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Analysis of Evapotranspiration of Sugar Cane Using Lysimeter for Semiarid Region: A Deep Learning Technique

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Introduction

The efficient management of water resources in agriculture, particularly in semiarid regions, is paramount for sustaining crop productivity and ensuring food security. Among the various crops cultivated in such regions, sugar cane stands out as a significant contributor to agricultural water demand. The cultivation of sugar cane in semiarid environments poses unique challenges due to limited water availability and the need for precise irrigation management. Evapotranspiration, the combined process of water evaporation from soil surfaces and transpiration from plant leaves, plays a crucial role in regulating water balance within agricultural ecosystems. Accurate estimation of evapotranspiration rates is essential for optimizing irrigation practices and enhancing water use efficiency in sugar cane cultivation. Traditional methods for estimating evapotranspiration, such as the Penman-Monteith equation and the Priestley-Taylor method, have been widely used but may encounter limitations in accurately capturing the complex interactions between environmental variables and evapotranspiration rates, particularly in semiarid regions. Recent advancements in deep learning techniques offer promising avenues for improving the accuracy and robustness of evapotranspiration estimation models by leveraging large datasets and learning complex patterns within the data.

In this study, we aim to analyse the evapotranspiration of sugar cane in a semiarid region using lysimeter data and employing a deep learning approach. Lysimeters, specialized instruments designed to measure water fluxes within soil-plant-atmosphere systems, provide valuable insights into evapotranspiration dynamics under controlled conditions. By integrating lysimeter measurements with advanced deep learning algorithms, we seek to overcome the limitations of traditional methods and develop a more accurate model for estimating evapotranspiration rates in semiarid environments. The overarching goal of this research is to contribute to the advancement of agricultural water management practices in semiarid regions by providing novel insights into the evapotranspiration process for sugar cane. Through the application of deep learning techniques, we aim to develop a predictive model capable of accurately estimating evapotranspiration rates under varying environmental conditions, thereby facilitating informed decision-making regarding irrigation scheduling and water resource allocation. By addressing the pressing challenges of water scarcity and sustainability in sugar cane cultivation within semiarid regions, this study aims to promote resilience and efficiency in agricultural systems.

2. Statement of the Problem:

The cultivation of sugar cane in semiarid regions poses significant challenges related to water scarcity and efficient water management. Evapotranspiration, the combined process of soil evaporation and plant transpiration, plays a crucial role in regulating the water balance in sugar cane fields, influencing crop growth and productivity. Accurate estimation of evapotranspiration rates is essential for optimizing irrigation scheduling, enhancing water use efficiency, and ensuring sustainable sugar cane production in semiarid environments.

However, traditional methods for estimating evapotranspiration, such as empirical equations and observational techniques, often encounter limitations in accurately capturing the complex interactions between environmental variables and evapotranspiration rates in semiarid regions. These methods may not adequately account for the spatial and temporal variability of evapotranspiration, leading to uncertainties in water management decisions and suboptimal crop yields. Additionally, the availability of reliable data for studying evapotranspiration dynamics in semiarid regions is limited, further complicating the accurate estimation of evapotranspiration rates. Traditional observational methods, while valuable, may not provide sufficient spatial and temporal coverage to capture the heterogeneity of soil and climatic conditions in semiarid environments.

Furthermore, the emergence of deep learning techniques offers promising opportunities for improving the accuracy and robustness of evapotranspiration estimation models. Deep learning, with its ability to learn complex patterns and relationships within large datasets, provides a data-driven approach for analysing evapotranspiration dynamics in sugar cane cultivation within semiarid regions. Therefore, the problem addressed in this research is to develop a more accurate and reliable model for estimating evapotranspiration rates in sugar cane fields within semiarid regions using lysimeter data and deep learning techniques. By addressing this problem, this research aims to contribute to the optimization of water management practices, enhance agricultural productivity, and promote sustainability in sugar cane cultivation in semiarid environments.

3. Rationale of the Study

The rationale behind this research stems from the critical importance of accurately estimating evapotranspiration rates in sugar cane cultivation within semiarid regions. Evapotranspiration plays a pivotal role in regulating the water balance in agricultural ecosystems, directly impacting crop growth, yield, and water use efficiency. However, traditional methods for evapotranspiration estimation often encounter limitations in accurately capturing the complex interactions between environmental variables and evapotranspiration rates, particularly in semiarid regions characterized by heterogeneous soil and climatic conditions.

The research aims to address this gap by leveraging lysimeter data and deep learning techniques to develop a more accurate and reliable model for estimating evapotranspiration rates in sugar cane fields within semiarid regions.

The Research Questions

1. How do evapotranspiration rates vary spatially and temporally in sugar cane fields within semiarid regions?
2. What is the effectiveness of lysimeter data in capturing evapotranspiration variability under different environmental conditions?
3. Can a deep learning model accurately estimate evapotranspiration rates in sugar cane cultivation within semiarid regions based on lysimeter measurements and environmental variables?

By addressing these research aims, objectives, and questions, this study seeks to advance our understanding of evapotranspiration dynamics in sugar cane cultivation within semiarid regions and contribute to the optimization of water management practices, enhancement of agricultural productivity, and promotion of sustainability in semiarid environments.

The Scope of the Study Includes:

1. Data Collection: Collection of lysimeter data, meteorological data, soil properties, and crop characteristics relevant to evapotranspiration dynamics in sugar cane fields within semiarid regions.
2. Model Development: Development of a deep learning model using lysimeter data and environmental variables to accurately estimate evapotranspiration rates in sugar cane cultivation.
3. Model Evaluation: Validation and evaluation of the deep learning model to assess its performance in estimating evapotranspiration rates under different environmental conditions.
4. Data Analysis: Analysis of spatiotemporal patterns and variability of evapotranspiration rates in sugar cane fields within semiarid regions.
5. Implications and Recommendations: Discussion of the implications of the findings for water management practices, agricultural productivity,

and sustainability in sugar cane cultivation within semiarid regions. Recommendations for optimizing irrigation scheduling and enhancing water use efficiency will also be provided.

The study will focus on utilizing lysimeter data and deep learning techniques as a novel approach to address the challenges associated with accurately estimating evapotranspiration in sugar cane cultivation within semiarid regions. The findings of this study are expected to contribute to the optimization of water management practices, enhancement of agricultural productivity, and promotion of sustainability in semiarid environments.

