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RESEARCH ARTICLE

Assessment of maize evapotranspiration, water requirements and productivity using weather data in Coimbatore's semiarid climate

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Abstract

Accurately estimating crop water use is crucial for efficient water management in conservation agriculture, especially in Coimbatore's semiarid climate. This study assessed maize water use and productivity over three growing seasons (2023-2024) at AC&RI, Coimbatore. Irrigation applied each season varied between 500.8mm and 554.1 mm, averaging 535.8 mm, while total water supply ranged from 810.6 to 985.3 mm. Actual evapotranspiration (ET_a) was estimated using locally developed crop coefficient curves (Lk_c) and FAO crop coefficients. Water productivity for maize was calculated based on these estimates. Daily ET_a for maize ranged from 0.9mm to 8.2 mm. Other than the different seasons, ET_a varied from 342.6 to 372 mm, averaging 355.6 mm with the Lk_c curve. By FAO K_c, ET_a ranged from 400.8mm to 479.1 mm, with an average of 444.2 mm. The irrigation requirement ranged from 579.6mm to 672.7 mm, with an average of 629.5 mm using LK_c. Using FAO K_c, the range was 637.8mm to 762.9 mm, with an average of 718 mm. Crop water use efficiency (CWUE) ranged from 0.8 and 0.9 kg/m^3, with an average of 0.9 kg/m^3. The evapotranspiration water use efficiency (ETWUE) ranged from 2.0 to 2.1 kg/m^3, with an average of 2.1 kg/m^3. The irrigation water use efficiency (IWUE) varied across seasons, averaging 1.4 kg/m^3. Strong correlations were observed between CWUE, IWUE and the amount of seasonal irrigation (R^2 = 0.98 and 0.99, respectively). CWUE and ETWUE strongly correlated with IWUE (R^2 = 0.98 and 0.75, respectively). These findings suggest that maize irrigation in Coimbatore's semiarid regions should be tailored to local conditions to enhance water productivity.

Keywords

evapotranspiration; irrigation requirements; maize; water use efficiency

Introduction

Sustainable water management is essential as climate change worsens water scarcity and intensifies stress on natural resources, threatening agriculture, ecosystems and livelihoods. Efficient water use enhances resilience to unpredictable climate conditions and is essential for maintaining long-term food security. India, home to 18% of the global population, possesses only 4% of the world's water resources, making it particularly vulnerable to water stress. Groundwater, which supplies 40% of India's water needs, is being rapidly depleted. India, as the foremost extractor of groundwater globally, constitutes

12% of total extraction. According to a NITI Aayog report, if no mitigation measures are implemented, India could face a 6% GDP loss by 2050, as water demand is expected to surpass supply (1). The escalation of global climate change has resulted in increased droughts and water scarcity, posing a significant risk to food security (2). In India, agriculture is the largest water consumer, necessitating substantial efforts to improve water use efficiency (WUE) in the agriculture sector (3). The growing water demand, due to rapid population growth, has made it imperative to boost food production by increasing irrigation and industrial output to meet human needs. The primary purpose of irrigation is to provide water to support crop evapotranspiration (ET_c) when rainfall is inadequate. The main challenges limiting crop yields include the uneven and unpredictable distribution of monsoons and soil moisture stress during the summer months. Accurate data on crop water requirements, irrigation withdrawals, crop and soil type and weather conditions are essential for efficient planning. The water balance, along with the crop water and irrigation needs for different crops in the region, is ultimately determined by rainfall and evapotranspiration (ET). Farmers can achieve effective water management by maintaining or reducing water usage on their farms without negatively impacting crop yields and profitability. Efficient irrigation practices offer a practical approach to alleviating drought and tackling water scarcity in agriculture (4).

Maize (*Zea mays* L.), a key global food crop, plays a vital role in ensuring food security (5). Maize is known as the "Queen of Cereals" because of its exceptional genetic potential. All plant components, including the grain, leaves, stem, tassel and cob, hold economic significance and are utilized to manufacture various food and non-food goods. This highly adaptable crop is cultivated in over 166 countries, thriving in tropical, subtropical and temperate climates, from sea level up to altitudes of 3000 meters (6).

