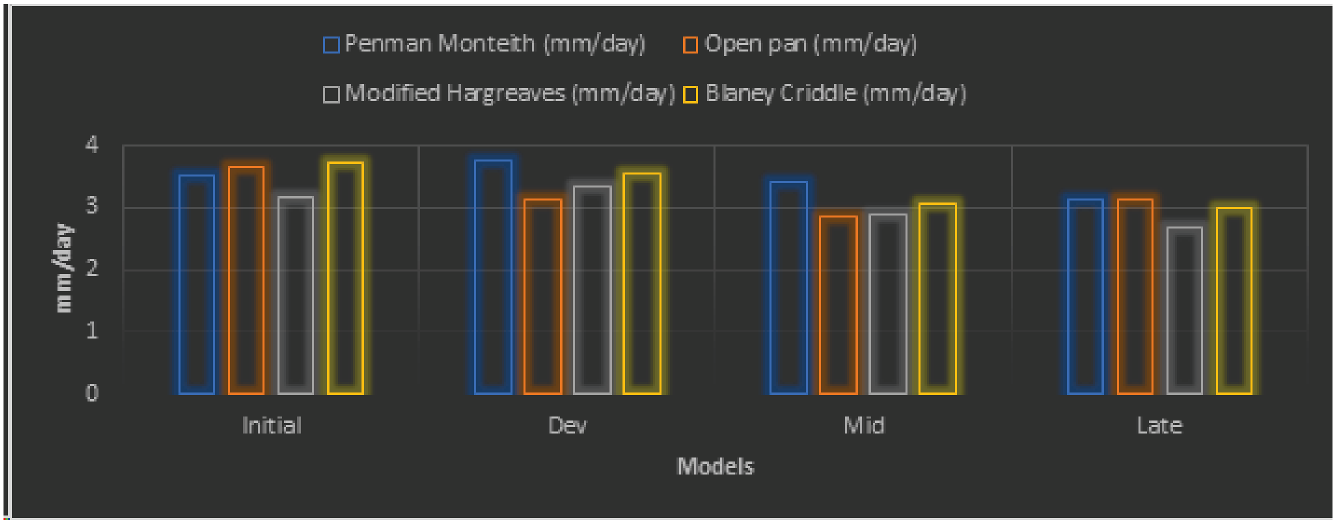

Fig. 3: Stage wise Reference evapotranspiration by using different methods

Stage Wise Mean Crop Evapotranspiration (ETc) by Using Lysimeter and Empirical Methods

The stage wise mean ETc was calculated by different empirical methods by multiplying the reference evapotranspiration with crop coefficients given in FAO-56 and by lysimeter using water balance equation. The stage wise mean crop evapotranspiration is presented in Table 1. It was observed from the table that the ETc was found to be highest in mid stage of Penman Monteith method i.e., 3.61 mm/day and lowest in initial stage of Modified Hargreaves method i.e., 1.91 mm/day.

Table 1: Stage wise mean Crop evapotranspiration (ETc) by using lysimeter and empirical methods

Stages	Penman Monteith (mm/day)	open pan (mm/day)	Modified Hargreaves (mm/day)	Blaney Criddle (mm/day)	Lysimeter (mm/day)
Initial	2.06	2.19	1.91	2.23	2.04
Dev	3.33	3.08	3.30	3.49	3.09
Mid	3.61	3.29	3.32	3.53	3.78
Late	2.49	2.5	2.15	2.41	2.39

Table 2: Comparison of Measured and Modeled ETc Using Penman–Monteith Method

Stage	Method	Mean Lysimeter	Mean Method	Variance Lysimeter	Variance Method	Observations	z	P(Z<=z) one-tail	z Critical one-tail	P(Z<=z) two-tail	z Critical two-tail	Statistical Significance (5%)
Initial	Penman Monteith	2.048	1.962	0.48	0.63	30	0.447	0.327	1.645	0.655	1.96	No significant difference
Initial	Hargreaves	2.048	1.962	0.48	0.63	30	0.447	0.327	1.645	0.655	1.96	No significant difference
Initial	Blaney Criddle	2.048	2.232	0.48	0.49	30	-1.024	0.153	1.645	0.306	1.96	No significant difference
Initial	Open Pan	2.048	2.194	0.48	0.41	30	-0.847	0.199	1.645	0.397	1.96	No significant difference

