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Assessment of Actual Crop Evapotranspiration and Crop Coefficient in Onion (*Allium cepa* L.) using a Digital Weighing Lysimeter

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Abstract

This study investigates the actual crop evapotranspiration (ET_c) and crop coefficient (K_c) of Onion (*Allium cepa* L.) crop during Rabi season of 2023-24. Actual crop evapotranspiration (ET_c) was estimated with the help of digital weighing lysimeter further to estimate crop coefficient (K_c). Reference evapotranspiration (ET_r) was estimated by six (06) different methods such as Penman-Monteith Method, Hargreaves-Samani method, Modified Penman method, Priestly Taylor method, FAO radiation method and Pan Evaporation method. The seasonal ET_r obtained were 449.46, 583.14, 524.31, 667.27, 640.94 and 612.24 mm respectively. The highest correlation (R^2=0.90) was found in Modified Penman Monteith method while standard Penman-monteith method also did well (R^2=0.81). Crop evapotranspiration (ET_c) was estimated using the digital weighing lysimeter data ranging between 1.17 to 6.31 mm day^{-1} 346.62 mm for the entire season. Crop coefficients (K_c) were derived by taking the ratio of crop evapotranspiration (ET_c) to reference evapotranspiration (ET_r). Based on these ratios, polynomial regression models were created to predict daily Kc values as a function of the crop growth ratio ($t\ T^{-1}$), where "t" represents the current growth stage and "T" represents the total growth period. The stage-wise Kc was obtained i.e. initial, mid, development and end season for Penman-monteith method 0.73, 1.18, 1.31 and 0.97 respectively, for Hargreaves-Samani method 0.60, 1.01, 1.08 and 0.65 respectively, for Modified Penman method 0.63, 1.00, 1.11 and 0.75 respectively, for Priestly Taylor method 0.63, 1.03, 1.07 and 0.64 respectively, for FAO radiation method 0.67, 0.95, 1.00 and 0.62 respectively, for Pan Evaporation method 0.76, 1.07, 1.11 and 0.83 respectively. The seasonal Kc values are 1.09, 0.90, 0.92, 0.91, 0.87 and 0.98 respectively.

Key words : Onion crop coefficient, digital weighing lysimeter, crop evapotranspiration, reference evapotranspiration.

Onion (*Allium cepa* L.) botanically belongs to the Amaryllidaceae family. It has been valued as a food and a medicinal plant since ancient times. It is widely cultivated, second only to tomato, and is a vegetable bulb crop known to most cultures and consumed worldwide (FAO,2012). Total world production of onions exceeds 100 million metric tons annually. It is short duration horticultural crop (Brewster,1990) grown at low latitudes. It is commonly known as “Queen of the kitchen” due to its highly valued flavour, aroma, and unique taste, and the medicinal properties of its flavour compounds (Selvaraj,1976; Griffiths et al.,2002). As the largest producer of onions, India accounts for over 25% of the world’s total onion production, producing around 20 million metric tons annually. Onions are grown in over 5 million hectares globally. India, being the largest producer, also holds the largest cultivated area for onions, with around 1.5 million hectares dedicated to its cultivation. Other major producers like China, the United States, and Egypt have substantial areas under onion cultivation, though India's area stands out due to its production volume. India is not only the largest producer but also the largest exporter of onions. The country leads the world in both onion production and cultivated area, making it a crucial player in the global onion market. The onion crop is grown in Maharashtra, Karnataka, and Madhya Pradesh being the top contributors.

Reference Evapotranspiration (ET_r) is one of the main components of hydrologic cycle. The commonly used methods for estimating ET_r are Penman Monteith method (Allen et al.,1998), Hargreaves Samani method (Hargreaves and Samani, 1985), Priestly-Taylor method (Priestly and Taylor,1972), Modified Penman method (Doorenbos and Pruitt,1977) and FAO Radiation Method (Doorenbos and Pruitt,1977). Each method has its advantages and limitations, and the selection of an appropriate method depends on the availability of meteorological data, computational resources, calculation complexities and the desired level of accuracy.