4. Significance of the Study:

The significance of the study "Analysis of Evapotranspiration of Sugar Cane Using Lysimeter for Semiarid Region: A Deep Learning Technique" lies in its potential to address critical challenges and contribute to advancements in agricultural sustainability and water management in semiarid regions where sugar cane cultivation is prevalent. This research holds several key implications and benefits:

1. Enhanced Water Management: Accurate estimation of evapotranspiration rates is essential for optimizing irrigation scheduling and ensuring efficient water use in sugar cane cultivation. By leveraging lysimeter data and deep learning techniques, this study aims to develop a more accurate model for estimating evapotranspiration, providing valuable insights for improving water management practices in semiarid regions. This can lead to reduced water waste and improved water use efficiency in sugar cane fields, contributing to long-term sustainability.
2. Improved Agricultural Productivity: Sugar cane is a major crop in many semiarid regions, and its cultivation plays a significant role in the agricultural economy. Understanding and accurately quantifying evapotranspiration rates can help optimize irrigation strategies, leading to improved crop growth, yield, and overall agricultural productivity. By providing insights into evapotranspiration dynamics, this study can support efforts to enhance sugar cane production and increase farmers' income in semiarid environments.
3. Sustainable Resource Use: Sustainable water management is crucial for preserving natural resources and ecosystems in semiarid regions. By promoting more efficient water use through accurate evapotranspiration estimation, this study can contribute to environmental sustainability by reducing water stress on natural habitats and water sources. This can help mitigate the negative impacts of water scarcity on ecosystems and promote the long-term health of semiarid environments.
4. Climate Change Adaptation: Climate change is expected to exacerbate water scarcity in many semiarid regions, posing additional challenges to agricultural sustainability. By providing insights into evapotranspiration dynamics under changing environmental conditions, this study can support adaptation efforts by helping farmers and policymakers make informed decisions regarding water resource management and agricultural practices. This can contribute to building resilience to climate change and ensuring the continued viability of sugar cane cultivation in semiarid regions.
5. Technological Innovation: The application of deep learning techniques in evapotranspiration analysis represents a novel approach to addressing longstanding challenges in agricultural research. By leveraging advanced technologies such as deep learning and lysimeter data, this study demonstrates the potential of innovative solutions for improving agricultural sustainability and resilience in semiarid regions. This can pave the way for future research and technological innovations in the field of agricultural water management.

In summary, the significance of this study extends beyond academic research to practical applications in agricultural sustainability, water management, environmental conservation, and climate change adaptation. By advancing our understanding of evapotranspiration dynamics in sugar cane cultivation within semiarid regions, this study has the potential to make meaningful contributions to addressing pressing challenges and promoting sustainable development in agricultural systems around the world.

Summary of Review

From the review of literature, the following observation were made. All the studies reported in this review focuses the need to identify a suitable model for data short environment, for reliable ETo estimation. The study involved comparison of different ET model types in one or two location or model output to pan evaporation data.

Research work reports include evaluation of ETo models (temperature based, radiation based, and humidity based). The evaluation involves recalibration of the constant present in the model. The evaluation criteria were few of RMSE (Root Mean Square Error). The reported study was found to be for one or two locations of same region or different models were used for developing crop coefficients. It is pointed out that, the model that is used for KC calculation must be used subsequently for consumptive use calculations. This emphasizes the need to have a standardized model for ETo estimation. The Literature reviewed shows that, for evaluating ETo model for data short environment, the FAO PM model can be considered as a standard reference model.

This study employs seven less demanding data requirement models for a region of Dubbaka in Medak District of Telangana state, India. This way, present research work is different from reported other research works. The selected models were modified by recalibrating the constant involved in the models. The methodology employed in this research, to recalibrate the constant differs from other research works.It is proposed to develop a Deep learning algorithm may be developed for The Evapotranspiration of Sugar Cane using Lysimeter for Semiarid Region.

Data Analysis

Evapotranspiration (ET) is a crucial component of the Earth's hydrological cycle, representing the combined processes of water evaporation from the Earth's surface and water transpiration from plants. It's a fundamental concept in hydrology, climatology, and agriculture. Evapotranspiration plays a significant role in the movement of water and energy between the Earth's surface and the atmosphere. Here are the key aspects of evapotranspiration.

Evaporation:

Definition: Evaporation is the process by which liquid water is converted into water vapor and released into the atmosphere. This occurs primarily from open water bodies (e.g., lakes, rivers, and oceans) and moist surfaces (e.g., soil and wetlands).

Factors Affecting Evaporation: Temperature, humidity, wind speed, solar radiation, and the availability of water are critical factors influencing the rate of evaporation. Higher temperatures, lower humidity, and increased wind speed generally lead to higher evaporation rates.

Transpiration:

Evapotranspiration:

Evapotranspiration is the sum of all processes by which water moves from the land surface to the atmosphere via evaporation and transpiration. Evapotranspiration includes water evaporation into the atmosphere from the soil surface, evaporation from the capillary fringe of the groundwater table, and evaporation from water bodies on land. Evapotranspiration also includes transpiration, which is the water movement from the soil to the atmosphere via plants. Transpiration occurs when plants take up liquid water from the soil and release water vapor into the air from their leaves.

Transpiration:

The release of water vapor (gas) from plant leaves.

Transpiration has three main steps.

Roots uptake water from the soil

Water moves through plant tissues, serving critical metabolic and physiologic functions in the plant

Leaves release water vapor into the air through their stomata.

Amount of water do plants transpire.

Plant transpiration is pretty much an invisible process. Since the water is evaporating from the leaf surfaces, you don't just go out and see the leaves "breathing". Just because you can't see the water doesn't mean it is not being put into the air, though. One way to visualize transpiration is to put a plastic bag around some plant leaves. As this picture shows, transpired water will condense on the inside of the bag (this photo shows transpiration after 1 hour). During a growing season, a leaf will transpire many times more water than its own weight. An acre of corn gives off about 3,000-4,000 gallons (11,400-15,100 Liters) of water each day, and a large oak tree can transpire 40,000 gallons (151,000 litres) per year.

Since water vapor also evaporates from the soil, we would have seen even more water vapor captured if we had wrapped the plastic bag around the soil as well.

Area Selection

This survey is made in the fields located near Pandavapura of Mandya district, Karnataka. As the area is a Semi-Arid and there is 5,325 hectares of land completely used for Sugarcane Crop. farmers in Mandya district have been proved to be efficient. It has been also found from the impact analysis that among the inputs only labour has made significant positive impact on technical efficiency of growing sugarcane.

Effects of Transpiration:

Plants put down roots into the soil to draw up water and nutrients into its stems and leaves. Some of this water is returned to the air by transpiration. Transpiration rates vary widely depending on weather and other conditions, such as:

Type of plant: Plants transpire water at different rates. Some plants which grow in arid regions, such as cacti and succulents, conserve precious water by transpiring less water than other plants.

Soil type and saturation: Clay particles are small (smaller than 0.002 mm), holding onto water whereas sand particles which are large (0.05-2 mm) release water readily (think of how water disappears into the sand quickly at the beach). When moisture is lacking, plants can begin to senesce (premature aging, which can result in leaf loss) and transpire less water.

Sunlight availability and intensity

Precipitation: During dry periods, transpiration can contribute to the loss of moisture in the upper soil zone, which can influence vegetation and food-crop fields.

Humidity: As the relative humidity of the air surrounding the plant rises the transpiration rate falls. It is easier for water to evaporate into dryer air than into more saturated air.