In India, maize is grown on 99.61 lakh hectare, with a productivity rate of 3260 kg per hectare (7). However, maize production in India faces unique challenges compared to regions like the U.S. and China, where advanced irrigation enhances water efficiency. Indian farmers, who predominately depend on rain-fed systems, grapple with unpredictable weather patterns and limited infrastructure.

To address these challenges, research tailored to India's specific conditions covering studies on ET, water requirements and productivity is crucial, such efforts are essential to improving water management practices and ensuring sustainable maize production across the country's diverse climates and soils.

Crop evapotranspiration, which includes both soil surface evaporation and plant transpiration, plays a crucial role in the water balance of farmland and the hydrological cycle. Accurate estimation of crop water requirements is essential for developing effective irrigation schedules. Research on ET_c is important for enhancing agricultural water efficiency, conserving irrigation resources, and safeguarding food security (8). Similarly, ET_a is a fundamental component in environmental, agricultural and hydrological research. It is indispensable for planning and managing irrigation systems to optimize water use in agriculture. Applying the right amount of water at the appropriate times is vital to meeting crop water demands and achieving optimal yields.

Traditional methods for measuring ET at specific sites, such as the Bowen ratio-energy balance method, weighing lysimeters, eddy covariance systems and photosynthesis instruments (9, 10), are limited by their need for specialized equipment, high costs and their suitability only for point or field scales. Although crop evapotranspiration (ET_c) can be directly measured using lysimeters and eddy covariance systems, it is more commonly estimated indirectly by combining reference crop evapotranspiration (ET_o) with crop coefficients (Kc). The Penman-Monteith formula, is widely regarded as one of the most accurate methods for calculating crop water demand and can facilitate large-scale mapping of ET_a (11). However, this method requires detailed information about crop structure (10).

The water balance method is another approach for estimating regional evapotranspiration (ET), provided the other hydrological components are known (12). The ET_a was linked with the reference evapotranspiration (Et_o) using a factor called the crop coefficient (13). The relationship between ET_a and Et_o is quantified using the crop coefficient (13). The Kc value varies depending on crop type, growth stage, soil type and moisture, management practices, canopy resistance and aerodynamic resistance. Additionally, climatic factors such as energy availability, air vapor content, and vapor pressure deficit (VPD) significantly influence Kc (14). High energy levels and VPD increase water loss and raise Kc, while lower levels have the opposite effect. Efficient irrigation practices must account for these variations to optimize crop growth while conserving water resources.

The Penman-Monteith method for calculating Et_o is widely recognized as it integrates various meteorological variables such as air temperature, humidity, wind speed, and solar radiation and is considered one of the most accurate among the various ET_o equations (15-20). Following the methodology proposed in earlier research, mid- and late-season were tabulated (21). The Kc values were adjusted to reflect local conditions, including crop characteristics, climate and growth stages (22). These adjustments consider factors such as the crop's height, the wind's speed and the minimum relative humidity, which influence both crop and aerodynamic resistance. Initial values of K_c should be mainly determined by soil type and the status of irrigation (23). Identifying crop phenology at each site and aligning tabulated K_c values with actual growth periods is crucial (24). Crop growth models that simulate crop phenology through thermal units are essential for refining these estimates (25). Developing K_c curves based on thermal units ensures that the physiological traits of the crop are adequately considered. The widely used two-step approach for estimating crop ET_a is commonly used and generally correlates well with ET_a values obtained from lysimeters (26, 27).

To address the climatic conditions and future projections, accurately estimating crop water use is crucial for effective planning and management within CA. The findings of this study on maize water use and productivity in Coimbatore's semi-arid region can guide irrigation scheduling, improve water management practices and improve WUE in similar climatic conditions.

Materials and Methods

Experimental site

The experimental area was situated at the Eastern Farm of the Agricultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, with geographical coordinates of approximately 11°N latitude and 76°E longitude. The study was conducted during the years 2022 - 2023. Weather data, including maximum and minimum temperature, minimum, maximum and average relative humidity (RHmin, RHmax, RHmean), solar radiation (Rs) and wind speed (u2), were collected from the Automated Weather Station at the site. The thermal units (TU) for maize were calculated during the maize-growing seasons of the year. The climatic data for the experimental period (2022-2023) are shown in Fig. 1.

