

Development and Performance Evaluation of Modified Cost-Effective Non-Weighing Paddy Lysimeter for Estimation of Actual Crop Evapotranspiration

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ABSTRACT

Accurate estimation of actual crop evapotranspiration (ET_c) is fundamental for precise irrigation scheduling and enhancing water use efficiency under increasing water constraints. In the present study, a modified, cost-effective non-weighing paddy lysimeter was designed, developed, and evaluated under conventional puddled rice cultivation. To assess its performance, a field experiment was conducted at the research farm of ICAR–Research Complex for Eastern Region (ICAR–RCER), Patna, wherein the lysimeter was used to quantify the water balance components including percolation losses, evapotranspiration, and root-zone water storage, along with the estimation of ET_c. Results indicated that percolation losses beyond the root zone and evapotranspiration accounted for 262.48 mm (35.36%) and 369.4 mm (49.77%), respectively, of the total applied water, while 14.87% was retained within the root zone during the crop growing period. Stage-wise mean daily ET_c during the initial, crop development, mid-season, and late-season stages were 3.86 ± 0.95 , 4.51 ± 1.41 , 4.05 ± 1.28 , and 2.52 ± 0.51 mm day⁻¹, respectively. Corresponding model-predicted ET_c obtained using the Penman–Monteith approach were 3.59 ± 0.77 , 4.05 ± 1.16 , 4.07 ± 1.26 , and 2.50 ± 0.50 mm day⁻¹, respectively. A good agreement was observed between measured and modelled ET_c ($R^2 = 0.63$, MSE = 0.64, RMSE = 0.80), confirming the reliability of the developed lysimeter for field-scale application. The study demonstrates that the modified lysimeter provides a cost-effective, robust, and practical alternative for quantifying ET_c and water balance components in rice fields where commercial lysimeters are not accessible. Moreover, the stage-wise K_c values derived from the study can facilitate regional-scale irrigation planning in similar agro-climatic conditions.

Keywords: Paddy Lysimeter, Rice, Evapotranspiration, Water balance

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food crop cultivated in 118 countries across the globe, occupying nearly 146 million hectares (Mha) in Asia alone (FAO, 2019). In India, it covers more than 44 Mha of agricultural land and provides food security for approximately 65% of the population (Directorate of Economics and Statistics, 2020; Mohanty and Yamano, 2017; Chatterjee et al., 2020). Rice is cultivated under diverse agro-ecosystems ranging from lowland to upland conditions, employing various establishment methods such as conventional puddled transplanted rice (CPR or TPR), direct-seeded rice (DSR), and the system of rice intensification (SRI) under both irrigated and rainfed environments.

Despite recent advances in resource-conserving technologies like DSR and SRI, transplanted puddled rice (TPR) continues to dominate due to its reliability in weed control and yield stability. However, the conventional puddled rice system, which typically involves continuous flooding with a ponding

depth of 5–10 cm, led to high water and nutrient losses (Bouman and Tuong, 2001). Under such conditions, 50–80% of the applied water is often lost through deep percolation, under-bund seepage, and surface evaporation (Sudhir-Yadav et al., 2011; Kumari et al., 2022). Many earlier studies have reported that where rice is consistently flooded, the groundwater table has going down at an alarming rate. Under such situation, estimation of crop water requirement (CWR) in rice crop is very important for judicious irrigation scheduling as well as irrigation planning and management. Crop water requirement is mainly depends on local climatic conditions, crop management practices, crop types, varieties and their growth stages etc. In order to effectively manage water, actual crop evapotranspiration (AET) estimation is essential for significantly improve the water use efficiency of these crops at regional scale. The majority of studies used lysimeter (Weighing and Non-weighing type) which provided a direct method of estimating actual crop evapotranspiration (Tyagi et

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al., 2000; Kingra *et al.*, 2004; Tripathi, 2004). The lysimeter, on the other hand, is difficult to use, expensive, and should only be used by highly qualified research personnel, yet it allows for precise and continuous measurements of actual crop evapotranspiration within the field. However, ET has been also estimated indirectly using both simple and complicated models, which must be validated against experimental values at regional scale (Bogawski and Bednorz, 2014; Djaman *et al.*, 2015; Subedi and Chávez, 2015). Keeping in mind, an attempt has been made to develop a cost-effective non-weighing paddy lysimeter by slight modifications to estimate in situ actual crop evapotranspiration along with water budgeting studies and its performance were evaluated by comparing Actual ET_c estimated using developed lysimeter with standard crop evapotranspiration estimation using Penman-Monteith equation. This method is easy, low-cost, and does not necessitate skilled labour. The modified lysimeter is the volumetric type which estimates the crop evapotranspiration as a residual by measuring all other components of the soil water balance. Such type of study helps in precise application of irrigation water under local management practices in similar agro-climatic regions of India.

