ESTIMATION OF ACTUAL EVAPOTRANSPIRATION AND CROP COEFFICIENT TO IMPROVE WATER USE EFFICIENCY OF SESAMUM (*Sesamum indicum* L.) IN *KHARIF* SEASON USING DIGITAL WEIGHING LYSIMETER

Abstract

The study was conducted on Estimation of Actual Evapotranspiration and Crop Coefficient to Improve Water Use Efficiency of Sesamum (*Sesamum indicum* L.) in *Kharif* Season Using Digital Weighing Lysimeter," was conducted during the 2023-24 *Kharif* season with the aim of enhancing sesamum water use efficiency. For estimation of actual evapotranspiration and crop coefficient following are the objectives were to calculate and compare reference evapotranspiration (ETr) using various methods, measure crop evapotranspiration (ETc) using a digital weighing lysimeter, estimate crop coefficient (Kc) value. ETr was calculated using six different methods: Penman-Monteith, Modified Penman-Monteith, FAO Radiation, Priestly-Taylor, Hargreaves-Samani, and Pan Evaporation. The result obtained from that is the seasonal ETr was found 328.53, 395.47, 369.37, 430.26, 416.04, 372.90 mm respectively. While calculating or estimating reference evapotranspiration it is observed that The Modified Penman Monteith method had the highest correlation (R^2=0.98) with the standard Penman-Monteith method, while the FAO Radiation and Pan Evaporation methods also performed well. crop Evapotranspiration (ETc) of Sesamum crop, measured using a digital weighing lysimeter, ranged from 0.61 to 5.65 mm/day, with a total of 244.94 mm for the season and the Crop coefficients (Kc) values were calculated by ratio of crop Evapotranspiration (ETc) with Reference Evapotranspiration(ETr), from that polynomial regression models were developed to estimate daily Kc values based on the crop growth ratio (t/T). The daily Kc values determined by using the best fit polynomial equations were averaged over initial, development, mid-season and end-season stage, the Kc values developed by using different methods *i.e* (Penman-Monteith method) are 0.58, 0.77, 1.00, and 0.36; Kc values (Modified Penman Monteith method) were 0.48, 0.64, 0.84 and 0.32; Kc values (FAO Radiation method) were 0.61, 0.73, 0.91 and 0.33; Kc values (Priestly Taylor method) were 0.26, 0.61, 0.98 and 0.33; Kc values (Hargreaves Samani method) were 0.36, 0.58, 0.92 and 0.28; and Kc values (Pan Evaporation method) were 0.48, 0.65, 0.93 and 0.32, respectively. On an average Kc determined by Penman Monteith method, Modified Penman Monteith method, FAO Radiation method and Pan Evaporation method overestimated the Kc by 26.17, 7.00, 21.92 and 9.38 per cent, respectively compared to FAO-56 values. However, Priestly-Taylor method and Hargraves-Samani method underestimated Kc by 5.55 and 5.78 per cent, respectively.

Keywords : Sesamum Crop coefficient, Crop evapotranspiration, Weighing type lysimeter.

1. Introduction

Sesamum (*Sesamum indicum* L.) is an annual oil seed crop known as 'The queen of oils' due to its high nutritional, medicinal, cosmetic and cooking qualities (Nirav Parmar *et al.,* 2020). It is cultivated in semi-arid conditions preferably in well drained soils of tropical regions with moderate rainfall. The world sesamum production is 7 million tonnes. India ranks first in area (19.53 lakh ha), production (8.50 lakh tonnes) and export of sesamum in the world. The productivity of sesamum is 463 kg/ha. Sesamum is ranked fourth in terms of total oilseed production and third in terms of total area under oilseed cultivation. Gujarat, West Bengal, Maharashtra, Rajasthan, Tamil Nadu and Karnataka are the leading producers of sesamum. In India, sesame plays a significant role in agriculture, especially during the *kharif* season. In Maharashtra this crop is primarily cultivated in districts of Akola, Chandrapur, Jalgaon, Bhandara, Ahmednagar, Dhule and Osmanabad in Summer and *Kharif* seasons as irrigated and rainfed oil seed crop. However, sesamum cultivation is highly sensitive to water availability, making irrigation water management critical for ensuring optimal growth, yield and productivity. In regions with limited water resources and irregular rainfall patterns, efficient irrigation practices are essential to sustain sesamum production. The irrigation scheduling is the most important parameter in enhancing the production and productivity of sesamum crop.