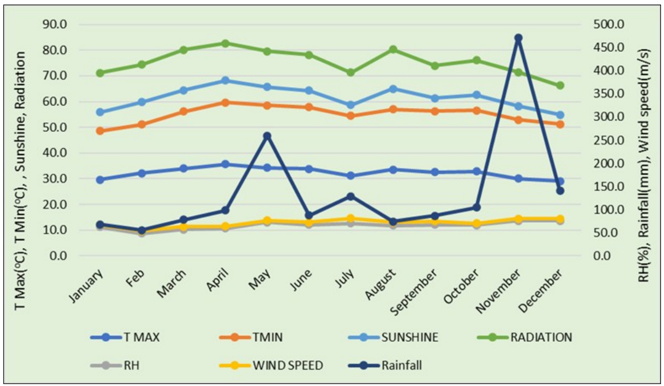

Fig. 1. Climatic data for the year 2022-2023.

Penman Monteith method

The daily grass Et_o was calculated by applying the ASCE version of the P-M equation.

$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + (\gamma C_n u_2/(T+273))(e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)} \quad \text{Eqn.1}$$

In this equation, ET_o - reference evapotranspiration (mm/day), Rn - net radiant energy received at the surface of the crop (MJ/m^2/d) and G denotes the soil heat flux density (MJ/m^2/d). T - air temperature at 2 meters height (°C), u_2 - wind speed at 2 meters above the ground (m/s), "e_s" - vapor pressure when the air is fully saturated with moisture (kP_a), "e_a"- actual vapor pressure (kP_a), (e_s - e_a) - saturation vapor pressure deficit, Δ - rate of change of saturation vapor pressure with temperature (kP_a/°C). C_n and C_d are constants with values of 900 °C mm s^3 Mg^{-1} d^{-1} and 0.34 s m^{-1}, respectively and γ is the psychrometric constant, which quantifies the relationship between heat and moisture (kP_a/°C).

Crop coefficients (K_c)

Maize was cultivated with sufficient fertilizer and water and its ET_a was calculated using a crop coefficient (K_c) curve from a previous study (28). The K_c for maize varies depending on factors such as climate, soil moisture content and crop growth stages. As maize progresses through its growth stages, from initial to late-season, variations in ground coverage, plant height and leaf area influence ET rates, causing fluctuations in K_c throughout the growing season. To estimate the Kc values for the maize growing season, thermal units were used with the following equation (28).

$$K_c = 0.12 + 0.00168{*}TU - 2.45{*}10^{-7}{*}TU^2 - 4.37{*}10^{-10}{*}TU^3 \quad \text{Eqn.2}$$

where, K_c represents the crop coefficient of maize calculated daily and TU is the thermal unit (°C)

The ET_a for the growing season of the maize crop was computed daily using crop coefficients for maize, which are defined under standard climatic conditions. These coefficients vary according to crop stage, with values of 0.3, 1.15 and 0.4 for initial, mid and late-season stages, respectively) (22).

A comparison was done between the ET_a estimated using a locally derived crop coefficient (K_c) and that recommended by the FAO. During the crop development and late-season phases, the Kc values were interpolated linearly between two established values. In the initial stage of maize, ET_a was primarily influenced by evaporation, so the adjustment of Kc during this phase is mainly dependent on climatic conditions. The FAO-56 method indicates that the crop coefficient is influenced by various factors, including crop height. Therefore, the standard Kc values for the mid-and late-season stages were adjusted based on climatic conditions and crop height.

$$K_c\,\text{Stage} = K_c\text{Stage} + [0.04(u_2-2) - 0.004(RH_{min}-45)]\,(h/3)^{0.3} \quad \text{Eqn.3}$$

where, K_c Stage is the universal value given by the FAO. During the growth stage, the speed of the wind at 2 meters above the ground is represented by u_2 (m/s) and RH_{min} denotes the minimum relative humidity at daily basis. The plant height varies from 0.1 m to 10 m across different growth stages.