MATERIALS AND METHODS

Site Description, Climate and Soil

A field experiment was carried out in 2021-22 on the experimental farm of the Indian Council of Agricultural Research Complex for the Eastern Region (ICAR-RCER) Patna, Bihar, India located at 25° 35'30" N latitude and 85° 05'03" E longitudes at an altitude of about 52 m above mean sea level (Fig. 1).

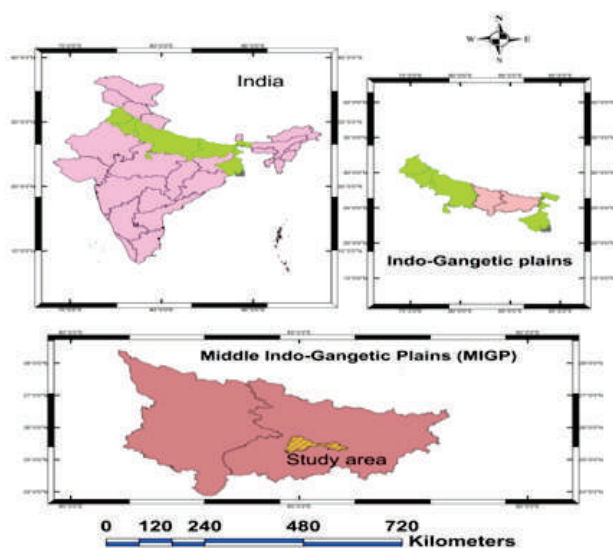


Fig. 1: Location of study area

This region's climate is subtropical humid, with an average annual rainfall of 1130 mm, with 85–90% of that falling between June and September. Fig. 2 depicts weather variations during the crop season.

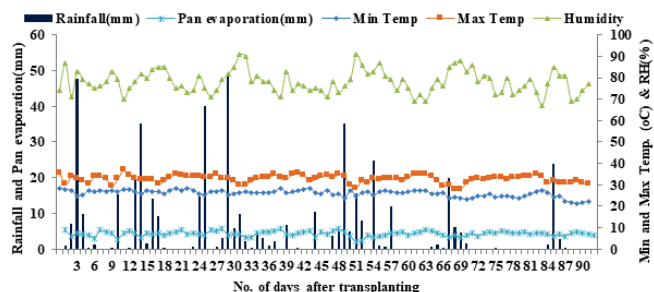


Fig. 2: Daily weather variation during cropping season

Soil sampling was done as per the standard procedure to find out the physical properties of soil. Details of the physical properties of soils are given in Table 1.

Table 1: Physical properties of the soil of experimental plot

Parameters	Values
Soil type	Sandy Loam
Particle size distribution (%)	
Sand	54
Silt	28
Clay	18
Hydraulic conductivity (cm/h)	1.55
Bulk density (g/cm ³)	1.52
pH (1:1 soil: water)	7.87
OC (%)	0.51
Field Capacity	18.42
Permanent wilting point	8.42

For transplanted twenty-five-day-old seedlings of the rice cultivars Swarn Shreya, standard agronomic package and practices were used. In general, rice growth was classified into four stages: I) the initial growth stage; (II) the crop development stage; (III) the mid-season stage; and (IV) the end-season stage.

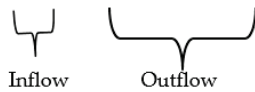
Estimation of Actual Evapotranspiration (ET_c) and Water Balance Components Using Modified Lysimeter

In this method, three drums (A, B, and C), each with a diameter of 50 cm and a height of 125 cm, are buried in a rice field, with roughly one-fourth of their height above ground level (Figure 3). Out of three drums, two namely B and C have had their bottoms removed and in drum C, outlet pipes are inserted at bund height for precise measurement of runoff. Daily crop evapotranspiration was assessed by regular monitoring of water level change having bottom being closed (A) to avoid percolation losses whereas, percolation losses assessed by monitoring the water level change in drum A and B in consecutive days. Frequent refilling was done to keep the

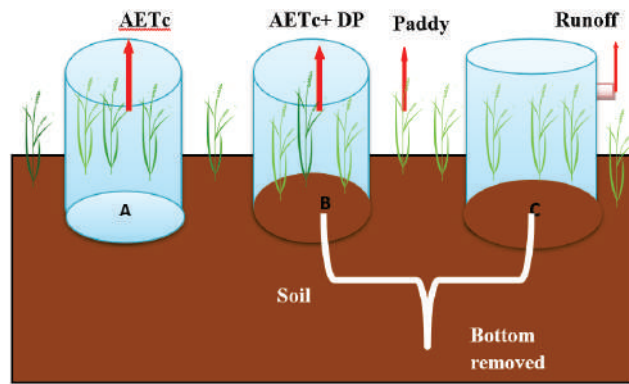
water level in the cylinders at the same level as the surrounding water depth in the plots. During the entire crop growth period, a total of 250 mm irrigation water was applied in 3 irrigations including land preparation (100 mm) at 5 cm depth each time. In addition, crop also received 492.2 mm water as rainfall during the entire crop growth period. No overflow occurred from drum C throughout the season; hence no runoff observed from paddy field.

