Determination of Evapotranspiration and Crop Coefficient for Tomato by Using Non-Weighing Lysimeter in Semiarid Region

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ABSTRACT: Providing an accurate amount of water to crops based on their requirements is the primary objective of irrigated agriculture. The crop evapotranspiration and coefficient of tomato were measured using non-weighing lysimeters. The trial was conducted at the Melkassa Agricultural Research Center's experimental farmland in Ethiopia. The soil water balance approach was applied to compute tomato crop evapotranspiration, whereas the reference evapotranspiration was computed using the Penman-Monteith method. The crop coefficient was calculated using the ratio between the measured crop evapotranspiration and the reference evapotranspiration. A total of 590.4 and 413.3 mm of tomato seasonal evapotranspiration was recorded in the experimental years 2022 and 2023, respectively. The mean crop evapotranspiration for tomatoes over the two experimental years was 501.83 mm. The mean locally produced crop coefficient values were 0.63 for the initial, 1.18 during the mid, and 0.94 at the end of the season. The FAO-adjusted *Kc* values were 1.12 during the mid and 0.86 at the end of the season. The FAO-adjusted crop coefficient values differed from the crop coefficient values developed. Hence, to ensure efficient irrigation scheduling and planning, measuring the crop evapotranspiration and coefficient for optimal crop production under specific climatic conditions is vital.

KEYWORDS: Tomato, crop coefficient, crop evapotranspiration, reference evapotranspiration, non-weighing lysimeter

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Introduction

Precise application of water to crops based on their needs is vital for reducing water scarcity in global agriculture (Negash et al., 2023). Globally, agriculture is a major consumer of water. It accounts for more than 80% of the available freshwater (Dingre & Gorantiwar, 2020). Nevertheless, this share continued to reduce its availability for irrigation in arid and semi-arid areas of the world. Semi-arid areas of Ethiopia cover 301,500 km², which accounts for 27% of the total land of the country, and represents a crop production area under severe moisture stress (Engida, 2000), needs to conserve water and enhance on-farm water management. In these parts of the country, food insecurity has been reported (Intergovernmental Authority for Development [IGAD] and Food and Agricultural Organisation [FAO], 1995). This is due to the shortage of rainfall, occurrences of extreme events due to climate change, and other unknown phenomena. In this area, however, there is a low possibility of frequent irrigation water application to the crop owing to water shortages. This calls for an enhancement in water use efficiency to satisfy the water requirement of the irrigated crops. Hence, an accurate estimation of crop water requirement and coefficient is essential to develop an effective irrigation management strategy.

Tomato (*Solanum Lycopersicum*) is an essential staple vegetable crop widely grown in the tropics and sub-tropic areas of the world and ranks second among vegetables (Reddy et al., 2023). It is produced in the form of fresh and processed food. It originated from tropical parts of Mexico to Peru (Anastacia et al., 2011; FAO, 2005). Tomato plants are sensitive to water stress (Zheng et al., 2013). In 2020, the global total fresh tomato production was 186.82 million tons (Yang et al., 2022). In Ethiopia, tomatoes are grown both under rainfed and irrigation conditions. Approximately 7,710.16 hectares of land is covered with tomatoes. With this mass of land, a total yield of 336,558.42 quintals of tomatoes was harvested (ESS, 2022). Recently, this number has increased in the country due to the expansion of irrigation agriculture practices in the state and private farms. However, the yield of these vegetable crops is affected by inadequate water supply and inappropriate irrigation scheduling. Hence, to enhance crop production, water should be applied according to the consumptive demand of the crops. Therefore, knowledge of crop evapotranspiration (ETc) is essential to improve water use efficiency, yield, and quality of irrigated crops.