Thermal unit (TU)

Thermal units, or growing degree days (GDD), are crucial for maize growth as they measure the accumulated heat needed for the crop's development. Adequate thermal units ensure timely germination, flowering and maturation. The Thermal unit (TU) represents the cumulative growing degree days (GDD) and reflects the total temperature contributing to maize growth over the entire season. It was calculated by the formula:

$$TU = \sum_{i=1}^{n} \frac{T_{max} + T_{min}}{2} - T_b \quad \text{Eqn.4}$$

Here, TU denotes the thermal unit (°C), T_{max} and T_{min} represent the maximum and minimum air temperature (°C), T_{base} is the maize threshold base temperature (10°C) and n is the number of days. The minimum temperature at which plant growth begins is the base temperature used to calculate growing degree days. A temperature range was applied for this calculation, with a maximum and minimum threshold of 30°C and 10°C respectively. Temperatures exceeding 30°C were limited to 30°C, while those falling below 10°C were adjusted to 10°C, as plant growth does not occur outside this range. The thermal unit (TU) value was recorded as zero if the daily average temperature fell below the base temperature.

Crop management

Maize [COH(M) 6] was planted in January, May, and September and harvested in April, August and December for the first, second and third seasons, respectively. Following TNAU recommendations, fertilizers were applied at the recommended rates of 250: 75: 75 kg/ha of N, P, K, respectively.

The field was maintained free of weeds to maximize grain yield, using the pre-emergence herbicide Atrazine, followed by human weeding. The field was irrigated based on ET data using an automated irrigation system, with irrigation scheduled at 40 -45% of the total available water depletion criteria to prevent plant stress. Insecticides were applied as needed when insect damage was detected. A combine harvester was utilized during harvest to collect maize and evaluate grain yield. The weight and moisture content of the grain from each plot were recorded and the yield was calculated in kg/ha, with the moisture adjusted to 15.5%.

Actual evapotranspiration (ET_a)

The ET_a was estimated by multiplying the crop coefficient with Et_o (13, 22).

$$ET_a = K_c * ET_o \qquad \text{Eqn. 5}$$

In this context, K_c represents the daily crop coefficient, ET_a represents actual evapotranspiration and ET_o represents the grass Et_o.

Irrigation water requirement (IWR)

The IWR was calculated using the FAO equation.

$$IWR = ET_{crop} - P_e \qquad \text{Eqn. 6}$$

Here, ETcrop represents the crop evapotranspiration (mm) and Pe denotes effective precipitation (mm), which was determined using the method provided by the USDA Soil Conservation Service.

Crop water use efficiency

Crop water use efficiency in terms of ET_C, evapotranspiration water use efficiency (ETWUE) and seasonal IWUE were determined using the following equations:

$$CWUE = \frac{Yield}{Seasonal\ water\ supply} \qquad \text{Eqn. 7}$$

$$ETWUE = \frac{Yield}{Maize\ seasonal\ ETa} \qquad \text{Eqn. 8}$$

$$IWUE = \frac{Yield}{Seasonal\ irrigation\ amount} \qquad \text{Eqn. 9}$$

In these calculations, ET_C and Irrigation water use efficiencies were expressed in kg/m^3, with yield measured in kg/ ha. Maize seasonal ET_a denotes total evapotranspiration for the crop season (mm), while seasonal irrigation represents the total irrigation applied during the entire crop season (mm). The seasonal water supply was calculated by adding the precipitation to the total irrigation (mm).

Evaluation criteria

Comparisons were made using t-tests, graphical analyses and simple linear regression. To assess differences in ET_a estimates based on the two Kc values, a paired t-test was employed with a significance level of 5%. The null hypothesis proposed that the seasonal maize ET_a estimates from the locally derived K_c and the FAO- K_c originated from the same population, indicating no significant difference in their means.

Linear regressions were constrained to pass through the origin, reflecting the theoretical expectation that ET_o should be zero in the absence of evapotranspiration. The estimated seasonal irrigation requirements were also compared to the actual irrigation rate using criteria similar to those applied to the estimates of ET_a.

Results and Discussion

Maize actual evapotranspiration

Daily evapotranspiration for maize ranged from 1.4 to 7.9 mm/ day in Season I, 1.3 to 7.2 mm/day in Season II and 0.9 to 8.2 mm/day in Season III during the 2023-24 year. Peak evapotranspiration occurred on days 102, 103, 106 and 107 in Season I; on days 39, 48, 49 and 70 in Season II; and on days 45, 63, 70 and 75 in Season III after planting. Evapotranspiration values calculated using the two K_c values are given in Fig. 2.