Stage	Method	Mean Lysimeter	Mean Method	Variance Lysimeter	Variance Method	Observ ations	z	P(Z<=z) one-tail	z Critical one-tail	P(Z<=z) two-tail	z Critical two-tail	Statistical Significance (5%)
Dev	Penman Monteith	3.097	3.334	0.788	0.969	40	-1.129	0.13	1.645	0.259	1.96	No significant difference
Dev	Hargreav es	3.097	3.3	0.78	0.65	40	-1.095	0.137	1.645	0.274	1.96	No significant difference
Dev	Blaney Criddle	3.294	3.53	1.48	0.86	40	-0.976	0.165	1.645	0.329	1.96	No significant difference
Dev	Open Pan	3.097	3.081	0.78	0.65	40	0.088	0.465	1.645	0.93	1.96	No significant difference
Mid	Penman Monteith	3.294	3.617	1.48	1.25	40	-1.234	0.109	1.645	0.217	1.96	No significant difference
Mid	Hargreav es	3.294	3.326	1.48	1.17	40	-0.123	0.451	1.645	0.902	1.96	No significant difference
Mid	Blaney Criddle	3.294	3.53	1.48	0.86	40	-0.976	0.165	1.645	0.329	1.96	No significant difference
Mid	Open Pan	3.294	3.3	1.48	1.17	40	0.021	0.492	1.645	0.983	1.96	No significant difference
Late	Penman Monteith	2.392	2.492	0.41	0.43	20	0.49	0.312	1.645	0.624	1.96	No significant difference
Late	Hargreav es	2.392	2.15	0.41	0.57	20	1.091	0.138	1.645	0.275	1.96	No significant difference
Late	Blaney Criddle	2.392	2.377	0.48	0.71	20	0.06	0.476	1.645	0.952	1.96	No significant difference
Late	Open Pan	2.392	2.515	0.41	0.34	20	0.639	0.261	1.645	0.523	1.96	No significant difference

The z-test summary table comprehensively analyzes the agreement between lysimeter-measured and empirically calculated crop evapotranspiration (ETc) for tomato across all growth stages in the temperate region of Kashmir. Four empirical methods Penman Monteith, Hargreaves, Blaney Criddle, and Open Pan were assessed against direct lysimeter observations during the initial, development, mid, and late phases shown in Table 2. For each method and stage, the mean ETc values, variances, and z-test statistics were calculated to determine if the differences were statistically significant at the 5% level. Across all paired comparisons, the computed z-values were consistently lower than the critical thresholds, and P-values exceeded 0.05, indicating no significant difference in any case. This result shows strong agreement between direct measurement and modeling approaches for ETc estimation. The absence of statistical difference validates those empirical models can reliably estimate water requirements for tomato under local agro-climatic conditions. This enhances confidence in using these models for practical irrigation scheduling and strategic water resource planning.

The consistent outcome across all stages and methods demonstrates their robustness for decision support in agriculture. These findings reinforce the practicality of empirical ET models as a scientific basis for managing crop water needs efficiently in the region.

Single and Dual Crop Coefficients of Tomato

Single crop coefficient (Kc) for tomato during Kharif (2022) was estimated to be 0.54, 0.85, 1.04 and 0.62 for initial (0-30DAS), development (31-70), mid (71-110 DAS), late (111-130 DAS) stages, respectively as shown in Fig 4 and for dual Kc (Kcb+Ke) the value of basal crop coefficient (Kcb) was 0.52, 0.83, 1.01 and 0.59 and the soil evaporation component (Ke) was 0.21, 0.4, 0.13 and 0.18 for initial, development, mid and late stages, respectively.

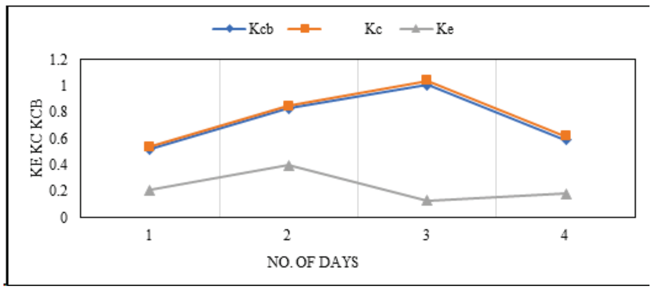

Fig. 4: Variation of crop coefficient (Kc), basal crop coefficient (Kcb) and evaporation Variation of crop coefficient (Kc), basal crop coefficient (Kcb) and evaporation component of crop coefficient (Ke) during kharif 2022