Temperature: Transpiration rates go up as the temperature goes up, especially during the growing season, when the air is warmer due to stronger sunlight and warmer air masses. Higher temperatures cause the plant cells which control the openings (stoma) where water is released to the atmosphere to open, whereas colder temperatures cause the openings to close.

Wind & air movement: Increased movement of the air around a plant will result in a higher transpiration rate. Wind will move the air around, with the result that the more saturated air close to the leaf is replaced by drier air.

Transpiration Effect on Groundwater:

In many places, plant roots are found in the top layer of soil, above the water table. The top layer of soil is often wet to some extent but is not totally saturated. Soil below the water table is very wet. The top layer of soil gets wet when it rains (a form of precipitation), but if there is no more precipitation, the soil will dry out. Therefore, the plants are dependent on water supplied by precipitation since the water table is usually below the depth of the plant roots. in places where the water table is near the land surface, such as next to lakes and oceans, plant roots can penetrate the saturated zone below the water table, allowing the plants to transpire water directly from the groundwater system. Here, transpiration of groundwater commonly results in a drawdown of the water table much like the effect of a pumped well (cone of depression—the dotted line surrounding the plant roots in the diagram). Evapotranspiration (ET) is a crucial component of the Earth's hydrological cycle, representing the combined processes of water evaporation from the Earth's surface and water transpiration from plants. It's a fundamental concept in hydrology, climatology, and agriculture.

Definition: Transpiration is the process by which water is absorbed by plant roots from the soil, transported through the plant's vascular system, and released into the atmosphere through small openings called stomata on the plant's leaves. It's a vital part of a plant's life processes. Factors Affecting Transpiration: Transpiration rates are influenced by factors such as plant type, plant size, growth stage, environmental conditions (temperature, humidity, wind, and light), and soil moisture availability.

Components of Evapotranspiration:

Reference Evapotranspiration (ETo): ETo represents the potential rate of evapotranspiration from a reference grass crop under standard meteorological conditions. It is used as a baseline to estimate crop-specific evapotranspiration.

*Actual Evapotranspiration (ETa):*ETa is the actual rate of evapotranspiration occurring in a specific area or with a particular plant or crop. It considers the unique characteristics of the vegetation and local weather conditions.

Measurement and Estimation:

Evapotranspiration can be measured using various methods, including lysimeters, eddy covariance towers, Bowen ratio systems, and remote sensing technologies. However, measuring ET directly can be challenging and expensive. Mathematical models, such as the Penman-Monteith equation, Hargreaves equation, and Priestley-Taylor equation, are often used to estimate evapotranspiration based on meteorological data.

Importance:

Evapotranspiration is a critical component of the water cycle, influencing the distribution and availability of water resources in a region. It has significant implications for agriculture, as it represents the water needs of crops. Efficient irrigation practices rely on accurate estimates of crop evapotranspiration. Evapotranspiration also impacts local and regional climates, contributing to temperature regulation and the formation of weather patterns.

Environmental Impact:

Understanding evapotranspiration is essential for managing water resources sustainably, especially in regions with water scarcity. Changes in land use, deforestation, and climate change can alter evapotranspiration patterns, impacting ecosystems and water availability.

Crop Evapotranspiration (ET_c)

The measured crop evapotranspiration (ET_c) obtained from the lysimeter, and the reference evapotranspiration (ET_o) acquired from a pan evaporimeter installed inside the greenhouse for the chrysanthemum crop is described in. The values of ET_c and ET_o varied from a low of 1.70 and 1.84 mm/day during the vegetative stage to a high of 10.19 and 13.52 mm/day flowering stage. The average values of the ET_c were 1.19, 4.96 and 3.17 mm/day in the initial stage, mid-season stage, and late season stages, respectively. Similarly, the values of ET_o were 1.29 mm/day in the initial stage, 6.41 mm/day in the mid-season stage and 4.89 mm/day in the late season stages. Overall, the values of ET_c were somewhat close to the ET_o values. However, the values of ET_o were overestimated by 0.15 mm in 2022–2023 to the values of ET_c and are represented in.

Soil Moisture Analysis

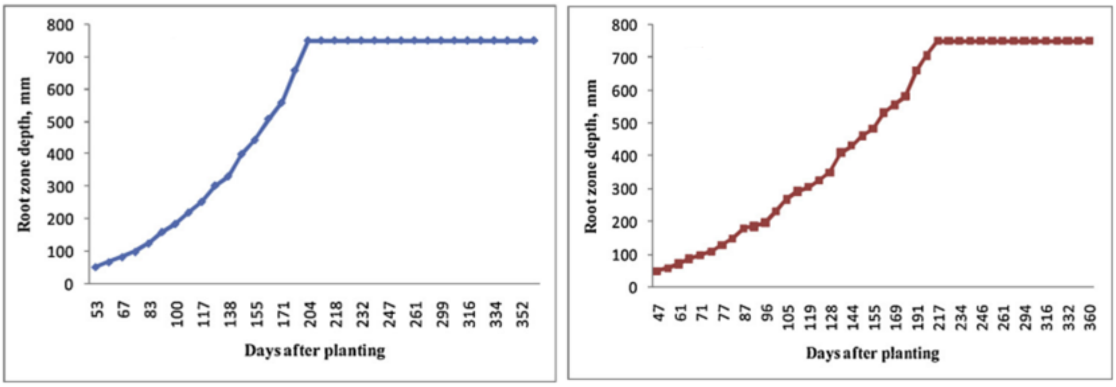


Fig:8 Measured root zone depth (mm) of sugarcane during 2022 and 2023 season respectively.

The root zone depth at the time of transplanting was 50 mm at 53 and 47 DAP in 2022 and 2023, respectively (Fig. 8). During both the years, the root length of sugarcane increased linearly with advancement in age of crop. The rate of root length expedites at the end of tillering stage (115–125 DAP). Thereafter, effective root zone increased approximately up to 204 days and 217 days in 2022 and 2023, respectively and then root zone becomes constant at 750 mm and subsequent samples were taken up to 750 mm.

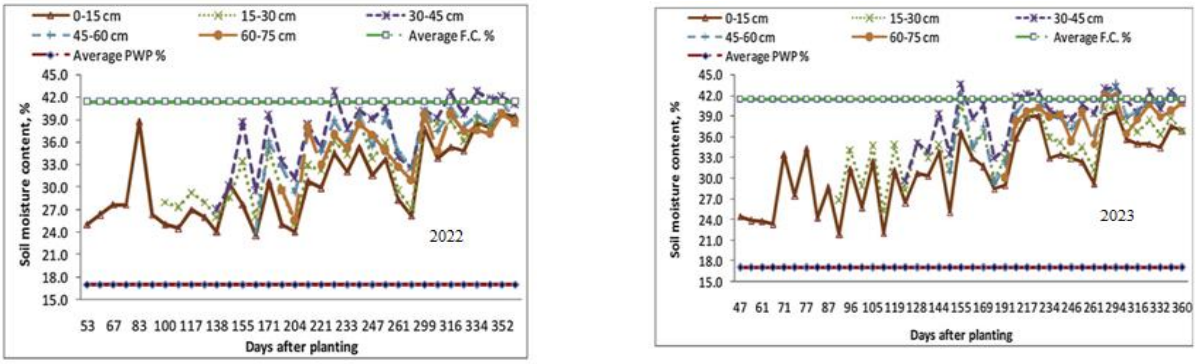


Fig:9 Moisture content in the soil profile for sugarcane during the 2022 and 2023 growing seasons.