ETc can be measured using the soil water balance technique with the help of a lysimeter (weighing and non-weighing types) setup. A lysimeter is a device in which the major components of the hydrological water balance can be measured. A lysimeter of a non-weighing-type can measure long-term ETc on a weekly, decadal, and monthly basis, and can be used to manage and plan irrigation systems (Allen et al., 1998). Weighing-type lysimeters can measure ETc values for short

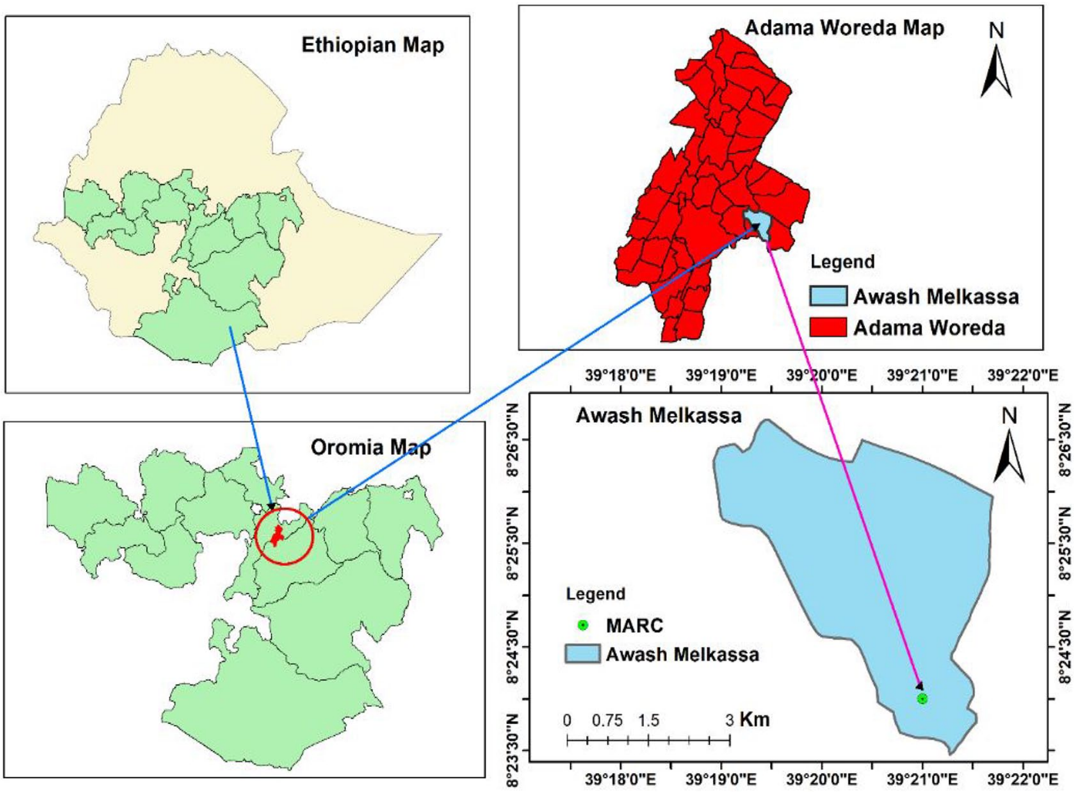

Figure 1. Study area map.

periods, but their installation and maintenance costs are high (Srinivas & Tiwari, 2018). Hence, measuring the daily, seasonal, and peak evapotranspiration rate of tomatoes using non-weighing lysimeters was the first objective of this study.

Moreover, ETc can be estimated by utilizing a two-step method that relates crop-specific coefficient *Kc* to ETo. This method is highly convenient for computing ETc and is primarily employed by technicians and irrigation professionals in real-world scenarios. Nevertheless, to facilitate irrigation planning, the crop coefficient (*Kc*) is necessary when utilizing the measured ETc. The crop coefficient (*Kc*) signifies the crop's unique water consumption, which varies throughout the growing period attributable to physiological changes in the crop. In 1968, Jensen introduced the crop coefficient methodology for ETc estimation which was further modified by numerous scholars (Allen et al., 1998; Doorenbos & Pruitt, 1977). *Kc* is developed with a ratio of ETc to ETo. The authors underlined the importance of developing *Kc* values for each crop based on lysimeter and local climatic data. *Kc* based on lysimeter studies has not been developed for important crops like tomatoes in the semi-arid climate of Ethiopia, particularly in the warm cropping season. Hence, deriving the *Kc* values for tomatoes using daily climatic (ETo) and measured crop evapotranspiration (ETc) data for irrigation planning and management at a local level was the second objective of this study.