The crop evapotranspiration under standard conditions, denoted as ET_c, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. It can be directly measured using Lysimeters by isolating the crop root zone from its environment and controlling the processes that are difficult to measure, the different terms in the soil water balance equation can be determined with greater accuracy. In precision weighing lysimeters, the water loss is directly measured by the change of mass, evapotranspiration can be obtained with an accuracy of a few hundredths of a millimetre, and small time periods such as an hour can be considered.

The crop coefficient (K_c) is basically defined as the ratio of actual evapotranspiration and grass/alfalfa reference evapotranspiration and always measured by lysimeter in localized area in the field, which then generalized on the whole irrigated land. The K_c values represent the integrated effects of changes in leaf area, plant height, crop characteristics, irrigation method, rate of crop development, crop planting date, degree of canopy cover, canopy resistance, soil and climate conditions, and management practices. Each crop will have a set of specific crop coefficient and will predict different water use for different crops for different growth stages. In general, crop growth stages can be divided into four main growth stages: initial, crop development, mid-season, and late season. The length of each of these stages depends on the climate, latitude, elevation, planting date, crop type, and cultural practices. Local field observations are best for determining the growth stage of the crop and adjust the empirical Kc values accordingly. Hence, 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. Therefore, on realizing importance of estimation crop coefficient as a ratio crop evapotranspiration to reference evapotranspiration at the local level the study on, " Assessment of Actual Crop Evapotranspiration and Crop Coefficient in Onion (*Allium cepa* L.) using a Digital Weighing Lysimeter " was conducted.

Materials and Methods

Location of Study Area : The field experiment on "Assessment of Actual Crop Evapotranspiration and Crop Coefficient in Onion (*Allium cepa* L.) using a Digital Weighing Lysimeter" was conducted at Lysimeter complex, RKVY-IWRAS, AICRP on Irrigation Water Management, Mahatma Phule Krishi Vidyapeeth, Rahuri for onion crop during Rabi season of 2023-2024. The geographical location of study area is presented in Plate 1.

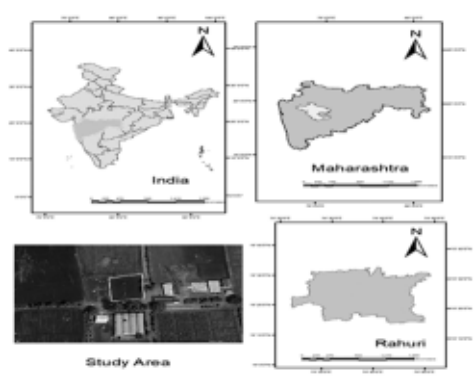


Plate 1. Geographical location of study area

Crop details:

Name of crop	: Onion
Botanical name	: *Allium cepa* L.
Crop growing season	: *Rabi* 2023-2024
Variety	: N-2-4-1
Crop spacing	: 20 cm x 15 cm
Sowing date	: 15/01/2024
Crop duration	: 90 days (3 months)
Irrigation	: Surface irrigation
Year of experiment	: 2023-2024

Meteorological data : Daily weather data obtained from Indian Meteorological Department (IMD) observatory located at AICRP on IWM, Mahatma Phule Krishi Vidyapeeth, Rahuri. The data include daily maximum and minimum temperature, maximum and minimum relative humidity, wind speed, sunshine hours during crop growth period of Onion crop. These data be used to calculate reference evapotranspiration (ET_r).

Table 1. Weather data

Weather parameter	Maximum value	Minimum value	Average value
T Min	27.3	7.9	18.1
T Max,	40.6	26.2	34.1
RH Min,	45	11	24
RH Max,	88	35	67
Sunshine hours, hrs day^{-1}	11.2	5.4	9.2
Wind speed, km hr^{-1}	5.1	0.2	1.6
Open pan evaporation, mm	9.6	4.6	7.3

Estimation of Reference evapotranspiration (ET_r) : Reference evapotranspiration (ETr) is defined as, the rate at which water evaporates from a hypothetical, well-watered crop surface. ETr is obtained with the help of Phule Jal application by the formulae mention in Table 2.

Estimation of ETc using Weighting Type Lysimeter : Crop evapotranspiration (ETc) is defined as, the amount of water lost through evaporation and transpiration from crops grown in ideal conditions.