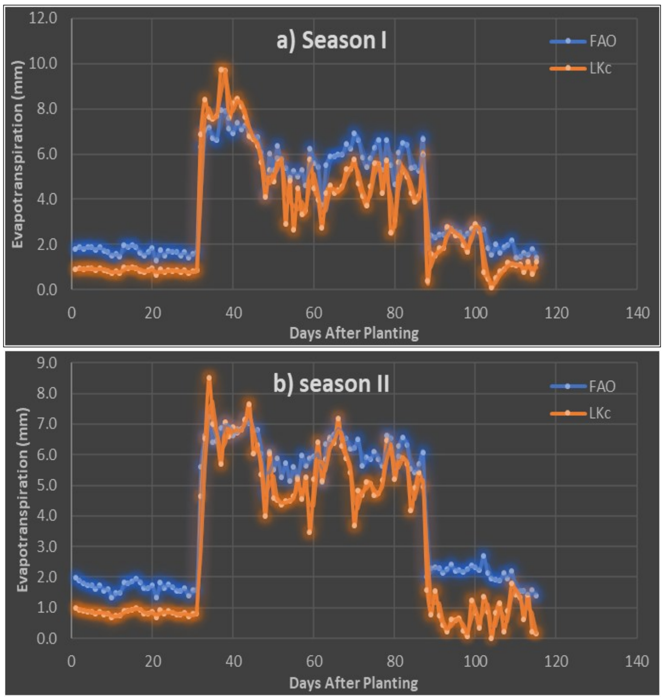

Fig. 2. Evapotranspiration based on Local kc (Lkc) and FAO method for a) Season I b) Season II.

Daily evapotranspiration (ET_a) of maize showed a strong correlation with accumulated thermal units, demonstrating the effectiveness of using these units to estimate daily water use. There was a significant correlation between seasonal ET_a and the amount of seasonal irrigation. Fig.3 depicts R^2 values was 0.83 when using the FAO-developed Kc factor and 0.69 with the locally developed Kc factor. The seasonal relationship between evapotranspiration and irrigation may have been influenced by factors such as crop physiology and irrigation practices.

According to the FAO's K_c factor, the seasonal evapotranspiration for maize ranged from 400.8 mm to 479.1 mm, with an average of 444.2 mm. Using the locally developed K_c value, the seasonal ET_a for maize ranged from 342.6 mm to 372 mm, averaging 355.6 mm (Table 1). These findings underscore the utility of the dual K_c method for accurately estimating ET_a, which aids in irrigation scheduling and total water use calculations, particularly considering the frequency of wetting (23).

The dual crop coefficient (Kc) method enhances the accuracy of ET_a estimation by separately considering soil evaporation and plant transpiration. This distinction allows

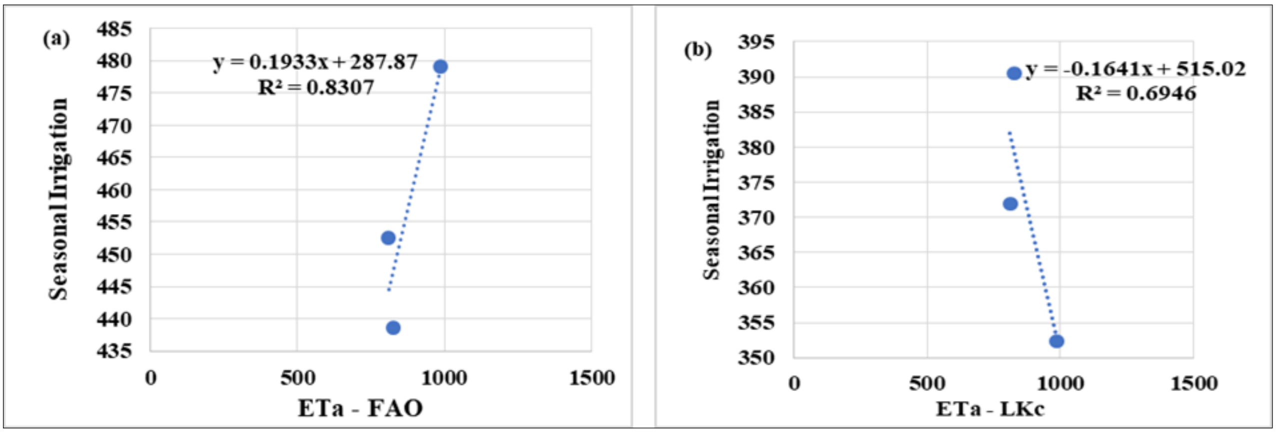

Fig. 3. Relationship between (a) FAO (ETa) and seasonal irrigation (b) Lkc (ETa) and seasonal irrigation.