CONCLUSION

During the crop growth period, reference evapotranspiration (ET_0) varied across methods and stages. Penman–Monteith consistently recorded higher values (3.15–3.75 mm/day) compared to other approaches, followed by Blaney–Criddle, Open Pan, and Hargreaves, which generally showed lower estimates. Overall, ET_0 values were maximum during the developmental stage and minimum during the end stage across all methods. Crop evapotranspiration (ETc) showed variation among methods across growth stages. During the initial stage, values ranged between 1.91–2.23 mm/day, with lysimeter and Penman–Monteith closely aligned. In the mid and developmental stages, ETc was higher (3.08–3.61 mm/day), with Blaney–Criddle and Penman–Monteith giving slightly higher estimates than the lysimeter, while Open Pan recorded comparatively lower values. Overall, lysimeter readings were in close agreement with Penman–Monteith across stages. Results showed that tomato water use was dominated by transpiration compared to soil evaporation, emphasizing the need to adopt technologies that reduce soil moisture loss. Both single and dual Kc values differed from FAO standards, confirming the importance of developing region-specific Kc values for accurate scheduling. The lysimeter experiment at SKUAST-K (May–Sept 2021) provided valuable data on actual evapotranspiration, transpiration, and soil evaporation, supporting efficient water management for tomato crops. The study highlighted that while the single crop coefficient method is simpler, the dual crop coefficient approach is more effective for irrigation scheduling under micro-irrigation systems, ensuring water savings and improved productivity.

REFERENCES

Allen R G, Pereira L S, Howell T A and Jensen M E. 2011. Evapotranspiration information reporting: II. Recommended documentation. Agricultural Water Management 98(6): 921-929.

Allen R G, Pereira L S, Raes D and Smith M. 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FAO, Rome, 300(9): D05109.

Djaman K, Balde A B, Sow A, Muller B, Irmak S, N'Diaye M K, Manneh B, Moukoumbi Y D, Futakuchi K and Saito K. 2015. Evaluation of sixteen reference evapotranspiration methods under sahelian conditions in the Senegal River Valley. Journal of Hydrology: regional studies 3: 139-159.

Doorenbos J and Pruitt W O. 1975. Revised (1977) Crop water requirements. Irrigation and Drainage Paper no. 24, FRO, Rome.

Hargreaves G H and Samani Z A. 1985. Reference crop evapotranspiration from temperature. Applied engineering in Agriculture 1(2): 96-99.

Howell T A, Schneider A D and Jensen M E. 1991. History of lysimeter design and use for evapotranspiration measurements. Lysimeters for evapotranspiration and environmental measurements 1-9.

Jagtap S S and Jones J W. 1989. Stability of crop coefficients under different climate and irrigation management practices. Irrigation Science 10(3): 231-244.

Kang S Z, Davies B, Shan L and Cai H. 2003. Water-saving agriculture and sustainable use of water and land resources. Shaanxi Science and Technology Press, Xian, PR China.

Kumar K, Gupta S C, Baidoo S K, Chander Y and Rosen C J. 2005. Antibiotic uptake by plants from soil fertilized with animal manure. Journal of environmental quality 34(6): 2082-2085.

Muniandy J M, Yusop Z and Askari M. 2016. Evaluation of reference evapotranspiration models and determination of crop coefficient for Momordica charantia and Capsicum annuum. Agricultural Water Management 169: 77-89.

Naidu D and Majhi B. 2019. Reference evapotranspiration modeling using radial basis function neural network in different agro-climatic zones of Chhattisgarh.

Journal of Agrometeorology 21(3): 316-326.

Pandey Y, Dadhich S M and Singh P K. 2023. Estimating Irrigation scheduling for Cabbage (Brassica oleracea) using the CROPWAT 8.0 Model in the Temperate Region of Kashmir. Journal of Community Mobilization and Sustainable Development 18(3): 1031-1038.

Pandey Y, Mehraj N, Dadhich S M, Akhtar Y and Lateef Z. 2023. Estimation of Crop-coefficients and Evapotranspiration of Field Pea (Pisum sativum L.) Using Lysimeter and Empirical Models under Temperate Climate. International Journal of Environment and Climate Change 13(11): 2751-2758.

Thornthwaite C W. 1948. An approach toward a rational classification of climate. Geographical review 38(1): 55-94.

Wright J L. 1982. New evapotranspiration crop coefficients. Journal of the Irrigation and Drainage 108(1): 57-74.

Citation:
Mir Z A, Pandey Y, Dadhich S M and Nazir N B.2025. Assessment of crop coefficients for tomato in temperate region of Kashmir. Journal of AgriSearch 12(3): 169-175.