Reference Evapotranspiration (ETr) serves as a baseline for calculating crop evapotranspiration (ETc), which is specific to the crop and its growth stage. There are several methods available to calculate ETr, including the widely accepted Penman-Monteith method 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), FAO Radiation Method (Doorenbos and Pruitt, 1977) and pan evaporation method. Crop evapotranspiration (ETc) is crucial component of irrigation scheduling and agricultural water management. Accurate estimation of crop evapotranspiration (ETc) is important for determining the precise irrigation requirements of the crop. Experimentally, ETc can be measured with lysimeters. the most reliable methods for measuring ETc is the use of a digital weighing lysimeter, a device that measures the actual water loss from the soil-plant system through evapotranspiration. By using lysimeter data, ETc can be directly measured for sesamum at various growth stages, providing detailed insights into the crop water requirement throughout the crop growth period.

The crop coefficient (Kc) is a critical factor in irrigation water management, as it relates ETc to ETr. Kc values vary according to the growth stage of the crop, reflecting changes in canopy cover, plant water use, root development, rate of crop development, crop planting date, soil type, climate conditions and irrigation management techniques. Allen *et al.* (1998) suggested Kc values of 0.35, 0.74, 1.10 and 0.25 for initial, development, mid-season and end-season stages. However, these Kc values are global averages and use of these Kc values may lead towards the overestimation or underestimation of crop water requirements. Allen *et al.* (1998) advised evaluating crop coefficient values in local climate circumstances using lysimeter data and observed data is necessary to avoid overestimation or underestimation of crop water requirements. Therefore, it is necessary to determine the Kc values for local climate conditions. Additionally, regional variations in climate and environmental factors necessitate the development of region-specific crop coefficients to account for local conditions. Also, the development of accurate Kc values for sesamum at different growth stages is essential for optimizing irrigation schedules and ensuring efficient water use.

Overall, to address the challenges of irrigation water management in sesamum crop cultivation, to identify accurate methods for estimating crop evapotranspiration and crop coefficients the experiment entitled, "Estimation of actual evapotranspiration and crop coefficient to improve water use efficiency of sesamum (*Sesamum indicum* L.) in *Kharif* season using digital weighing lysimeter", is planned and conducted at Climate Smart Research Block at Mahatma Phule Krishi Vidyapeeth, Rahuri during *kharif* season of 2023-2024.

2. Materials And Methods

2.1 Location of study area

The study was conducted at All India Co-ordinate Research Project (AICRP) Irrigation Water management and Climate Smart Research Block of Centre for Advanced Agriculture Science and Technology on Climate Smart Agriculture Water Management, Mahatma Phule Krishi Vidyapeeth, Rahuri during *kharif* season of 2023-2024. The geographical location of study area is presented in Figure 1.

Fig .1 Geographical location of study area

2.2 Crop details

Sesamum crop (*Sesamum indicum* L.) belongs to the Pedaliaceae family. The crop was sown on July 8, 2023 in kharif season with a spacing 30 x 10cm, variety we used for sowing was JLT-408 and the irrigation we applied is surface irrigation. crop was harvested at October 4, 2023 with total crop duration was 95 days.

2.3 Meteorological data

Daily weather data were obtained from Indian Meteorological Department (IMD) observatory located at All India Coordinate Research Project (AICRP) on Irrigation Water Management, Rahuri. The average meteorological conditions over the study area during the *kharif* seasons 2023-2024 is given below:-

It is observed from that Temperature(Tmin) value varies from 20.9 to 25.9 with average value 23.4, Temperature(T Max) value varies from 25.0 to 34.6 with average value 29.8, respectively, Relative Humidity (RH min) values varies from 37 to 88 with average value 62.5, Relative Humidity(RH Max) value varies from 72 to 98 with average value 85.0 respectively, Sunshine hours, hrs/day value varies from 0.0 to 9.9 with an average value 5.0 respectively, wind speed, km/hr with value varies from 0.7 to 7.4 with an average value 4.1 respectively.