Then, the water balance of rice fields' root zone was measured using modified paddy lysimeter by regular monitoring of water lost from each drum on daily basis by the following equation:

$$(I+R) - (AET_c + R_{off} + P) = \pm \Delta S \text{ (Change in soil moisture storage) } \dots (1)$$



Where, I: irrigation, R: rainfall, P: percolation below the root zone, R_{off}: runoff and ΔS is the change in soil water storage in the root zone.



*AET_c: Actual crop evapotranspiration; DP: Deep Percolation

Fig. 3: Modified locally constructed lysimeter to measure water balance components in paddy field

Estimation of Reference Evapotranspiration (ET₀)

The FAO CROPWAT model based on Penman-Monteith equation was used to determine reference evapotranspiration (ET₀) from daily weather data (Allen *et al.*, 1998 and 2006).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \dots (2)$$

Where,

- ET₀ = Reference evapotranspiration [mm day⁻¹]
- u₂ = Wind speed at 2 m height [m s⁻¹]
- R_n = Net radiation at crop surface [MJ m⁻² day⁻¹]
- G = Soil heat flux density [MJ m⁻² day⁻¹]
- T = Mean daily air temperature at 2 m height [°C]
- γ = Psychrometric constant [kPa °C⁻¹]
- Δ = Slope of vapour pressure curve [kPa °C⁻¹]
- e_s - e_a = Saturation vapour pressure deficit [kPa]

Then, Actual crop evapotranspiration is calculated by multiplying the reference evapotranspiration with FAO K_c values using following equation:

$$ET_c = ET_0 * K_c \dots (3)$$

Where, ET_c: Actual crop evapotranspiration (mm); ET₀: Reference evapotranspiration and K_c: Crop coefficient

Water Productivity

In this study, Crop water productivity (CWP) was determined by dividing the marketable grain yield by the water used to meet crop evapotranspiration requirement.

$$\text{Crop Water Productivity (kg ha}^{-1}\text{mm}^{-1}\text{)}$$

$$= \frac{\text{Grain Yield (kg ha}^{-1}\text{)}}{\text{Crop Evapotranspiration (mm)}} \dots (4)$$

Total water productivity (TWP) defined as the ratio of crop yield to the water used in the field is calculated as:

$$\text{Total Water Productivity (IWP)}$$

$$= \frac{\text{Crop Yield (kg ha}^{-1}\text{)}}{\text{Water used to produce yield (m}^3\text{ha}^{-1}\text{)}} \dots (5)$$

Statistical Analysis

Further, the performance evaluation of the developed lysimeter was carried out by assessing the strength of association between the observed (field-measured) and model-predicted evapotranspiration values using multiple linear regression analysis. The statistical significance of differences between stage-wise field-measured actual crop evapotranspiration and model-predicted evapotranspiration was examined using the Wilcoxon-Mann-Whitney test. To quantify the predictive accuracy, Mean Square Error (MSE), Root Mean Square Error (RMSE), and the Coefficient of Determination (R²) were computed between measured and predicted ET_c values for error analysis (Eqs. 5–7).

$$MSE = \frac{\sum_i^n (P_i - O_i)^2}{n} \dots (6)$$

$$RMSE = \sqrt{\frac{\sum_i^n (P_i - O_i)^2}{n}} \dots (7)$$

$$R = 1 - \frac{\sum_i^n (P_i - \bar{O})^2}{\sum_i^n (P_i - \bar{O})^2} \dots (8)$$

Where, P_i, O_i and $\bar{O}$ are the observed, estimated and mean estimated values, respectively.