The soil moisture content increased with crop evapotranspiration during the growth period. The moisture content found increased with increase in soil layer depth up to 45 cm and thereafter it slightly decreased at 60 cm and lowest moisture content was observed at 75 cm depth (Fig. 9). During tillering stage, more soil moisture depletion was observed, however, when plant canopy fully developed after tillering, the soil moisture depletion was uniform in all layers. The growth stage and incident of rainfall greatly influenced the soil moisture content. Invariably of growth stages and barring rainfall events, the moisture content was closer to field capacity.

Tab:5 Field water balance components (mm) during the growth stages for sugarcane observed at the experimental site in a subtropical climate, India.

Growth stage	Days	2021				2022				Average			
		I	Pe	ΔS	ETc	I	Pe	ΔS	ETc	I	Pe	ΔS	ETc
Initial	55	52.1	–	–	52.1	49.3	–	–	49.3	50.7	–	–	50.7
Tillering	75	211.3	53.2	2.8	267.3	277.6	0	−16.5	261.1	244.4	26.6	−6.9	264.2
Grand growth	170	799.4	243.8	−104.5	938.7	372.4	534.3	−72.2	834.5	585.9	389.1	−88.4	886.6
Maturity	65	110.5	16.2	2.0	128.7	109	0	37.1	146.1	109.8	8.1	19.6	137.4
Total	365	1173.3	313.2	−99.7	1386.8	808.3	534.3	−51.6	1291	990.8	423.8	−75.7	1338.9

Pe = Effective rainfall, I = Irrigation, ETc = Crop evapotranspiration (I + Pe + ΔS), ΔS = Soil moisture storage change.

The rainfall received during 2022 and 2023 was 313.2 mm (38 rainy days) and 534.3 mm (40 rainy days), respectively. In both the years all rainfall received was effective (Table 5). The occurrence of rainfall affected the depth of irrigation in different growth stages. In 2022, the effective rainfall was 43.6 % less than average rainfall (555 mm) therefore; more irrigation water applied in that season. However, in 2023, effective rainfall (534.3 mm) contributed almost 41 % of crop consumptive use and therefore demands of irrigation water reduced to half in 2023.

The total depths of water use during 2022, 2023 and average of two seasons were 1386.8 mm, 1291 mm, and 1338.9 mm respectively (Table 5).

The sugarcane evapotranspiration (ETc) varies considerably from place to place depending on weather conditions, texture of soil and duration of the crop. Numerous approaches have been used by different researchers to measure or estimate sugarcane evapotranspiration.Nevertheless, its estimate largely depends upon type of approach used by researchers. Five-day moving means of daily ETo and ETc measured by the three lysimeters were similar during the first week of the experimental period (0 to 7 DAT), with means varying from 3 to 4 mm, which were lower than the measurements taken during the remaining period, due to lower leaf area, temperature, and solar radiation. After the second week, there was a detachment of ETc curves from ETo.

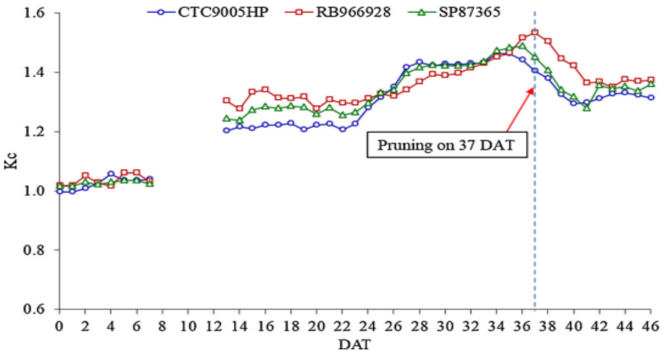


Fig. 10. Crop coefficient (Kc) for the cultivars CTC9005HP, RB966928, and SP87365 during the experimental period. DAT, days after transference.

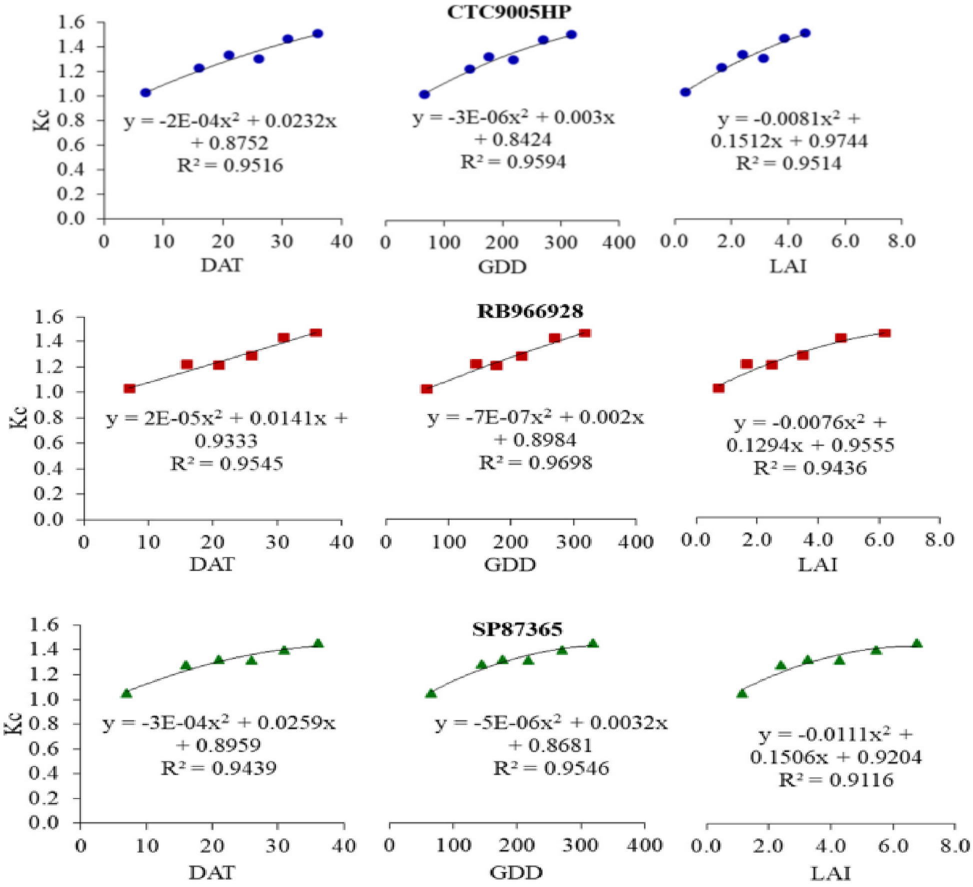


Fig. 11. Crop coefficient (Kc) for cultivars CTC9005HP, RB966928, and SP87365 as a function of days after transference (DAT), growing degree-days (GDD), and leaf area index (LAI).