2.4 Estimation of reference evapotranspiration (ETr)

For Estimation of crop evapotranspiration and crop coefficient firstly estimate the reference evapotranspiration by using Phule Jal application with five different methods. The methods used to estimate ETr in Phule Jal are described in table 1 as follows;

Table 1 Methods used to estimate ETr in Phule Jal

Sr.No.	Method	Formulae
1.	Penman-Monteith method	$ETr = \frac{0.408 * \Delta * (R_n - G) + \gamma * \left(\frac{900}{T + 273}\right) * U_2 * (e_s - e_a)}{\Delta + \gamma * (1 + 0.34 * U_2)}$
2.	Modified-Penman method	ETr = W. Rn + (1-W). f (u). (ea-ed)
3.	FAO Radiation method	$ET_r = C\left(\frac{\Delta}{(\Delta+\gamma)} \times \frac{Rs}{\lambda}\right)$
4.	Priestly Taylor method	$ET = \alpha\frac{\Delta}{\Delta+}\ (Rn - G)$
5.	Hargreaves-Samani method	$ETr = 0.0023. (T_{mean} + 17.8). (T_{max} - T_{min})^{0.5}. R_a$

2.5 Estimation of ETc using weighting type lysimeter

Crop evapotranspiration (ETc) was estimated using the digital type lysimeter based on the soil water balance equation as given below;

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

Fig 2 Digital weighing lysimeter for estimation of Crop Evapotranspiration

2.6 Estimation of crop coefficient (Kc)

The crop coefficient (Kc) is estimated as the ration of actual crop evapotranspiration to reference crop evapotranspiration as given below;

$$Kc = ETc / ETr$$

2.7 Statistical comparison of crop coefficients

The statistical comparison of Crop coefficient(Kc), Reference crop evapotranspiration is done by using the following parameters as given in the table 2 as below;

Table 2 Statistical comparison of crop coefficients

Sr. No.	Statistical Parameter	Equation
1.	Index of Agreement (d)	$d = 1 - \frac{\Sigma^{n}\ i=1(o_i - p_i)^{\ 2}}{\Sigma_{i=1}^{n}=1(\lvert p_i - o\rvert + \lvert o_i - \bar{o}\rvert^2}$
2.	Root Mean square error (RMSE)	$RMSE = \frac{\sqrt{\Sigma_{i=1}^{n}(o_i - p_i)^2}}{n}$
3.	Normalized Root Mean Square Error (NRMSE)	$NRMSE = \frac{RMSE}{0}$

3. Result and Discussion

3.1 Estimation of ETr by different methods

The reference evapotranspiration (ETr) is estimated by using six different methods in Phule Jal application *viz.* Penman- Monteith Method, Modified Penman- Monteith Method, FAO Radiation Method, Priestly-Taylor Method, Hargreaves-Samani Method and Pan Evaporation Method. The Descriptive statistics of daily ETr estimated by different methods is presented in Table 3. The daily variation of reference evapotranspiration (ETr) estimated by different methods during the sesamum crop growing season presented in Figures 3

Table 3. Descriptive statistics of ETr by different methods

Descriptive statistics	ETr-PMM	ETr-MPMM	ETr-FAO Rad	ETr-PT	ETr-HS	ETr-PE
Minimum	2.20	2.58	2.04	2.28	2.85	1.05
Maximum	5.54	6.06	6.70	7.88	5.22	5.55
Mean	3.46	4.16	3.89	4.53	4.38	3.93
Sum	328.53	395.47	369.37	430.26	416.04	372.90
Standard Error	0.09	0.11	0.16	0.13	0.05	0.08
Standard Deviation, SD (%)	0.90	1.04	1.51	1.29	0.48	0.82
Coefficient of Variance, CV (%)	25.96	24.94	38.90	28.56	10.87	20.82
Count	95.00	95.00	95.00	95.00	95.00	95.00

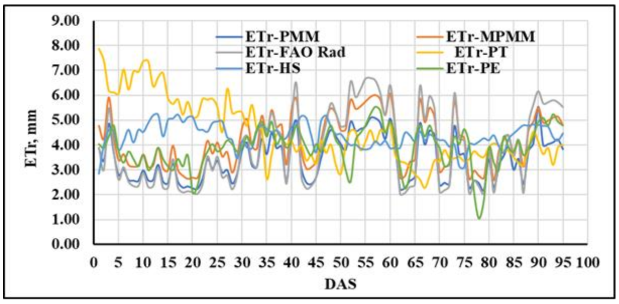

Fig. 3 Daily comparison of ETr calculated using all different methods

The linear regression model is used for the comparison of daily ETr estimated by different methods with ETr estimated using Penman-Monteith method. Linear regression models and corresponding coefficient of determination (R^2) are presented in Figure 4. The regression line slope, intercept and coefficient of regression are presented in Table 4.