Table 1. Water supply, requirement and ETa of maize

Season	Irrigation Applied (mm)	Rainfall (mm)	Total water supply (mm)	Effective Rainfall (mm)	ETa - Lkc (mm)	ETa FAO (mm)	Irrigation LKc (mm)	Irrigation FAO (mm)
I	552.6	258	810.6	200.7	372	452.6	672.7	753.3
II	554.1	431.2	985.3	208.8	352.4	479.1	636.2	762.9
III	500.8	325	825.8	187	342.6	400.8	579.6	637.8

better water management and irrigation scheduling, optimizing CWUE under varying soil and climate conditions. The results for maize were comparable across different treatments, with the ET_a values ranging from 481 mm and 634 mm for rainfed, limited and complete irrigation systems, with rainfed maize showing the minimum ET_a (14). Additionally, maize's seasonal ET_a varied with planting date, ranging from 675 mm to 703 mm for early planting, 664 mm to 702 mm for normal planting and 623 mm to 675 mm for late planting. On silt loam soils, ET_a for maize varied from 679 mm to 709 mm for early planting, 662 mm to 714 mm for normal planting and 625 mm to 687 mm for late planting (29).

Estimating maize ET_a using crop coefficients based on thermal units closely matched the ET_a in northeastern regions (14). Using crop coefficients based on thermal units simplifies evapotranspiration forecasting and irrigation scheduling, reducing the need for adjustments due to unusual weather or planting dates (30). Whenever feasible, farmers should rely on ET_a rather than Et_o for irrigation planning.

In Mexico, a 28,000-hectare irrigation project utilized the FAO-56 Penman-Monteith ET method for scheduling irrigation (31). This method was enhanced by integrating growth stages into Kc values, setting wind limits, applying a dryness code, incorporating meteorological corrections recommended by FAO-56 and adjusting coefficients. These refinements reduced ETa estimation errors from 75 mm to 10 mm, corresponding to a decrease from 23% to 3% of ETa during the first 80 days.

Numerous studies have demonstrated the effectiveness of the FAO-56 Penman-Monteith method in improving irrigation efficiency, showing a strong correlation between crop yield and ET_a (29). Field studies in Nebraska revealed that fully irrigated maize exhibited ET_a values ranging from 526 mm to 655 mm (32, 33).

Maize seasonal irrigation requirements

The seasonal irrigation applied ranged from 500.8 mm to 554.1 mm, averaging 535.8 mm. Seasonal precipitation ranged between 258 mm and 431.2 mm, while the Cumulative water supply was between 810.6 mm and 985.3 mm. The lowest irrigation requirement was observed during Season III (September - December), likely due to the influence of the Northeast monsoon. Using locally developed K_c values, maize irrigation needs were estimated to be between 579.6 mm and 672.7 mm, averaging 629.5 mm. In comparison, irrigation needs calculated with FAO Kc values ranged from 637.8 mm to 762.9 mm, averaging 718 mm (Table 1). The reduced water application was attributed to the use of an automated irrigation system. Fields using surface irrigation systems often exhibit higher water needs. In contrast, subsurface drip irrigation, known for its greater efficiency, can lower overall crop watering requirements for maize production in similar climates and management settings (34, 35). With the subsurface drip irrigation system, water demand was approximately reduced by 25% while maintaining optimal production levels (36).

Water use efficiencies of maize

Maize showed variation in water used efficiencies, with CWUE spanning from 0.8 to 0.9 kg/m^3, averaging 0.9 kg/m^3. The ETWUE was higher, ranging between 2.0 and 2.1 kg/m^3, with a mean value of 2.1 kg/m^3. The IWUE for maize fluctuated annually, averaging 1.4 kg/m^3 (Table 2). Strong correlations were found between CWUE and seasonal irrigation amounts, as well as between seasonal amount of irrigation and IWUE, with R^2 values of 0.98 and 0.99, respectively (Fig.4). Both Crop and Irrigation efficiencies of water demonstrated a linear decrease with increasing irrigation volumes. Additionally, CWUE exhibited a linear increase in relation to IWUE, with R^2 0.98, while ETWUE exhibited a moderate correlation with IWUE showing R^2 0.75 (Fig. 5).