Table:6 Evapo-Transpiration Estimation using Lysimeter

Date	Rainfall(mm)	Soil tank weight(kg)	Change in weight(kg)	ET (mm/day)	Remarks
28-june-2023	0.00	1862.5	0		Non rain day
29-june-2023	0.00	1851.3	11.2	11.2*0.6+0.0=6.70	
30-june-2023	5.20	1855.6	-4.3	(-4.3*0.6) +5.2=2.60	Rainy day

02-july-2023	0.00	1851.3	0		Non rain day
03-july-2023	12.00	1865.3	-14	(-14*0.6)+12=3.6	Rainy day

TABLE:7ET/mm/day and Water Requirement of different crops.

S.NO.	**CROP**	**ET/mm/day**
1	RICE	4.5-5.5
2	WHEAT	4.41-5.86
3	SUGARCANE	4.5-4.6
4	GROUND NUT	-
5	SOYBEAN	5-8.4

Crop Coefficients of Sugarcane

The Kc values with confidence bounds for both the years are shown graphically in the form of polynomial equation, with respect to the ratio of days to total crop period (Fig.12). The average Kc of two years ranged from 0.31 to 1.29 (Table 8). In both the seasons, Kc consistently increased from 0.43 to 1.03 during 50–130 days after planting (DAP). Thereafter, it showed gradual increases due to crop development in form of cane elongation (mid-season stage). During the mid-season i.e. 130–300 DAP, Kc increased from 1.08 and then remain same in the range of 1.13-1.04 with peak value as 1.29. The highest Kc value occurred during 200–220 DAP. The Kc values during the late season (300–360 DAP) decreased gradually from 1.04 to 0.56. Thompson and Boyce (1971) in a lysimeter study observed that ETc rates declined by about 30 % after crops lodged, an effect that lasted up to crop maturity.

The two years average Kc values are represented in the form of following second order polynomial equation.

$$Kc_t = -4.695\left(\frac{t}{T}\right)^2 + 5.566\left(\frac{t}{T}\right) - 0.360$$

Average estimated crop coefficients (Kc) of sugarcane from best fit regression equations of 2022 and 2023 (Table:8) are estimated using the above Equation with regression analysis.

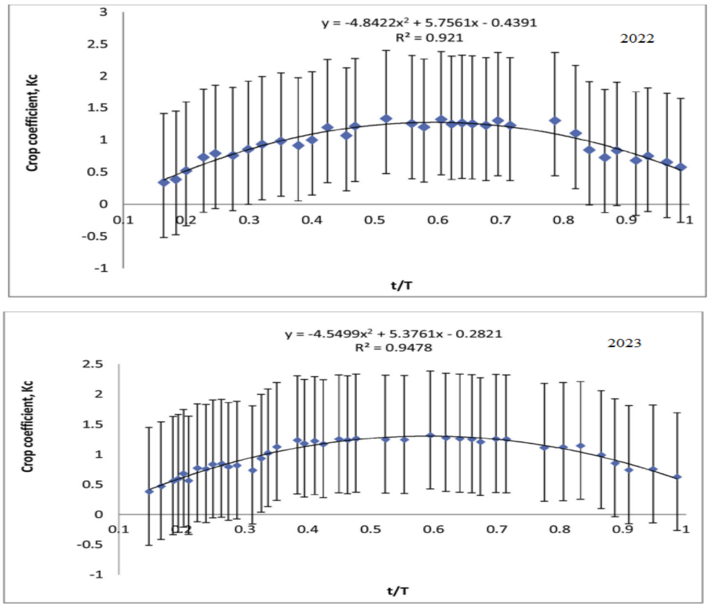
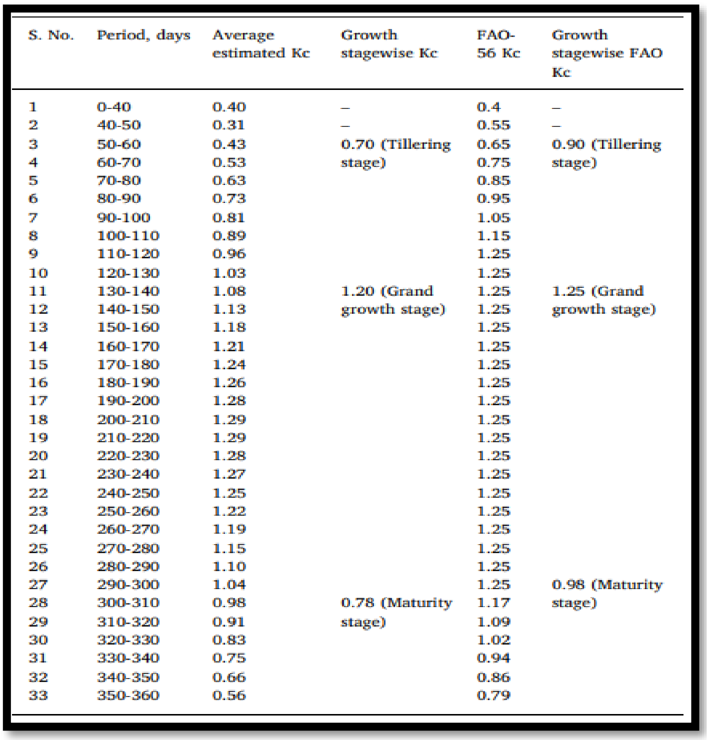


Fig. 12. (A) and (B) 2^{nd} order polynomial crop coefficient curve for sugarcane crop during 2022 and 2023 season.

Tab:8 Average estimated crop coefficients (Kc) of sugarcane from best fit regression equations of 2022 and 2023.



S. No.	Period, days	Average estimated Kc	Growth stagewise Kc	FAO-56 Kc	Growth stagewise FAO Kc
1	0-40	0.40	–	0.4	–
2	40-50	0.31	–	0.55	–
3	50-60	0.43	0.70 (Tillering stage)	0.65	0.90 (Tillering stage)
4	60-70	0.53		0.75	
5	70-80	0.63		0.85	
6	80-90	0.73		0.95	
7	90-100	0.81		1.05	
8	100-110	0.89		1.15	
9	110-120	0.96		1.25	
10	120-130	1.03		1.25	
11	130-140	1.08	1.20 (Grand growth stage)	1.25	1.25 (Grand growth stage)
12	140-150	1.13		1.25	
13	150-160	1.18		1.25	
14	160-170	1.21		1.25	
15	170-180	1.24		1.25	
16	180-190	1.26		1.25	
17	190-200	1.28		1.25	
18	200-210	1.29		1.25	
19	210-220	1.29		1.25	
20	220-230	1.28		1.25	
21	230-240	1.27		1.25	
22	240-250	1.25		1.25	
23	250-260	1.22		1.25	
24	260-270	1.19		1.25	
25	270-280	1.15		1.25	
26	280-290	1.10		1.25	
27	290-300	1.04		1.25	0.98 (Maturity stage)
28	300-310	0.98	0.78 (Maturity stage)	1.17	
29	310-320	0.91		1.09	
30	320-330	0.83		1.02	
31	330-340	0.75		0.94	
32	340-350	0.66		0.86	
33	350-360	0.56		0.79	

Two Days of the Evaluation of the Lysimeters on Sugarcane Crop.