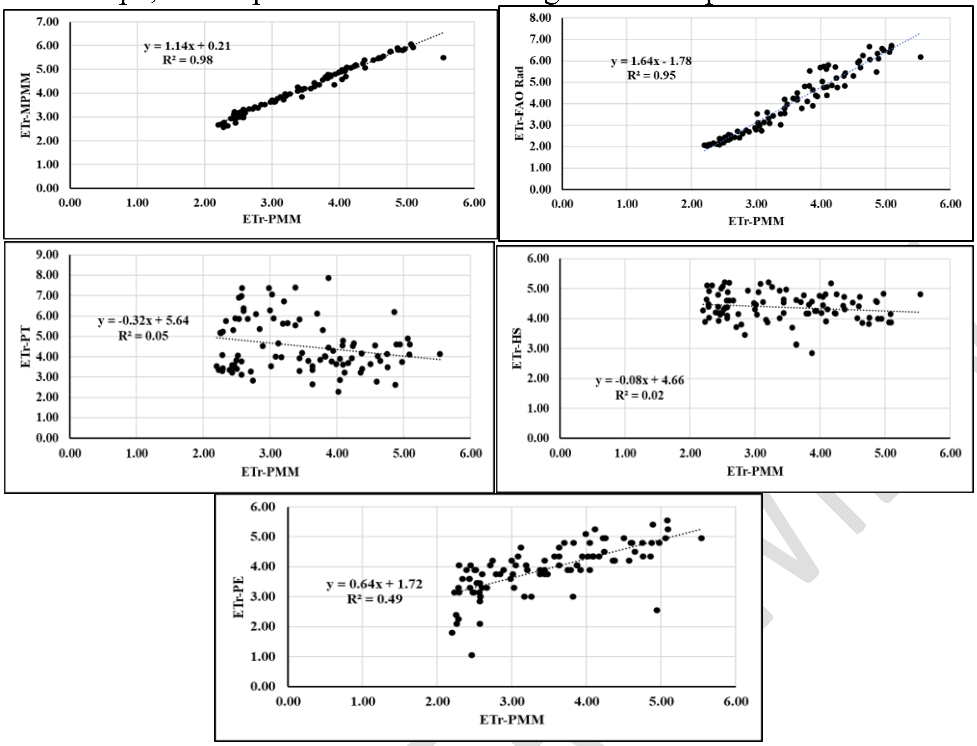

Fig.4 Comparative analysis of the ETr calculated using the Penman-Monteith technique, by all other methods.

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

Parameters	ETr-MPMM	ETr-FAO Rad	ETr-PT	ETr-HS	ETr-PE
m	1.14	1.64	-0.32	-0.08	0.64
c	0.21	-1.78	5.64	4.66	1.72
R^2	0.98	0.95	0.05	0.02	0.49

It is observed from Table 4 that ETr estimated by Modified-Penman Monteith method was closely associated with ETr estimated by Penman-Monteith method with maximum R^2 of 0.98 followed by FAO Radiation method, Pan evaporation method, Priestly Taylor Method, and Hargreaves Samani method with R^2 values of 0.49, 0.05 and 0.02, respectively.

ETr estimated by different methods was statistically compared with ETr estimated by Penman Monteith method statistical parameters viz. index of agreement (d) root means square error (RMSE) and Normalized Root Mean square Error (NRMSE). The results are presented in Table 5

Table 5. Statistical comparison of ETr estimated using different methods.