Pearson's correlation coefficient, on the other hand, was employed in this investigation to determine the strength of the association between the meteorological factors and actual crop evapotranspiration

RESULTS AND DISCUSSION

Water Balance Component Studies

Water balance components like rainfall, irrigation depth, crop evapotranspiration (ETc), percolation beyond root zone of the crop and surface runoff during the crop growth period was accounted by using equation (1) through regular monitoring of water lost from each drum on daily basis. Results showed that the percolation beyond root zone of the crop and water losses through evapotranspiration was 262.48 mm and 369.4 mm, respectively under conventional puddle rice method which was about 35.36% and 49.77% of total water applied during entire crop growing season and rest amount of water (14.87%) stored within root zone of the crop (Table 2). Comparatively, Yadav *et al.* (2011) reported slightly lower water losses in transplanted puddled rice, with evapotranspiration ranging between 28–43% and deep percolation between 22–27% of the total water applied. Similarly, Bouman and Tuong (2001), Choudhury *et al.* (2007) and Kukal *et al.* (2010) reported that a significant portion of this water (50–80%) is lost through unproductive deep percolation, under-bund seepage, and evaporation from ponded surfaces. Such variations among studies may be attributed to differences in weather conditions, cropping intensity, rice varieties, and management practices, which strongly influence the magnitude of water losses under flooded rice systems.

Table 2: Water balance components of paddy

Crop	Rain fall	Irrigati on	ETc	DP	Run off	±AS
	In mm					
Paddy (Swarn Shreya)	492.2	250	369.4 (49.77%)	262.48 (35.36%)	0	110.32 (14.87%)

Stage-wise Variation of Actual Crop Evapotranspiration and Model Predicted Evapotranspiration

Stage-wise measured daily mean actual crop evapotranspiration (AETc) during the initial, crop development, mid-season, and late-season stages were 3.86 ± 0.95 , 4.51 ± 1.41 , 4.05 ± 1.28 , and 2.52 ± 0.51 mm day⁻¹, respectively. Corresponding model-predicted values obtained using the Penman–Monteith approach were 3.59 ± 0.77 , 4.05 ± 1.16 , 4.07 ± 1.26 , and 2.50 ± 0.50 mm day⁻¹ (Fig. 4). Throughout the crop growth period, daily mean AETc ranged from 1.9 to 8.2 mm day⁻¹ with a mean of 4.01 ± 1.35 mm day⁻¹, while model-predicted ET varied between 1.55, and 6.28 mm day⁻¹ with an average of 3.84 ± 1.21 mm day⁻¹.

These results are consistent with reported ET values for rice in South and Southeast Asia, which typically vary from 4.4 to 14.3 mm day⁻¹, and from 4 to 9 mm day⁻¹ in most regions of Asia (Lage *et al.*, 2003). Variations in ET are largely influenced by crop characteristics such as vegetation type, density, growth stage, and stomatal conductance, as well as local

weather conditions and management practices (Tuong, 2000; Tyagi *et al.*, 2000; Chatterjee *et al.*, 2020).

Overall, daily mean actual and model predicted crop evapotranspiration increases from initial to mid-season and then decreased due to reduction in leaf area index led to reduction in transpiration losses. Similar trend was also reported by various researchers for lysimeter studies in India and abroad (Tyagi *et al.*, 2000; Kingra *et al.*, 2004; Kuo *et al.*, 2006; Choudhury *et al.*, 2013).

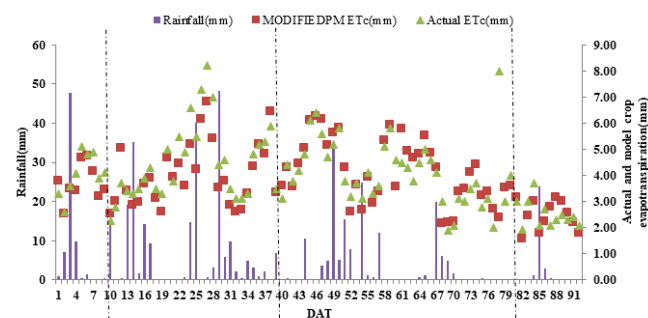
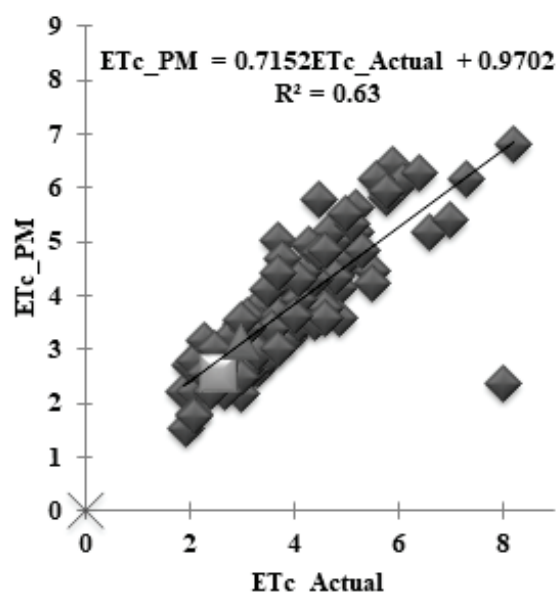


Fig. 4: Stage-wise variation of ETc measured using the developed lysimeter and model-predicted ETc calculated using the Penman–Monteith equation

Statistical Analysis

The multiple linear regression analyses as well as non-parametric Man-Witney U test were used to assess close agreement between actual crop evapotranspiration values using modified low cost lysimeter and model predicted crop evapotranspiration values. Results showed that overall, actual crop evapotranspiration were in line with model predicted values (R^2 : 0.63; MSE: 0.64 and RMSE: 0.80) but slightly higher though not significantly at the 5% level of significance (Figure 5 a & b).