Table 2. Yield and water use efficiencies of maize

Yield (kg ha^{-1})	CWUE (kg/m^3)	ETWUE (kg/m^3)	IWUE (kg/m^3)
7564	0.9	2.0	1.4
7439	0.8	2.1	1.3
7207	0.9	2.1	1.4

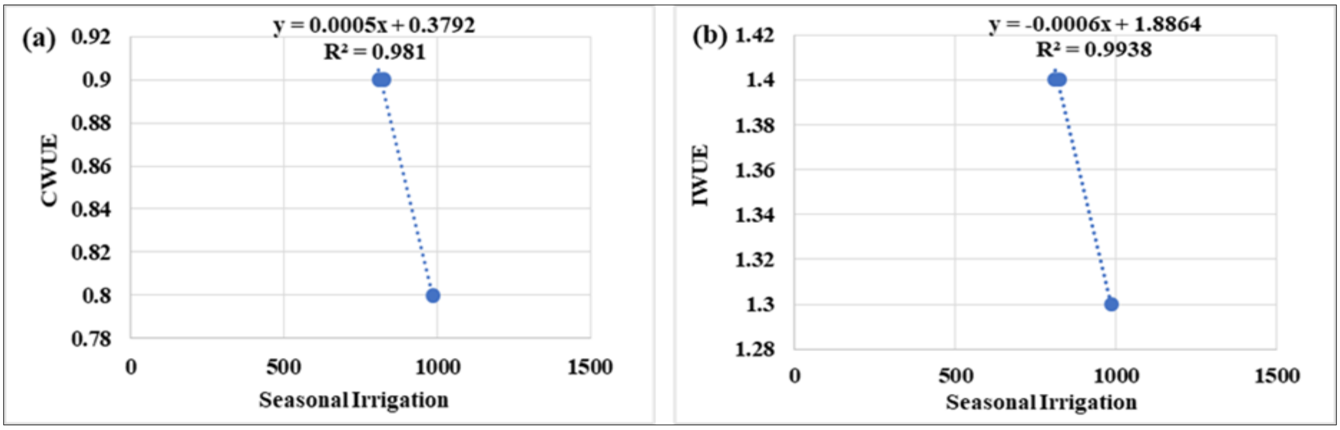

Fig. 4. Relationship between (a) CWUE and seasonal irrigation (b) IWUE and seasonal irrigation

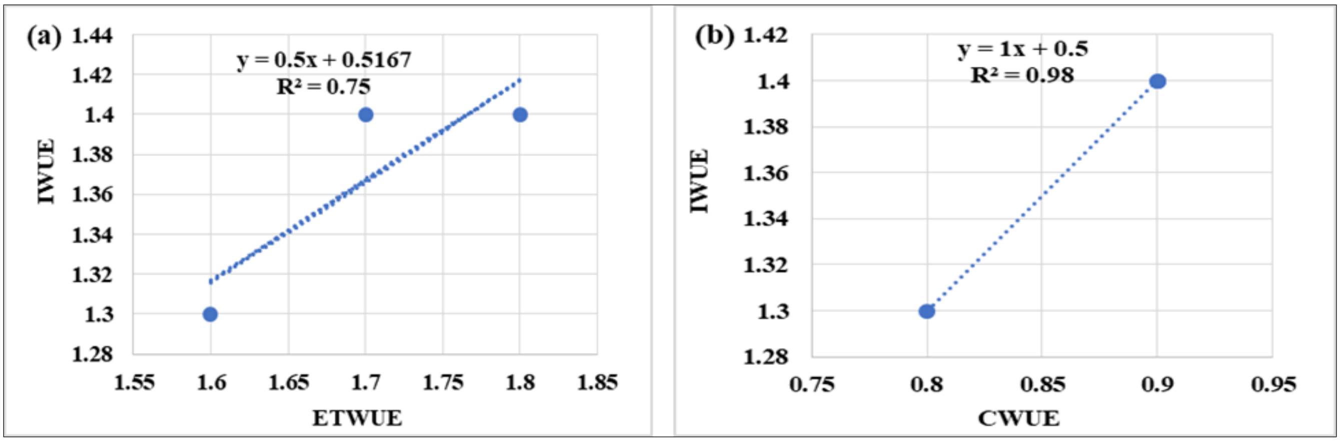

Fig. 5. Relationship between (a) ETWUE and IWUE (b). CWUE and IWUE.