Statistical Parameter	ETr-MPMM	ETr-FAO Rad	ETr-PT	ETr-HS	ETr-PE
d	0.886	0.867	-0.325	-0.16	0.752
RMSE	0.741	0.813	2.023	1.412	0.81
NRMSE	0.215	0.236	0.587	0.41	0.235

It observed from Table 5 that ETr estimated using Modified Penman Monteith method and FAO Radiation method were strongly correlated with ETr estimated using Penman

Monteith method with higher values of Index of Agreement (0.886 and 0.867) and lower values of RMSE (0.741 and 0.813 mm) with NRMSE (0.215 and 0.236 mm). This indicates that Modified Penman method performs statistically well as compared to other methods and was followed by FAO Radiation method. Pan Evaporation method showed moderate correlation with d value of 0.75, RMSE of 0.81mm and NRMSE of 0.23mm. Priestly Taylor method (d= -0.32, RMSE= 2.02 mm, NRMSE=0.58mm) and Hargreaves-Samani method(d=-0.16, RMSE=1.41mm, NRMSE=0.41mm) showed poor correlation with the Penman Monteith method.

3.2 Estimation of crop evapotranspiration (ETc) by lysimeter

Sesamum crop evapotranspiration (ETc) was estimated using digital weighing type lysimeter with water balance techniques during the period from 0.61 to 5.65 mm with a mean value of 2.58 mm over the sesamum crop growing period. The seasonal ETc was 244.94 mm. Daily ETc values showed high variation during sesamum crop growing period with SD of 1.34 and CV of 51.91 %.

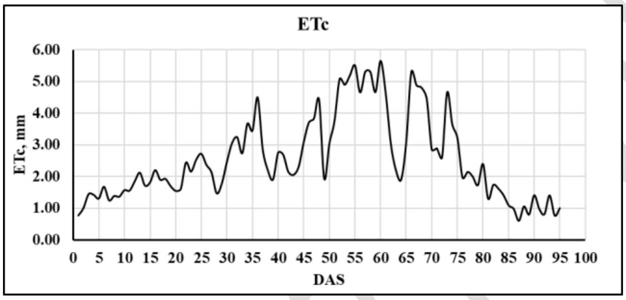

Fig. 5 Daily variation of crop evapotranspiration (ETc) measured using digital weighing type lysimeter during the sesamum crop growing season

3.3 Crop coefficients (Kc) of Sesamum

The crop coefficient for Sesamum crop is determined as the ratio of crop evapotranspiration (ETc) to reference crop evapotranspiration (ETr) estimated using different methods. Polynomial type of regression equations were developed for the estimation of daily crop coefficients. Daily Kc values were plotted against t/T, where it is the day of the week and T is the total crop period in days to develop a polynomial regression equation of different orders. The best fit polynomial equations were selected on the basis of maximum value of coefficient of determination (R^2).

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

ETr Method	Polynomial equation	R^2
Penman Montieth Method (PMM)	$Kc = 61.17(t/T)^5 - 165.739(t/T)^4 + 156.72(t/T)^3 - 63.31(t/T)^2 + 11.23(t/T) + 0.01$	0.86
Modified Penman Monteith Method (MPMM)	$Kc = 50.61(t/T)^5 - 137.67(t/T)^4 + 130.64(t/T)^3 - 52.89(t/T)^2 + 9.38(t/T) + 0$	0.87
FAO Radiation Method (FAO Rad)	$Kc = 53.81(t/T)^5 - 155.17(t/T)^4 + 156.97(t/T)^3 - 68.17(t/T)^2 + 12.57(t/T) - 0.03$	0.74
Priestly Taylor Method (PT)	$Kc = 47.54(t/T)^5 - 109.67(t/T)^4 + 80.73(t/T)^3 - 21.60(t/T)^2 + 3.13(t/T) + 0.09$	0.79
Hargreaves Samani Method (HS)	$Kc = 60.35(t/T)^5 - 145.66(t/T)^4 + 116.89(t/T)^3 - 36.53(t/T)^2 + 4.98(t/T) + 0.15$	0.69
Pan Evaporation Method (PE)	$Kc = 59.28(t/T)^5 - 157.01(t/T)^4 + 143.72(t/T)^3 - 55.18(t/T)^2 + 9.24(t/T) + 0.03$	0.77