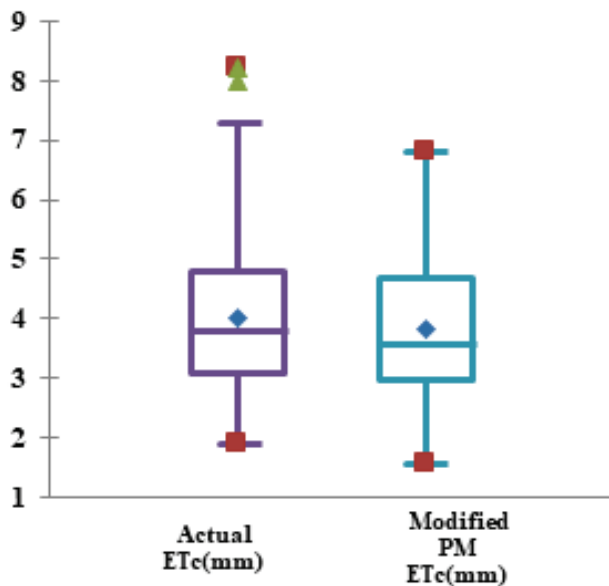


Fig. 5: Comparison of lysimeter-measured and modified Penman-Monteith (PM) estimated crop evapotranspiration (ETc) in rice. (a) Scatter plot showing the relationship between actual ETc and ETc_PM with box plot (b)

Stage-wise analysis revealed a strong correlation between measured and predicted ETc during the initial ($R^2=0.82$; MSE = 0.16; RMSE = 0.40) and crop development ($R^2=0.79$; MSE = 0.33; RMSE = 0.58) stages. In contrast, the relationship weakened during the mid-season ($R^2=0.47$; MSE=1.02; RMSE = 1.01) and late-season ($R^2=0.15$; MSE = 0.22; RMSE = 0.47) stages, likely due to seasonal variations in leaf area index, canopy structure, and microclimatic conditions affecting transpiration (Fig. 6).

These results demonstrate that the modified lysimeter reliably captured the temporal dynamics of AETc, particularly during the early growth stages, and offers a practical & cost-effective for in situ evapotranspiration measurement