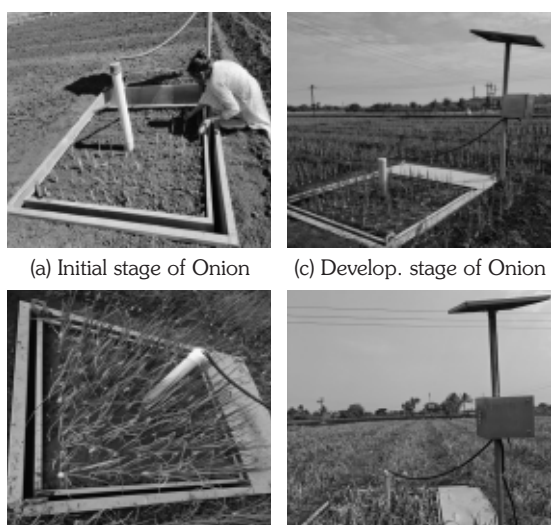
$$ETc = P + I \pm \Delta S - D$$

Crop coefficient (K_c) : Crop coefficient (K_c) is defined as, the ratio of crop evapotranspiration (ETc) to reference evapotranspiration (ETr)

$$Kc = ET_c / ET_r$$

Table 2. Different methods of estimation of ET_r in Phule Jal application

Method	Formula
Penman Monteith	$ETr = \frac{0.408.\Delta(Rn - G) + \gamma \frac{900}{T+273} u2(es - ea)}{\Delta + \gamma(1 + 0.34u2)}$
Hargreaves-Samani	$ET_r = 0.0023.\ (T_o mean + 17.8).\ (Tmax - Tmin).\ Ra$
Modified Penman	$ET_r = W.\ Rn + (1\text{-}W).\ f(u).\ (Ea\text{-}ed)$
Priestly Taylor	$ET = \alpha \frac{\Delta}{\Delta + \gamma}\ (R_n\text{-}G)$
FAO radiation	$ET_r = C[\frac{\Delta}{(\Delta+\gamma)} x \frac{Rs}{\lambda}]$
Pan Evaporation method	$ET_r = C[\frac{\Delta}{(\Delta+\gamma)} x \frac{Rs}{\lambda}]$



(a) Initial stage of Onion (c) Develop. stage of Onion

(b) Mid-season of Onion (d) Harvesting of Onion

Plate 1. Estimation ET_c by digital weighing lysimeters

Table 3. Descriptive statistics of ET_r by different methods

Descriptive statistics	ET_r - PM	ET_r - HS	ET_r - MP	ET_r - PT	ET_r - FAO	ET_r - PE
Minimum	2.45	4.31	3.20	4.61	4.30	3.68
Maximum	6.67	6.69	7.79	7.86	8.75	8.64
Mean	4.45	5.77	5.19	6.61	6.35	6.06
Standard Error	0.11	0.05	0.11	0.05	0.11	0.10
Standard Deviation, SD	1.09	0.54	1.07	0.51	1.07	0.97
Coefficient of Variance, CV (%)	24.60	9.39	20.56	7.79	16.85	16.08
Count	100	100	100	100	100	100

Table 4. Regression line slope (m), intercept (c) and coefficient of determination for linear regression model between ET_r obtained using various employing different methods

Parameters	ET_r - PM	ET_r - HS	ET_r - MP	ET_r - PT	ET_r - FAO	ET_r - PE
m	0.03	0.01	0.03	0.009	0.33	0.01
c	2.73	5.06	3.43	6.11	4.63	5.41
R^2	0.81	0.56	0.90	0.31	0.85	0.14

Table 5. Statistical comparison of ET_r estimated using different methods

	PM X MPM	PM X HS	PM PT	PM X FAO	PM X PE
R^2	0.78	0.55	0.34	0.73	0.22
D	0.83	0.42	0.19	0.50	0.3
RMSE	0.91	1.53	2.33	1.99	1.97
NRMSE	0.20	0.34	0.52	0.44	0.44

Results and Discussion

Estimation of Reference crop Evapotranspiration (ET_c) of Onion by weighing type lysimeter : Crop evapotranspiration (ET_c) was estimated using digital weighing type lysimeter with water balance techniques during the period from 1.17 to 6.31 mm with a mean value of 3.47 mm over the Onion crop growing period. The seasonal ETc was 346.62 mm. Daily ETc values showed high variation during Onion crop growing period with SD of 1.39 and CV of 40.22%.