Fluctuations in climatic conditions, including vapor pressure deficit (VPD), likely influenced Et_o, impacting maize's ET_a. Variability in annual rainfall and its distribution affected seasonal water supply requirements (32). Changes in seasonal ETa, irrigation levels and total water supply significantly influenced water use efficiencies. Achieving higher yields with reduced water usage enhances water productivity under sustainable farming practices.

The CWUE obtained here was similar to other research, which showed that the CWUE of maize ranged from 0.6 to 1.7 kg/m^3(29). Another study indicated that maize CWUE ranged from 1.24 to 2.03 kg/m^3 under a micro-irrigation system (37). Another study noted comparable findings, who discovered that The IWUE in Nebraska fluctuated based on planting date and density, with values ranging from 1.20 kg/m^3 to 5.22 kg/m^3 in maize (38). These results suggest the potential for implementing efficient irrigation and water management strategies to enhance crop productivity while minimizing water use. Adaptation of successful techniques from these regions to similar agricultural conditions appears promising. Another study reported that the maize ETWUE values ranged between 0.67 and 2.34 kg/m^3 (39). Maize ETWUE is influenced by the quantity and distribution of seasonal precipitation (40). The highest ETWUE values was achieved with minimal irrigation combined with addition to rainfall, emphasizing the efficient use of applied water and deeper soil moisture extraction to optimize stored soil moisture and precipitation.

A research documented ET_a between 517 and 655 mm, with CWUE ranging from 1.73 to 2.34 kg/m^3 across various practices of irrigation (32). Another study found CWUE values of 1.35 to 1.95 kg/m^3 under both full and limited irrigation conditions (41). In water-scarce environments, agricultural water productivity can be improved by implementing advanced irrigation and cultivation practices, such as partial irrigation, while maintaining yield levels. Variations in CWUE, ETWUE and IWUE are linked to differences in evapotranspiration, seasonal irrigation levels, water availability, climatic conditions and crop management practices, as highlighted in the referenced studies.

Conclusion

The water use and productivity of fully irrigated maize were evaluated in Coimbatore across three growing seasons in 2023-2024. Seasonal irrigation varied from 500.8 to 554.1 mm, while total water supply ranged between 810.6 to 985.3 mm. Maize ET_a varied across seasons, averaging 355.6 mm with the locally developed Kc curve and 444.2 mm using FAO Kc values. The average irrigation requirement was 629.5 mm with the local K_c and 718 mm based on FAO K_c values. The average irrigation requirement was 629.5 mm based on the local Kc and 718 mm using the FAO Kc.

Crop water use efficiency, ETWUE and IWUE fluctuated between seasons. A strong linear relationship was observed between CWUE and IWUE (R^2 = 0.98), while IWUE also had a significant correlation with ETWUE (R^2 = 0.75). The results of this study provided valuable insights for irrigation planners, agricultural project managers, researchers, stakeholders and producers, particularly in the domain of maize water management. It offered recommendations for optimizing CWUE, IWUE, or ETWUE under similar climatic and management conditions to enhance crop productivity with efficient use of water resources.

Soil type plays a crucial role in influencing irrigation requirements, as different soils have varying water retention capacities, permeability and drainage properties. Therefore, adapting these findings to different regions would require modifications based on the specific soil characteristics to achieve efficient water management and optimize maize productivity. Additionally, maize irrigation practices should match actual water needs, utilizing current local meteorological data. This strategy could enhance irrigation efficiency and promote sustainable agriculture in semiarid areas with scarce water resources.

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Authors' contributions

RM carried out conceptualization, data curation and writing the original draft. PS participated in conceptualization, supervision, funding acquisition, review and editing. RM carried out the methodology of the study and validation. KR performed software and formal analysis. RV corrected the manuscript. SA carried out the review and editing.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT to improve language and readability. After using this tool/ service, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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