Numerous approaches are presented to calculate reference evapotranspiration. In 1948, the original ETo equation was introduced by Penman and subsequently modified by several researchers (Allen et al., 1998; Doorenbos & Pruitt, 1977; Hargreaves & Samani, 1985; Watson & Burnett, 1995). The FAO-56 Penman-Monteith technique, after modification, stands as the only standardized approach capable of yielding satisfactory ETo outcomes across diverse climatic scenarios. Hence, driving the daily, seasonal, and peak reference evapotranspiration (ETo) using daily climatic data was the third objective of this study.

Material and Methods

Study site

The field trial was carried out at Melkassa Agricultural Research Center, Ethiopia (8°24'N and 39°21'E) (Figure 1). The study site climate was categorized as semiarid with irregular and unequal distributions of rainfall patterns. Between 1977 and 2019, the average minimum and maximum temperatures varied from 13.86°C to 28.73°C. The area receives a mean annual rainfall of 807.35 mm during the same period. July, August, and September had the highest rainfall. From 1977 to 2019, the area's mean annual wind speed and ETo varied between 0.3 and 3.23 m s^{-1} and between 3.8- and 5.42 mm day^{-1}, respectively. The average monthly weather parameters during the experimental year are shown in Figure 2. The soil in the study area consists of clay loam soil. The soil had a bulk density of 1.13 g cm^{-3}, field capacity (FC) of 0.346 m^3 m^{-3}, and permanent wetting point (PWP) of 0.176 m^3 m^{-3}.

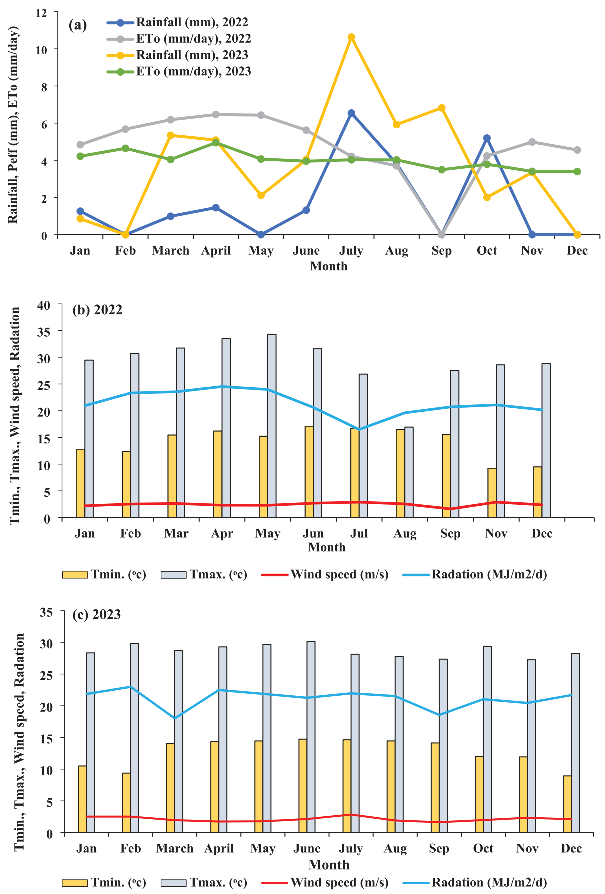

Figure 2. Monthly weather parameters during (a) 2022 and 2023 (b) 2022 and (c) 2023 tomato growing season.