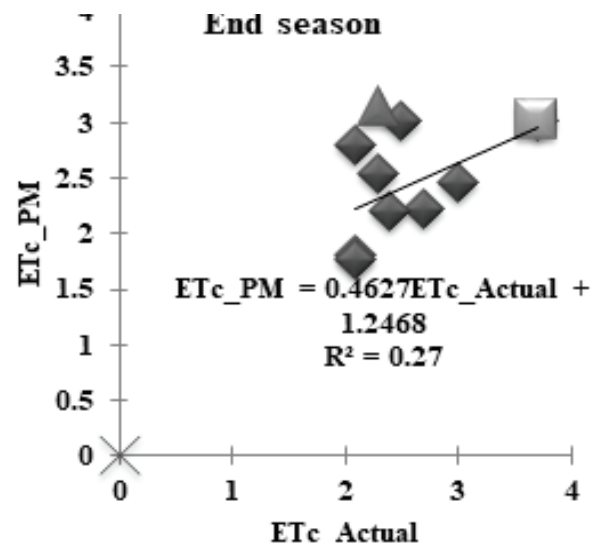
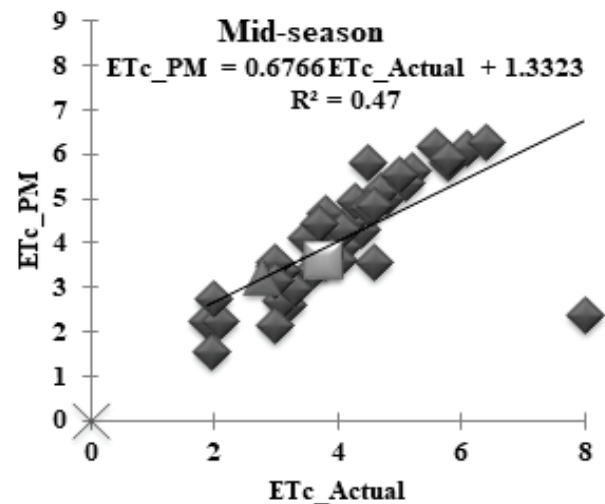
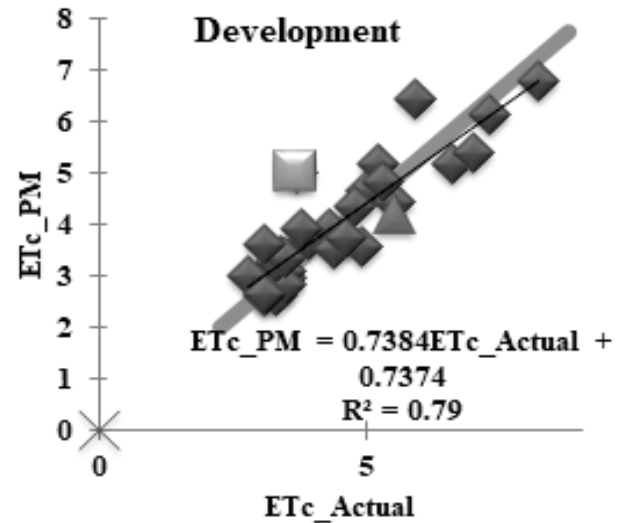
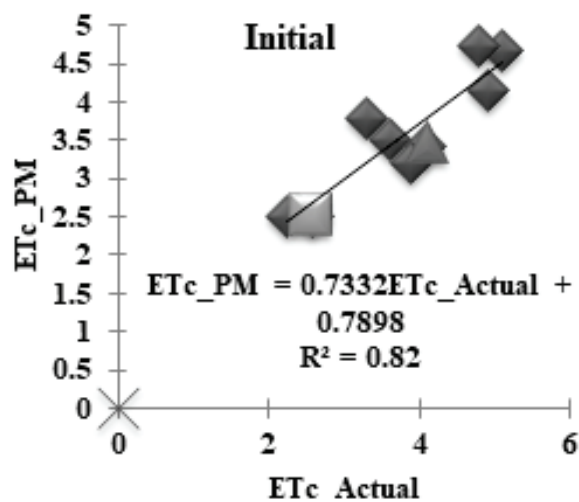


Fig. 6: Relationship between ETc_Actual measured by developed lysimeter and Model predicted ETc using Penman-Monteith Equation across different growth stages of rice i) Initial, ii) Development, iii) Mid-season and iv) End season

Association Between the Weather Variables and Actual Crop Evapotranspiration

Pearson correlation coefficients were calculated throughout the crop season to assess the relationship between weather variables and measured actual crop evapotranspiration (AETc) (Table 3 & Scatter plot in Figure 7). The analysis indicated that radiation intensity ($r = 0.59$), sunshine hours ($r = 0.46$), and maximum temperature ($r = 0.43$) had a substantial positive influence on AETc, whereas mean relative humidity (RHmean) exhibited a negative correlation ($r = -0.31$). These findings suggest that solar radiation and thermal conditions are key drivers of crop water use, while higher humidity reduces evapotranspiration rates by limiting vapor pressure deficit.

These results are consistent with previous studies; for instance, Choudhury et al. (2013) reported that net solar radiation, mean temperature, and wind speed were the most influential weather parameters affecting rice evapotranspiration, highlighting the importance of climatic factors in ET estimation based on correlation analyses.

Table 3: Correlation matrix among weather variables and actual ET

Variables	Min Temp (°C)	Max Temp(°C)	RH(%)	Wind speed (km/day)	Sunshine hours	Rad (MJ/m ² /day)	Actual ETc (mm)
Min Temp(°C)	1	0.405	-0.164	0.203	-0.125	0.067	0.321
Max Temp(°C)	0.405	1	-0.649	-0.160	0.471	0.545	0.432
RH mean (%)	-0.164	-0.649	1	-0.032	-0.520	-0.491	-0.305
Wind speed(km/day)	0.203	-0.160	-0.032	1	-0.051	0.038	0.399
Sunshine hours	-0.125	0.471	-0.520	-0.051	1	0.958	0.457
Rad(MJ/m ² /day)	0.067	0.545	-0.491	0.038	0.958	1	0.594
Actual ETc (mm)	0.321	0.432	-0.305	0.399	0.457	0.594	1