Crop Coefficients (K_c) of Onion : The ratio of crop evapotranspiration (ETc) to reference crop evapotranspiration (ETr), which is measured using several techniques, is the crop coefficient for onions (Dabral & Rao, 1997). Regression equations of the polynomial kind were created in order to estimate the daily crop coefficients. To create a polynomial regression equation of various orders, daily Kc values were plotted against t T^{-1}, where t is the whole crop period in days and t is the day of the week. The

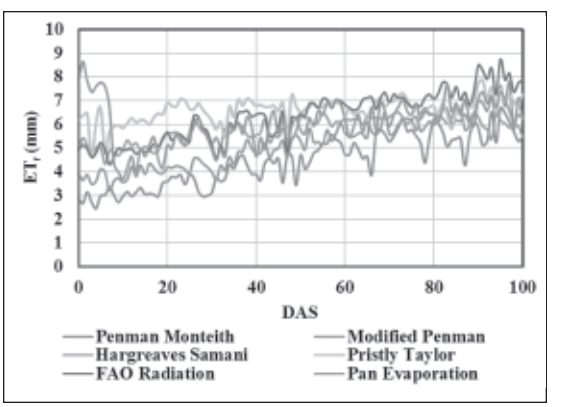
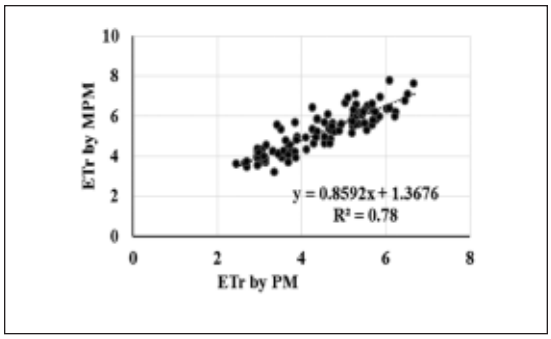
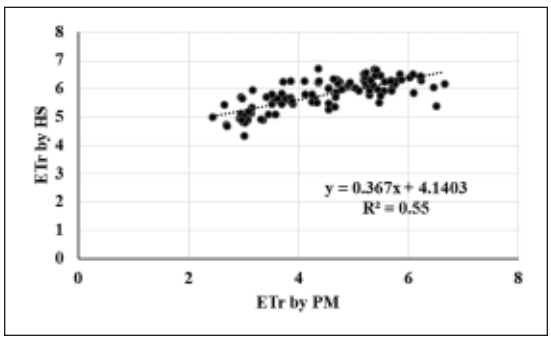


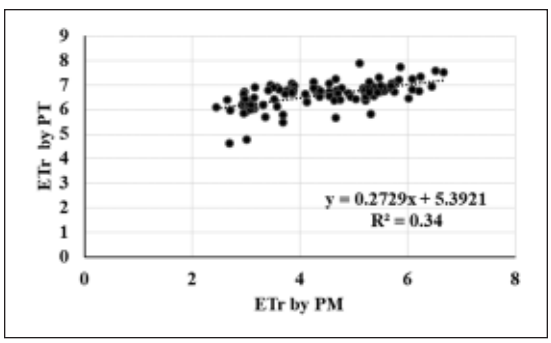
Fig. 1. Daily comparison of ETr calculated using all different methods

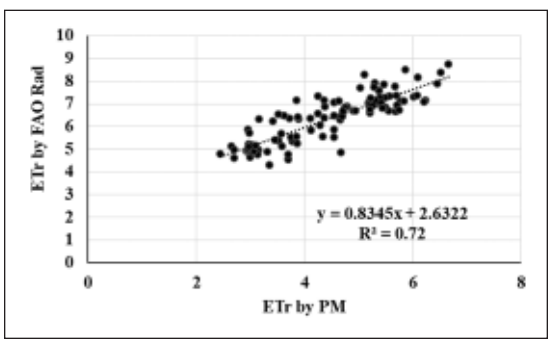
highest coefficient of determination (R^2) value was used to choose the polynomial equations that matched the data the best.