The experimental setup

Two lysimeters were utilized to measure ETc and *Kc* for tomatoes. The first lysimeter had an internal planting area of 2 m^2, while the second lysimeter had a larger area of 4 m^2. The overall depth of the lysimeters measured 2.6 m, comprising a 1 m effective soil depth along with an extra 0.5 m layer, 0.1 m of coarse sand, 0.1 m of gravel, 0.2 m coarse aggregate, 0.1 m R.C beams supporting, 0.45 m of mesh, 0.05 m drain chamber and 0.1 m rims above the soil surface (Figure 3). The total area of the lysimeter was 36 m^2 (6 × 6 m) including the internal area. Each lysimeter access chamber was linked to an underground steel pipe to drain excess water. The lysimeter rims were placed 0.1 m above the soil surface to prevent surface runoff from entering the lysimeter during rainy days. Access tubes were inserted up to a 1 m effective root depth to monitor the soil moisture level inside the lysimeters.

Experimental procedures

Before transplanting, the land was plowed, and nursery seedbeds measuring 1 m wide and 5 m long were prepared. Tomato seeds were hand-drilled into a nursery bed at a spacing of 15 cm. For each seed bed, 100 g diammonium phosphate (DAP) was used during sowing (EIAR, 2004). Dry grass straw mulch was used to cover the nursery bed, the plants were watered, and less competent plants were thinned to maintain vigorous growth. When a week was left for transplantation, the water application to the plants was reduced. After approximately 25 days in the nursery, uniform, healthy, and vigorous seedlings were selected and transplanted to the experimental field with 100 × 30 cm spacing.

Crop agronomic practice

Tomato variety (Gelilema) was sown on a 1 × 5 m bed at the beginning of February each year during the 2022 and 2023 growing seasons. The seedlings were transplanted into the experimental field after 25 days both inside and outside the lysimeter. Plant densities of 16 and 104 were transplanted inside and outside the lysimeter, respectively, with a lysimeter with an internal area of 4 m^2, and the plant densities of 8 and 112 were also transplanted inside and outside the lysimeter, respectively, with a lysimeter with an internal area of 2 m^2. The rows and plant spacings were 100 and 30 cm, respectively. All agronomic practices (fertilization, weed management, pest control, etc.) recommended by the EIAR (2004) were consistently applied to the crop. After about 100 days of transplantation, the tomato plants were harvested over two successive experimental seasons.

Irrigation application and soil moisture monitoring

Before and after each irrigation, the soil water content was measured within the lysimeter, and irrigation events were conducted based on the soil moisture levels. A neutron moisture meter (CPN503) and gravimetric (oven method) were employed to quantify the soil water content at depths ranging from 0 to 15 cm and 15 to 100 cm, respectively. Soil particle size distribution was determined using the Bouyoucos hydrometer method. The core method was used to collect undisturbed soil samples to compute the soil bulk density in the experimental field. The total available soil water can be computed by subtracting the permanent wilting point (PWP) from the field capacity (FC) after measuring the soil moisture at the FC and PWP using a pressure plate apparatus. Irrigation water was provided to the crop when the main rooting layer had been depleted by 40% of the available soil water. Watering can be used to apply a known volume of irrigation water to crops. Irrigation was terminated when the crop reached maturity. Equation (1) was used to compute the volume of applied irrigation water to the crop (Brouwer et al., 1985):

$$\text{Quantity of applied water}\left(m^3\right) = \text{Lysimeter area}\left(m^2\right) * \text{Applied depth}\left(m\right) \quad (1)$$