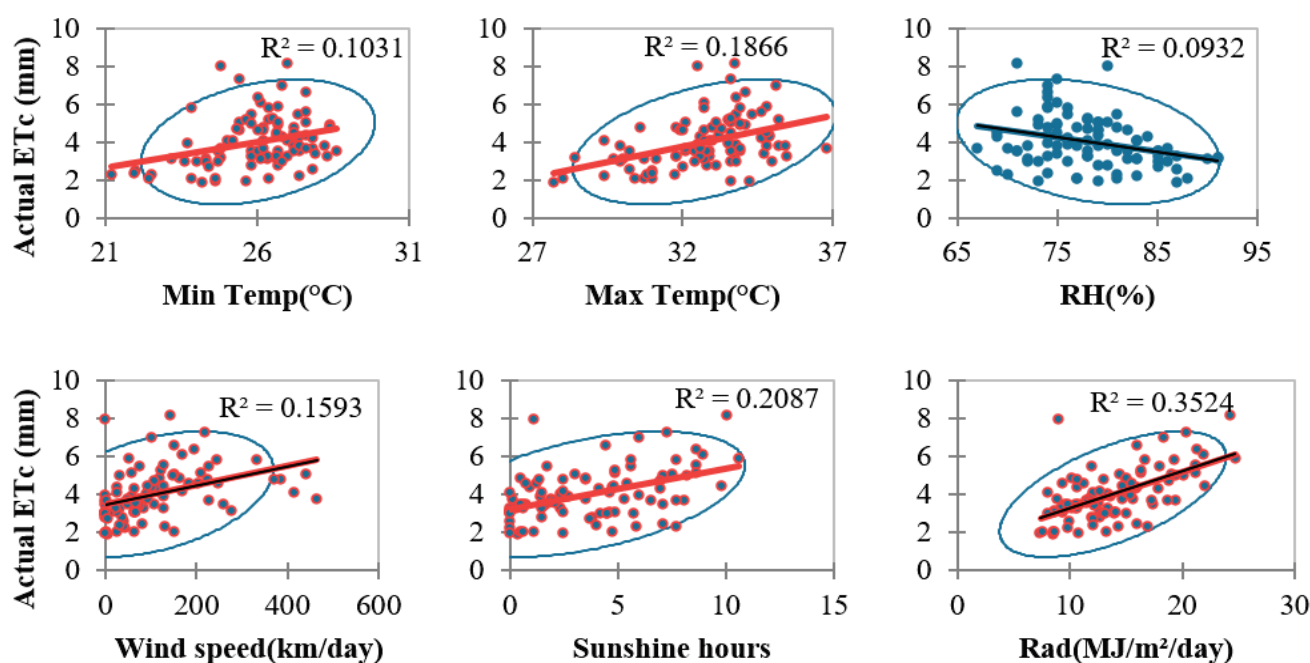


Fig. 7: Pearson correlation showing the relationships between weather variables and measured actual crop evapotranspiration (AETc) throughout the rice crop season

Water Productivity (WP)

The grain yield was recorded as 0.548 kg/m² and Total Water Productivity (TWP) was estimated as 0.74 kg/m³ whereas crop WP as 1.14 kg/m³. This figure fits within the range of

internationally recorded crop WP of rice (0.6 – 1.6 kg/m³) (Zwart and Bastiaanssen, 2004). Similarly, average WP of transplanted puddle rice in eastern India was reported as 0.65 kg/m³ compared to 0.49 kg/m³ in farmer's practice (Mali et al.

2020). Differences in water productivity are primarily governed by climatic conditions, soil type and structure, crop variety, and irrigation practices, highlighting the importance of site-specific water management strategies to optimize rice production and resource-use efficiency.

CONCLUSION

The modified cost-effective paddy lysimeter reliably captured the temporal dynamics of rice crop evapotranspiration (AET_c), showing close agreement with the modified Penman–Monteith model predictions ($R^2 = 0.63$; RMSE = 0.80), particularly during the initial and crop development stages. Water balance evaluation revealed substantial losses through percolation (35.36%) and evapotranspiration (49.77%), with only 14.87% of applied water retained in the root zone, underscoring the need for efficient water management in case of puddled rice. Correlation analysis identified solar radiation, sunshine hours, and maximum temperature as key drivers of ET_c, while higher relative humidity limited evapotranspiration. The observed grain yield (0.548 kg/m²) and total & crop water productivity (0.74 & 1.14 kg/m³, respectively) aligned with regional and international benchmarks, demonstrating the potential of integrating accurate ET_c measurements with site-specific irrigation strategies to optimize water use efficiency. Overall, the modified lysimeter offers a practical, cost-effective tool for in situ monitoring of actual evapotranspiration and water balance, enabling precise irrigation scheduling in locations lacking commercial lysimeter.