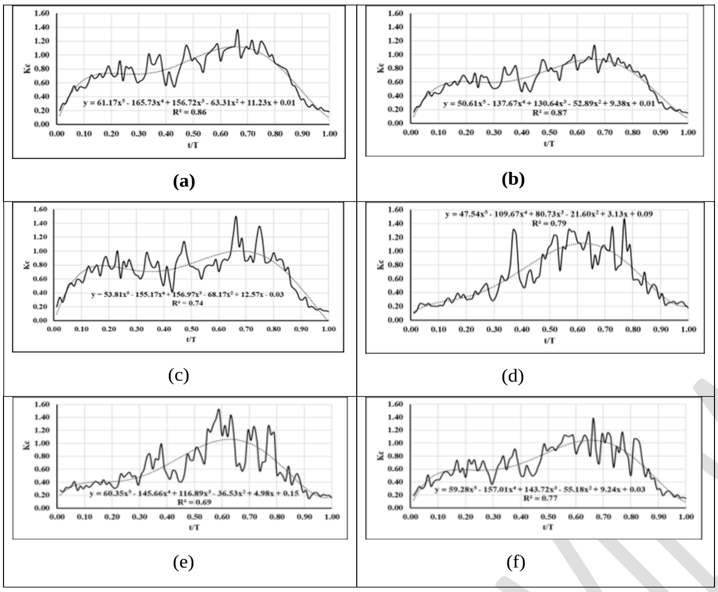

Fig. 6 Graphical representation of best fit polynomial equations for determination of daily Kc all different methods during the sesamum crop growing season.

Table 7 Descriptive Statistics of daily Kc estimated by different methods

Descriptive statistics	**Kc-PMM**	**Kc-MPMM**	**Kc-FAO Rad**	**Kc-PT**	**Kc-HS**	**Kct-PE**
Minimum	0.09	0.08	0.02	0.12	0.16	0.08
Maximum	1.11	0.94	1.00	1.12	1.06	1.04
Mean	0.75	0.63	0.71	0.63	0.61	0.66
Sum	71.34	59.97	67.30	59.61	58.17	63.16
Standard Error	0.03	0.02	0.02	0.03	0.03	0.03
Standard Deviation, SD (%)	0.27	0.22	0.24	0.33	0.29	0.26
Coefficient of Variance, CV (%)	35.69	35.32	34.15	52.27	46.74	38.98
Count	95.00	95.00	95.00	95.00	95.00	95.00

3.4 Crop growth stage-wise Kc

The daily Kc values determined by different ETr estimation methods were converted into the critical growth stages by taking the averages for respective stage and sesamum crop duration. The crop growth stage-wise Kc values are as below;

Table 8 Stage-wise Kc values of Sesamum crop by different methods of ETr estimation.

Crop growth stage	**Duration**	**Kc-PMM**	**Kc-MPMM**	**Kc-FAO Rad**	**Kc-PT**	**Kc-HS**	**Kc-PE**
Initial	20	0.58	0.48	0.61	0.26	0.36	0.48
Development	25	0.77	0.64	0.73	0.61	0.58	0.65
Mid-season	35	1.00	0.84	0.91	0.98	0.92	0.93
End season	15	0.36	0.32	0.33	0.33	0.28	0.32
Seasonal Kc	95	0.75	0.63	0.71	0.63	0.61	0.66

3.4.1 Comparison of estimated Kc

Here Kc estimated by using different method with Penman Monteith Method for estimating Index of Agreement, RMSE and NRMSE.

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	0.94	0.98	0.89	0.91	0.97
RMSE	0.13	0.08	0.20	0.23	0.09
NRMSE	0.17	0.10	0.26	0.17	0.12

It is observed form Table 9 that, Kc estimated by FAO Radiation method (Kc-FAO Rad) is closely related to KC-PMM with highest value of Index of Agreement (d= 0.98) and lower values of RMSE (0.08) and NRMSE (0.10) followed by Kc estimated using Pan evaporation method, Modified Penman Monteith method, Hargraves Samini method and Priestly-Taylor methos, respectively. These results vary from graphical interpretation of relationships between different methods of ETr and Penman-Monteith method because of difference in magnitude of ETr estimates. Although, Kc values obtained by using FAO Radiation method are closer to Kc values obtained by using Penman-Monteith method, lower difference in the magnitudes of Kc values resulted in higher values of Index of Agreement and lower values RMSE and NRMSE. This similar trend is followed by other methods. The study indicated that, in the absence of large data required for estimation of ETr by Penman Monteith method, Modified Penman Monteith method and FAO Radiation method, Pan Evaporation method provides an alternative solution with pan evaporation data.