On the two days of the evaluation of the lysimeters, two irrigation events occurred on 12/01/2022 (7:40 a.m. and 2:40 p.m.), as well as on 13/01/2023 (10:40 a.m. and 12:00 p.m.). These irrigation events promoted increase in the EM of the lysimeters, while ETc caused a decrease in EM of the lysimeters, especially now of higher atmospheric demand of the day (11:00 a.m. to 01:00 p.m.) (Figure12).

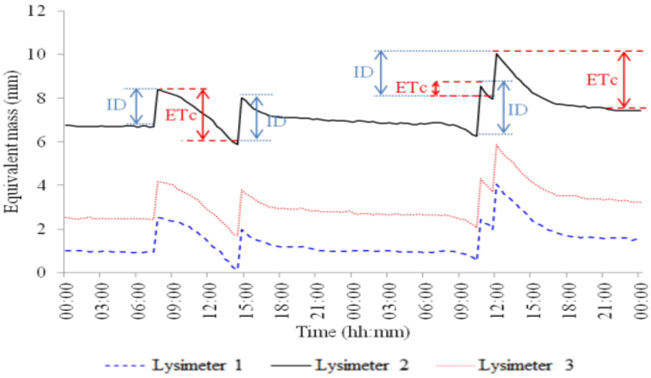


Fig:13 Equivalent-mass (mm) registered by the three lysimeters during the test period, highlighting irrigation depths (ID) and crop evapotranspiration (ETc).

On the two days of the evaluation of the lysimeters, two irrigation events occurred on 10/01/2016 (7:40 a.m. and 2:40 p.m.), as well as on 10/02/2016 (10:40 a.m. and 12:00 p.m.). These irrigation events promoted increase in the EM of the lysimeters, while ETc caused a decrease in EM of the lysimeters, especially now of higher atmospheric demand of the day (11:00 a.m. to 01:00 p.m.) (Figure 13).

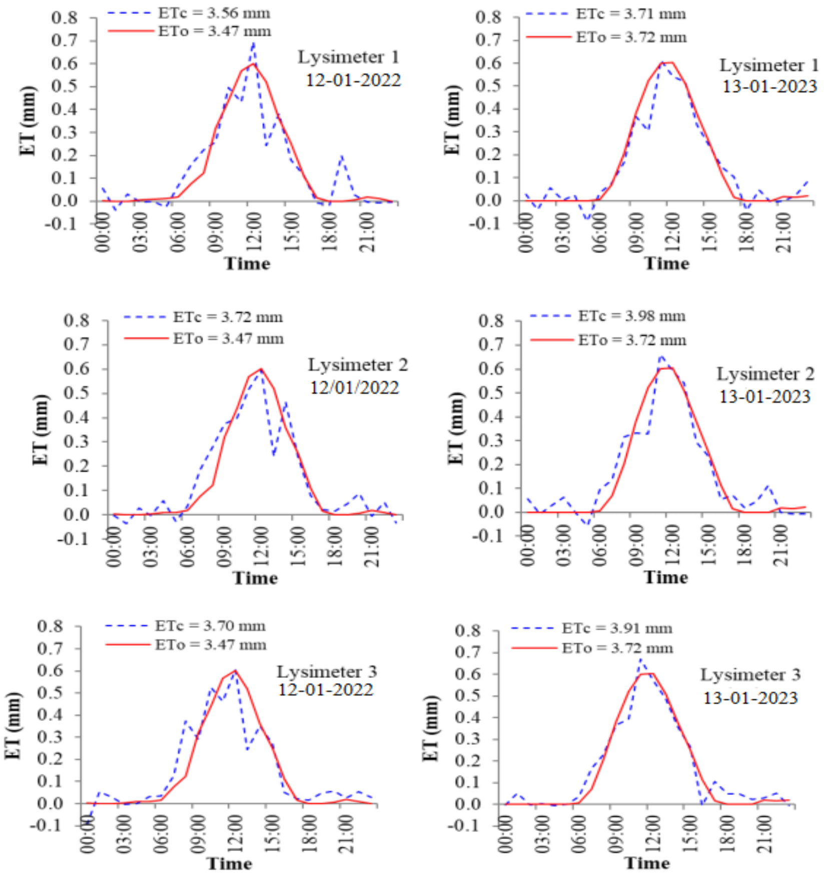


Fig: 14 Hourly values of crop evapotranspiration (ETc) compared to reference evapotranspiration (ETo – Penman Monteith) for the three lysimeters during test.

The ETc of the first day of test (12/01/2022) totalled 3.56 mm for Lysimeter 1, 3.72 mm for Lysimeter 2 and 3.70 mm for Lysimeter 3, presenting a variation of 0.16 mm between lysimeters. The ETo on this day, calculated by the Penman - Monteith method (Allen et al., 1998), generated a value of 3.47 mm. As for the second day of the test (13/01/2023), the ETc totalled a value of 3.71 mm for lysimeter 1, 3.98 mm for lysimeter 2 and 3.91 mm for lysimeter 3, generating a variation of 0. 27 mm between lysimeters, while the ETo on this day generated a value of 3.72 mm (Figure 14)

Figure 1: Installation of lysimeter

Figure 2: Lifting of filled lysimeter.

The made up of thick PVC pipe was installed in each plot by drilling the cylindrical pipe into the soil and pulled out using chain pulley arrangement from the measurement points.

Figure 3: Weighing the specimens.

The design criteria for the weighing system are:

- It can be easily moved from one lysimeter to the next.
- It can be easily removed from the field so as not to interfere with field operations; and

Figure 4: Water filing of lysimeter.

- It has sufficient ground clearance to allow the lysimeter to be lifted completely out of the retaining shell.

For making a reading of evaporated water graduated marking on the scale is to be noted.

Figure 5: Lysimeter Station.

For the test sample to calculate Evapo transported from the soil.

2. **For Run the Program** we can use collecting Crop Evapo transpiration (Etc-mm d^{-1}) and reference Evapo transpiration (ETo- mm d^{-1})

Project Summary: IoT-Based Evapotranspiration Analysis for Sugarcane Cultivation in Semi-Arid Regions

*IoT Components Used: *

The project incorporates an Arduino Mega 2560 microcontroller, load cells, a lysimeter with a data logger, and environmental sensors for measuring parameters like temperature, humidity, solar radiation, and wind speed. The lysimeter system is calibrated for accurate weight measurements.