REFERENCES

- Allen R G, Pereira L S, Raes D and Smith M. 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. In: Irrigation and Drainage. United Nations Food and Agriculture Organization, Rome, Italy, pp. 300 (Paper 56).
- Allen R G, Pruitt W O, Wright J L, Howell T A, Ventura F, Snyder R, Itenfisu D, Steduto P., Berengena J, Yrisarry J B, Smith M, Pereira L S, Raes D, Perrier A, Alves I, Walther I and Elliott R. 2006. A recommendation on a standardized surface resistance for hourly calculation of reference ET₀ by the FAO56 Penman-Monteith method. *Agric. Water Manage.* 81: 1–22.
- Bogawski P and Bednorz E. 2014. Comparison and validation of selected evapotranspiration models for conditions in Poland (Central Europe). *Water Resources Management* 28(14): 5021–5038.
- Bouman B A M and Tuong T P. 2001. Field water management to save water and increase its productivity in irrigated rice. *Agric. Water Manage.* 49: 11–30.
- Chatterjee D, Swain C K, Chatterjee S, Bhattacharyya P, Tripathi R, Lal B, Gautam P, Shahid M, Dash P K, Dhal B and Nayak A K. 2020. Is the energy balance in a tropical lowland rice perfectly closed? *Atmosfera* ISSN 2395–8812. <https://www.revis.tascca.unam.mx/atm/index.php/atm/article/view/52734>.
- Choudhury B U, Singh A K, Bouman B A M and Prasad J. 2007. System of rice intensification and irrigated transplanted rice: effect on crop water productivity. *J. Indian Soc. Soil Sci.* 55: 464–470.
- Choudhury B U, Singh A K and Pradhan S. 2013. Estimation of crop coefficients of dry seeded irrigated rice–wheat rotation on raised beds by field water balance method in the Indo-Gangetic plains. *Agric. Water Manage.* 123: 20–31.
- Directorate of Economics and Statistics. 2020. State-wise Area, Production and Productivity of Rice during 2014-15 to 2018-19. Directorate of Economics and statistics, Govt. of India.
- Djaman K, Balde A B, Sow A, Muller B, Irmak S, N'Diaye M K, Manneh B, Moukoubi Y D, Futakuchiand 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.
- FAO. 2019. FAO STAT- Food and Agricultural Organization. Rome. www.fao.org. Farooq, M.N., Kobayashi, A., Wahid, O., Ito Shahzad, M.A., Basra, 2009. Strategies for producing more rice with less water. *Adv. Agron.* 101: 351–388.
- Kingra P K, Hundal S S and Sharma P K. 2004. Characterization of crop coefficients for wheat and rice crops in Punjab. *J. Agrometeorol.* 6: 58–60.
- Kukul S S, Humphreys E, Thaman S, Singh B and Timsina J. 2010. Factors affecting irrigation water savings in raised beds in rice and wheat. *Field Crops Research* 118(1): 43–50.
- Kumari A, Upadhyaya A, Jeet P, Al-Ansari N, Rajput J, Sundaram P K, Saurabh K, Prakash V, Singh A K, Raman R K and Gaddikeri V. 2022. Estimation of actual evapotranspiration and crop coefficient of transplanted puddled rice using a modified non-weighing paddy lysimeter. *Agronomy* 12(11): 2850.
- Kuo S F, Ho S S and Liu C W. 2006. Estimation irrigation water requirements with derived crop coefficients for upland and paddy crops in Chinan Irrigation Association Taiwan. *Agric. Water Manage.* 82: 433–451.
- Lage M, Bamouh A, Karrou M and El Mourid M. 2003. Estimation of rice evapotranspiration using a microlysimeter technique and comparison with FAO

- Penman-Monteith and Pan evaporation methods under Moroccan conditions. *Agronomie* 23(7): 625-631.
- Mohanty S and Yamano T. 2017. Rice food security in India: emerging challenges and opportunities. In *The Future Rice Strategy for India*. Academic Press pp. 1–13.
- Subedi A and Chávez J L. 2015. Crop Evapotranspiration (ET) Estimation Models: A Review and Discussion of the Applicability and Limitations of ET Methods. *J. Agric. Sci.* 7: 50.
- Sudhir-Yadav, Humphreys E, Kukal S S, Gill G and Rangarajan R, 2011. Effect of water management on dry seeded and puddled transplanted rice part 2: water balance and water productivity. *Field Crops Res.* 120: 23–32.
- Tripathi R P. 2004. Evapotranspiration and crop coefficient for rice, wheat and pulses under shallow water table conditions of Tarai region of Uttaranchal. *J. Agrometeorol.* 6: 17–29.
- Tuong T P. 2000. Productive water use in rice production: opportunities and limitations. *J Crop Prod* 2: 241–264
- Tyagi N K, Sharma D K and Luthra S K. 2000. Determination of evapotranspiration and crop coefficients of rice and sunflower with Lysimeter. *Agric. Water Manage.* 45: 41–54.
- Zwart S J and Bastiaanssen W G M. 2004. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. *Agric. Water Manage.* 69(2): 115–133.

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