Crop Growth Stage-wise K_c : The daily









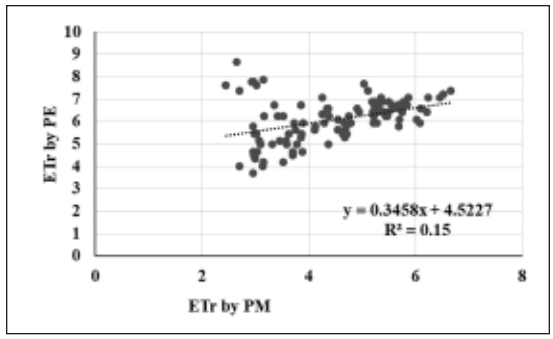


Fig. 2. Comparative analysis of the ET_r calculated using the Penman-Monteith technique, by all other methods

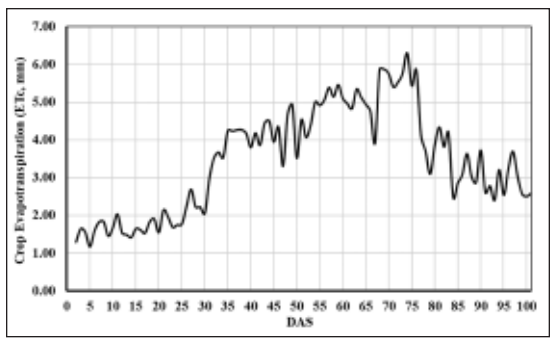


Fig. 5. Daily variation of crop evapotranspiration (ET_c) measured using digital weighing type lysimeter during the Onion crop growing season

Kc values determined by different ETr estimation methods were converted into the critical growth stages by taking the averages for respective stage and Onion crop duration.

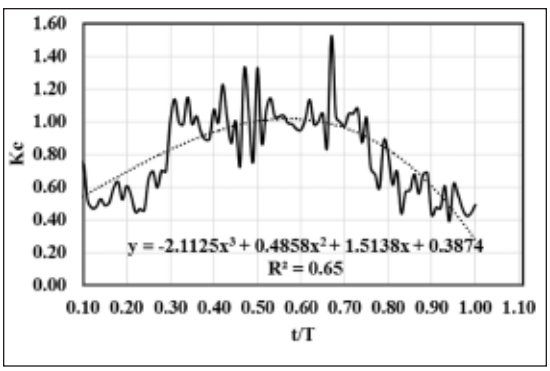
Comparison of estimated K_c : The crop coefficient (K_c) was determined in this study utilizing a variety of techniques, with the Penman-Monteith approach acting as the benchmark for assessing the Index of Agreement (d), Root Mean Square Error (RMSE), and Normalized RMSE (NRMSE). The Kc values calculated using the Modified Penman-Monteith approach (Kc-MPMM) had the best agreement with those obtained using the

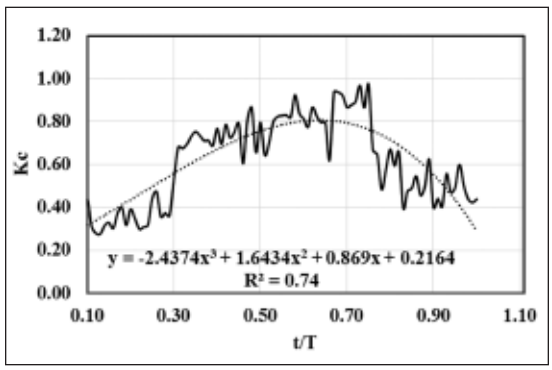
Table 6. Polynomial equations developed for the determination of daily Kc values using different ET_r estimation methods