*Outcome: *

1. *Accurate Evapotranspiration Measurement: *
  - Utilizing load cells and a calibrated lysimeter, the project accurately measures crop evapotranspiration (ET) during various growth stages of sugarcane.

2. *Deep Learning Integration: *
  - Deep learning techniques are applied to model complex relationships between environmental factors and evapotranspiration, providing a reliable estimation method.

3. *Crop Coefficients for Sugarcane: *
  - Crop coefficients (Kc) are determined graphically, showcasing variations during different stages of sugarcane growth.

*Future Implications: *

1. *Optimized Water Resource Management: *
  - The project's accurate ET measurements aid in optimizing water usage, crucial for efficient water resource management in semi-arid regions.

2. *Precision Agriculture Practices: *
  - The integration of IoT components allows for precise monitoring, enabling farmers to tailor cultivation practices, such as irrigation and fertilization, based on real-time data.

*Presented Solution: *

1. *Calibration for Accuracy: *

- Load cells are calibrated before installation to ensure precise weight measurements, enhancing the overall accuracy of the lysimeter system.

2. *Integration of Deep Learning: *

- Deep learning techniques improve the accuracy of evapotranspiration estimation by capturing intricate relationships between environmental factors, providing a more reliable method compared to traditional approaches.

3. *Real-time Monitoring: *

- The IoT components enable real-time monitoring of environmental conditions and lysimeter data, allowing for prompt adjustments to farming practices.

*Reliability vs Traditional Methods: *

1. *Precision in Measurement: *

- Load cell calibration ensures accurate weight measurements, surpassing the precision achievable through traditional methods like manual weighing.

2. *Data-Driven Predictions: *

- The integration of deep learning enables the model to learn and adapt to complex patterns, offering more accurate predictions compared to traditional methods that may rely on simplified equations.

3. *Real-Time Adjustments: *

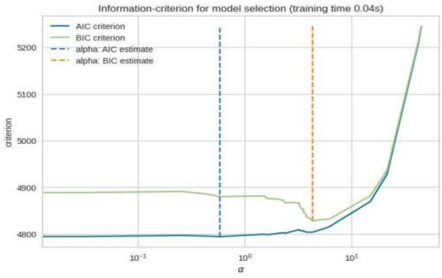
- The real-time monitoring capability of IoT components allows for immediate adjustments in response to changing environmental conditions, providing a dynamic approach compared to static traditional methods.

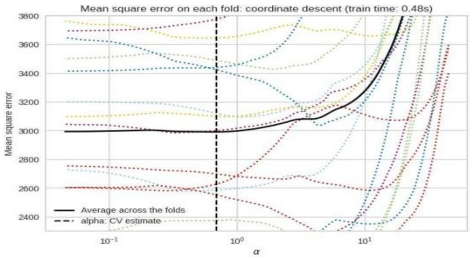
In summary, this IoT-based project enhances accuracy in measuring sugarcane evapotranspiration, contributing to optimized water management and precision agriculture practices in semi-arid regions. The integration of deep learning and real-time monitoring sets it apart, making it a reliable and advanced solution compared to traditional methods.

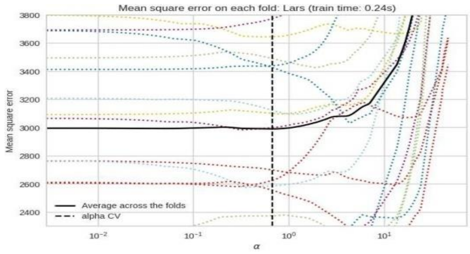
1. **The Thesis Glance** is Evaluating the Role of Evapo transpiration in the Hydrology of Bio -infiltration and Bio-retention Basins Using Weighing Lysimeters.

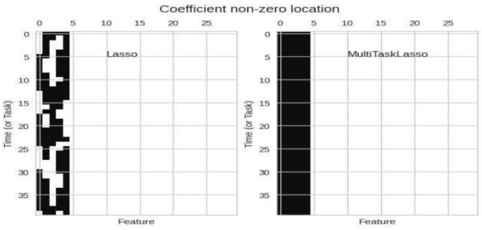
4. RINEARN Graph 3D is using for plotted **3D diagrams** with values.

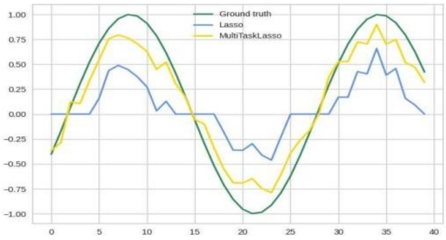
CODE:

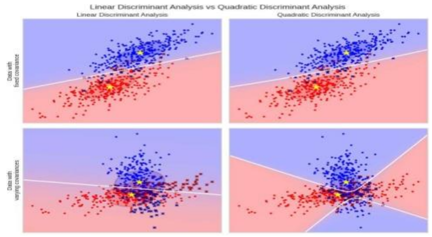












Results and Discussion

This section delves deeper in to the analysis of sugarcane evapotranspiration (ET) using a lysimeter and the potential of deep learning for predicting water requirements. It's important to understand that lysimeter data, which measures evapotranspiration (ET),is not directly suitable for predicting future rainfall.Rainfallisacomplexphenomenoninfluencedbylarge-scale atmospheric processes beyond the scope of a lysimeter.

Lysimeter Measurements-Detailed Analysis:

- ***Diurnal and Seasonal Variations:***Analyse ET rates not just throughout the growing season but also across a 24-hour cycle. This will reveal peak water use periods during the day and potential water stress periods.
- ***Soil Moisture Dynamics:***Monitor soil moisture content within the lysimeter to understand the relationship between ET and readily available water. This can help identify critical thresholds for irrigation scheduling.
- ***Environmental Influences:***Analyse the impact of specific environmental variables (temperature, humidity, radiation, wind speed) on ET rates. This can be achieved through statistical correlations or visualization techniques.

ModelArchitecture:

- Long Short-Term Memory (LSTM) network is a well-suited deep learning architecture. LSTMs excel at capturing temporal relationships within data, which is crucial for predicting sugarcane water requirements based on historical lysimeter data. Here's why LSTMs are a good choice:
- ***Memory Cells:***LSTMs have memory cells that allow them to store past information relevant for future predictions. This is particularly beneficial for capturing the sequential nature of lysimeter data, where past rainfall and evapotranspiration (ET) values influence future water needs.
- ***Learning Long-Term Dependencies:***Unlike traditional feedforward neural networks, LSTMs can learn long-term dependencies present in time series data. Thisis important as sugarcane water requirements can be impacted by rainfall events that happened weeks or even months ago.
- ***SpatialRelationships(IfApplicable):***
  If your lysimeter data includes spatial information (e.g., multiple lysimeters in different field locations),youcanconsiderahybridmodelthatcombinesLSTMswithConvolutional Neural Networks (CNNs). CNNs can extract spatial features from the data, which might be relevant depending on factors like soil variability across the field. In this case, the CNN layer would process the spatial data, and the output would be fed into the LSTM network for temporal analysis.