3.4.2 Comparison of Kc estimated using different methods with FAO-56 Kc values.

The stage-wise FAO-56 Kc values for initial, development, mid-season and end-season for Sesame crop are 0.35, 0.74,1.10 and 0.25, respectively. The percentage deviation of Kc estimated using different ETr estimation methods is presented in Table 10.

Table 10 Percent deviation of Kc from FAO-56

Crop growth stage	Duration	Kc-FAO56	Kc-PMM	Kc-MPMM	Kc-FAO Rad	Kc-PT	Kc-HS	Kc-PE
Initial	20	0.35	65.71	37.14	74.29	-25.71	2.86	37.14
Development	25	0.74	4.05	-13.51	-1.35	-17.57	-21.62	-12.16
Mid-season	35	1.10	-9.09	-23.64	-17.27	-10.91	-16.36	-15.45
End season	15	0.25	44.00	28.00	32.00	32.00	12.00	28.00

It is observed from Table 10 that, the Kc values estimated using Lysimetric approach and different ETr estimation methods varied from -1.35 % to 65.71 % irrespective of method and crop growth stage. On an average Kc determined by Penman Monteith method, Modified Penman Monteith method, FAO Radiation method and Pan Evaporation method overestimated the Kc by 26.17, 7.00, 21.92 and 9.38 %, respectively. However, Priestly-Taylor method and Hargraves-Samani method underestimated Kc by 5.55 and 5.78 %, respectively.

Conclusions

1. Reference evapotranspiration (ETr) was estimated using six methods based on meteorological data collected from the IMD station at the AICRP, Irrigation Water Management during the sesame crop-growing period. Key findings for ETr estimation were:- Penman-Monteith Method ETr ranged from 2.20 to 5.54 mm/day with a seasonal total of 328.53 mm, respectively, Modified Penman Method ETr ranged from 2.58 to 6.06 mm/day with a seasonal total of 395.47 mm, respectively, FAO Radiation Method ETr ranged from 2.04 to 6.70 mm/day, seasonal total 369.37 mm, respectively, Priestly-Taylor Method ETr ranged from 2.28 to 7.88 mm/day, seasonal total 430.26 mm, respectively, Hargreaves-Saman method ETr ranged from 2.85 to 5.22 mm/day, seasonal total 416.04 mm respectively, Pan Evaporation Method: ETr ranged from 1.05 to 5.55 mm/day, seasonal total 372.90 mm respectively.
2. The Penman-Monteith method, regarded as the standard, was used to compare other methods. The Modified Penman method showed the highest correlation (R^2=0.99) with the Penman-Monteith method, followed by the FAO Radiation and Pan Evaporation methods. The Priestly-Taylor and Hargreaves-Samani methods showed poor correlations. The Modified Penman method had the best statistical performance, with the highest Index of Agreement (0.886) and lowest Root Mean Square Error (RMSE of 0.741 mm) when compared with Penman-Monteith.
3. Sesame crop evapotranspiration (ETc) was measured using a digital weighing lysimeter. ETc ranged from 0.61 to 5.65 mm/day with a seasonal total of 244.94 mm.
4. A strong relationship (R^2=0.97) 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 Kc values (Penman-Monteith method) were 0.58, 0.77, 1.00 and 0.36, respectively, Kc values (Modified Penman Monteith method) were 0.48, 0.64, 0.84 and 0.32, respectively, Kc values (FAO Radiation method) were 0.61, 0.73, 0.93 and 0.33, respectively, Kc values (Pristly Taylor method) were 0.26, 0.61, 0.98 and 0.33, respectively, Kc values (Hargreaves Samani method) were 0.36, 0.58, 0.92 and 0.28, respectively and Kc values (Pan Evaporation method) were 0.48, 0.65, 0.93 and 0.32, respectively.

All things considered, the study offers insightful information about enhancing sesame water usage efficiency through the integration of spectral data, crop coefficients, and evapotranspiration. It emphasizes how well the FAO Radiation and Modified Penman approaches work as substitutes for the Penman-Monteith approach in estimating ETr and Kc.

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