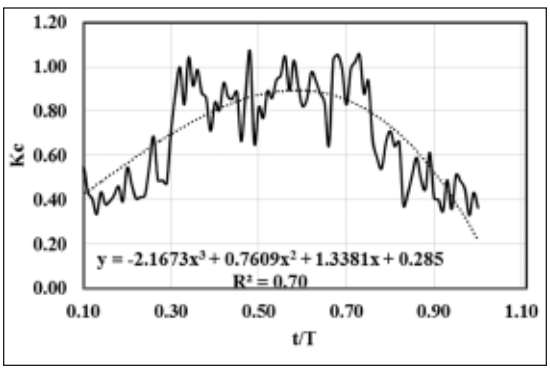
ET_r Method	**Polynomial equation**	**R^2**
Penman Montieth Method (PMM)	$K_c = 3.5198(t/T)^5 + 5.772(t/T)^4 - 23.725(t/T)^3 + 16.724(t/T)^2 - 2.4173(t/T) + 0.6023$	0.72
Modified Penman Monteith Method (MPMM)	$K_c = 8.1271(t/T)^5 - 8.6729(t/T)^4 - 7.6302(t/T)^3 + 9.3035(t/T)^2 - 1.1647(t/T) + 0.4344$	0.76
FAO Radiation Method (FAO Rad)	$K_c = 9.368153\ (t/T)^5 - 14.19453\ (t/T)^4 + 0.080253\ (t/T)^3 + 5.470153\ (t/T)^2 - 0.705953\ (t/T) + 0.3292$	0.76
Priestly Taylor Method (PT)	$K_c = 15.627(t/T)^5 - 30.47(t/T)^4 + 14.432(t/T)^3 + 0.8063(t/T)^2 - 0.2618(t/T) + 0.2651$	0.83
Hargreaves Samani Method (HS)	$K_c = 14.92(t/T)^5 - 26.561(t/T)^4 + 9.0252(t/T)^3 + 3.3252(t/T)^2 - 0.5465(t/T) + 0.323$	0.82
Pan Evaporation Method (PE)	$K_c = 22.008(t/T)^5 - 47.97(t/T)^4 + 33.142(t/T)^3 - 9.113(t/T)^2 + 2.2215(t/T) + 0.1436$	0.78

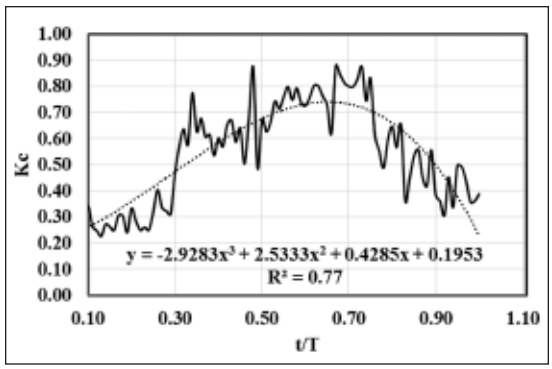
conventional Penman-Monteith approach, as shown in Table 9. Among the approaches compared, this was demonstrated by the lowest RMSE (0.15) and NRMSE (0.19), as well as the greatest Index of Agreement (d = 0.91).

After Kc-MPMM, there was increasingly less agreement between the FAO Radiation method, Priestley-Taylor method, Hargreaves-Samani method, and Pan Evaporation method. Mostly because of differences in the magnitude of ET_r estimates, these results are not the same as the graphical comparison of ET_r values derived using various approaches against the Penman-Monteith method. Higher agreement and lower error indices were helped by the comparatively









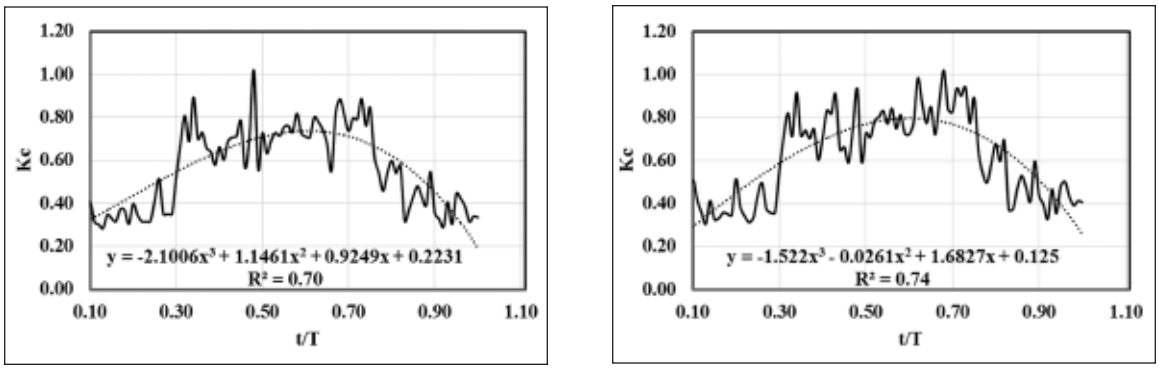


Fig. 3. Graphical representation of best fit polynomial equations for determination of daily K_c all different methods during the Onion crop growing season conclusion, (a) PM, (b) HS, (c) MPM, (d) PT, (e) FAO RAD (f) PE