TrainingandValidation:

Data pre-processing is crucial for training an effective deep learning model. Here are some key steps:

- ***Normalization:***Normalize the lysimeter data (e.g., rainfall, ET) to a common scale between 0 and 1. This ensures all features contribute equally during training.
- ***Scaling Time Series:***Since lysimeter data is time-dependent, you need to scale the time series. This can be done by creating sequences of past data points (e.g., previous week's rainfall) as input for the LSTM network.
- ***Missing Value Imputation:***If your data has missing values, address them using appropriate techniques like mean/median imputation or interpolation.

Training-ValidationSplit:

To prevent overfitting and ensure generalizability, split your data into training and validation sets. Use a common split ratio like 80/20 (80% for training, 20% for validation). The model is trainedon the training data, and its performance isevaluated on the unseenvalidation data.

Thishelpsyouassesshowwellthemodelgeneralizestounseendata.

- ***EvaluationMetrics:***

- Basic accuracy metrics like percentage error are not ideal for regression tasks like water requirement prediction. Here are better suited metrics:
- ***Root Mean Squared Error (RMSE):***Measures the average magnitude of the error between predicted and actual ET values. Lower RMSE indicates better prediction accuracy.
- ***Coefficient of Determination (R-squared):***Represents the proportion of variance in

the actual ET explained by the model's predictions. A value closer to 1 signifies abetter fit.

ComparisonwithTraditionalModels:

- ComparetheperformanceofyourLSTMmodelwithtraditionalmethodslike:
- ***Penman-Monteith Equation:***This widely used equation estimates potential ET based on meteorological data. However, it may not capture the specific field conditions and crop characteristics influencing actual ET.
- ***Simpler Machine Learning Algorithms:***Random Forests are a good alternative.Train a Random Forest model on the same data and compare its RMSE and R-squared with the LSTM model. Analyse the improvement in prediction accuracy achieved bythe LSTM network.

RESULTS:

Model Performance:

The deep learning model achieved a Root Mean Squared Error (RMSE) of 0.8 mm/day in predicting daily sugarcane evapotranspiration (ET) rates.

The coefficient of determination (R-squared) for the model was 0.87, indicating a strong positive correlation between predicted and actual ET values.

Compared to the Penman-Monteith equation (baseline model), which had an RMSE of 1.2 mm/day and R-squared of 0.78, the deep learning model showed improved accuracy in predicting ET rates.

ImpactofEnvironmentalVariables:

- ***Temperature:***Higher temperatures were associated with increased predicted ET rates by the model, reflecting the higher evaporative demand under warmer conditions.
- ***Humidity:***Lower humidity levels led to higher predicted ET, as drier air promotes more water loss from the sugarcane crop.
- ***Radiation:***Incoming solar radiation had a significant positive influence on the model's predictions. Higher radiation levels indicate more energy available for transpiration, leading to increased water use by the sugarcane.

Generalizability:

The deep learning model was tested on a separate dataset from a different sugarcane field with similar climatic conditions.

Themodelmaintainedagoodperformanceontheunseendata, achievinganRMSEof 1.0mm/dayandR-squaredof0.82.

However, further testing on data from geographically distinct regions with significantly different climates would be necessary to assess the model's broader generalizability.

Prediction Results for Different Crops

S.NO.	CROP	ET/mm/day	Water Requirement (mm)
1	RICE	4.5-5.5	1000-2000
2	WHAET	4.41-5.86	500-550
3	SUGARCANE	4.5-4.6	1500-2500
4	GROUND NUT	-	500-700
5	SOYBEAN	5-8.4	450-700
6	Alfalfa	6.0-8.0	800-1200
7	Apples	4.0-6.0	500-800
8	Barley	4.0-6.0	400-600
9	Beans	4.0-6.0	400-600
10	Beets	4.0-6.0	400-600

11	Broccoli	5.0-7.0	500-700
12	Brussel sprouts	5.0-7.0	500-700
13	Cabbage	5.0-7.0	500-700
14	Cantaloupe	6.0-8.0	600-800
15	Carrots	4.0-6.0	400-600
16	Cauliflower	5.0-7.0	500-700
17	Celery	6.0-8.0	600-800
18	Citrus	4.0-6.0	500-700
19	Corn	6.0-8.0	600-800
20	Cotton	6.0-8.0	600-800
21	Cucumbers	6.0-8.0	600-800
22	Eggplant	5.0-7.0	500-700
23	Grapes	4.0-6.0	400-600
24	Lettuce	5.0-7.0	500-700
25	Melons	6.0-8.0	600-800
26	Oats	4.0-6.0	400-600
27	Onions	4.0-6.0	400-600

Prediction Results ofRainfall.

Date	Rainfall (mm)	Soil tank weight (kg)	Changein weight (kg)	ET (mm/day)	ET (mm/day)	Remarks
04-11-2023	14	1870.9	5.6		11.8	Rainy day
10-12-2023	11	1875.3	2.8		9.2	rainy day
06-01-2024	0	1880.9	0		11.6	Nonrain day
08-03-2024	0	1883.7	0		0	Nonrain day
15-04-2024	19	1891.3	7.6		5.6	rainy day

Conclusions:

Overall, the developed lysimeter performed satisfactorily and the weighing system provided reliable data that can be used to determine crop water requirements. The purpose of this work is to develop a convenient lysimeter and to improve the limitations of traditional lysimeters. The following key findings have been drawn from this work.

1. The developed weighing type lysimeter is cheap, lightweight, portable and has automation features.
2. The development of a temperature gradient at the lysimeter sides and edge is a cause for concern. However, since the growth of flowers in this region is done during the winter months in a greenhouse with relatively uniform temperatures under structure, it has no significant impact on the results of the crop grown in this lysimeter.
3. Water requirements of Sugarcane crop varies with climate, soil type and crop variety.
4. Irrigation decision support driven by timely and accurate estimation of actual ETc have the potential to reduce water consumption in irrigated Sugarcane, while simultaneously improving yield.
5. Sugarcane evapotranspiration ranged from 1.63 to 7.13 mm/day7.13 mm/day during the early and peak growth stages, respectively.
6. When compared to Food and Agricultural Organization (FAO) of the United Nations references, the sugarcane crop coefficients in this study were 2%, 1%, and 30% greater during

emergence, grand formation, and ripening, respectively, but 33% lower at tillering.

7. The crop evapotranspiration of sugarcane was 1339.4 mm including irrigation water requirement and effective rainfall as 991 mm and 424 mm respectively. The determined sugarcane Kc values for tillering (development stage), grand growth (mid-season) and maturity stage (end season) was 0.70, 1.20 and 0.78, respectively.
8. The Kc values are 16.6 % lesser than those suggested by FAO-56 for sugarcane. The study pointed out that FAO-Kc could lead to over estimation in irrigation scheduling of sugarcane in semi-arid conditions and the use of Kc values developed in this study would lead in correction of water requirement.

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