Table 6. Descriptive Statistics of daily K_c estimated by different methods

Descriptive statistics	Kc -PM	Kc -HS	Kc -MP	Kc -PT	Kc -FAO Rad	Kc -PE
Minimum	0.47	0.45	0.54	0.39	0.74	0.44
Maximum	1.09	0.86	0.95	0.78	0.91	0.73
Mean	0.78	0.71	0.74	0.61	0.78	0.66
Standard Error	0.02	0.01	0.02	0.02	0.00	0.01
Standard Deviation, SD (%)	0.22	0.14	0.15	0.17	0.05	0.08
Coefficient of Variance, CV (%)	28.26	20.00	20.75	28.06	5.79	12.17
Count	100	100	100	100	100	100

Table 7. Stage-wise Kc values of Onion crop by different methods of ET_r estimation

Crop growth stage	Duration	Kc-PM	Kc -HS	Kc -MP	Kc -PT	Kc-FAO Rad	Kc -PE
Initial	20	0.53	0.84	0.58	0.77	0.75	0.70
Development	35	0.91	0.66	0.81	0.56	0.78	0.65
Mid-season	25	0.95	0.60	0.87	0.49	0.79	0.63
End season	20	0.56	0.82	0.62	0.76	0.77	0.67
Seasonal Kc	100	0.66	0.55	0.61	0.47	0.54	0.52

Table 9. Statistical comparison of Kc determined by using different methods with Kc determined by using Penman-Monteith method

Statistical parameter	PM Vs MPMM	PM Vs FAO	PM Vs PT	PM Vs HS	PM Vs PE
d	0.91	0.72	0.68	0.79	0.79
RMSE	0.15	0.26	0.29	0.22	0.23
NRMSE	0.19	0.34	0.37	0.29	0.30

smaller magnitude discrepancies, even if the K_c values obtained by the FAO Radiation approach were numerically similar to those obtained by the Penman-Monteith method. Similar trends were noted with the other approaches.

CONCLUSION

1. Using meteorological data gathered from the

IMD station at the AICRP, Irrigation Water Management during the Onion crop growing period, reference evapotranspiration (ET_r) was estimated using six different methods. The main conclusions for ET_r estimation were: Penman-Monteith Method ET_r ranged from 2.45 to 6.67 mm day^{-1} with a seasonal total of 449.46 mm, respectively; Modified Penman Method ET_r ranged from 3.20 to 7.79 mm day^{-1} with a seasonal total of 524.31 mm, respectively; FAO Radiation Method ET_r ranged from 4.3 to 8.75 mm day^{-1}, seasonal total 640.94 mm, respectively; Priestly-Taylor Method ET_r ranged from 4.61 to 7.86 mm day^{-1}, seasonal total 667.27 mm, respectively; Hargreaves Saman method ETr ranged from 4.31 to 6.69 mm day^{-1}, seasonal total 583.14 mm, respectively.

2. The seasonal ET_c of Onion crop was observed 346.62 mm with the mean value of 3.47 mm by using weighing type of lysimeter.

3. A strong relationship was developed between Kc and the crop growth ratio (t/T), allowing estimation of Kc on a daily basis using different methods. The daily Kc values were averaged for critical growth stages. For the initial, development, mid-season and end-season stages, the K_c values (Penman-Monteith method) were 0.54, 0.91, 0.95 and 0.56, respectively, K_c values (Modified Penman Monteith method) were 0.58, 0.81, 0.87 and 0.62, respectively, Kc values (FAO Radiation method) were 0.75, 0.78, 0.79 and 0.77, respectively, Kc values (Pristly Taylor method) were 0.77, 0.56, 0.49 and 0.76, respectively, Kc values (Hargreaves Samani method) were 0.84, 0.66, 0.60 and 0.82, respectively and Kc values (Pan Evaporation method) were 0.70, 0.65, 0.63 and 0.67, respectively.

Disclaimer (Artificial Intelligence) :

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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