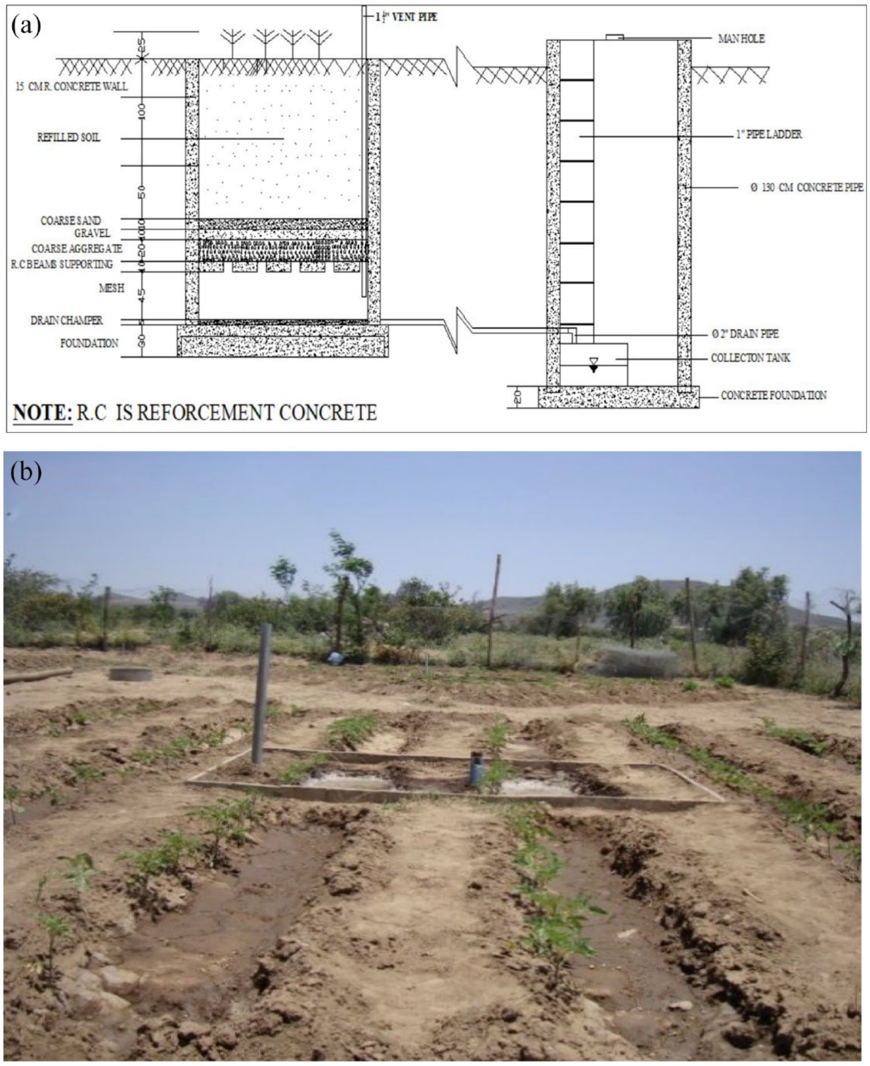

Figure 3. Drawing of designed drainage (non-weighing) lysimeter (a), photo of drainage (non-weighing) lysimeter during tomato transplanting (b).

Crop evapotranspiration (ETc) and reference evapotranspiration (ETo)

Crop evapotranspiration (ETc) is the amount of water transferred from the soil to the atmosphere through evaporation and transpiration by plants. The average daily ETc of the crop was computed using equation (2). The effective rainfall, which was part of the rainfall that fell on the soil and became accessible for crops in mm, was computed using equations 3 and 4. This is because it was developed based on analyses of different semi-arid climates.

$$\mathrm{ETc} = \left[\frac{\mathrm{I} + \mathrm{P_{eff}} - \mathrm{D} \pm \Delta \mathrm{S}}{\Delta \mathrm{t}}\right] \tag{2}$$

Where: ETc = crop evapotranspiration (mm day^{-1}), P_{eff} = effective rainfall (mm), I = applied irrigation depth (mm), ΔS = change in soil moisture (mm), D = drainage depth (mm), and t = time between two consecutive observations in days. Graduated cylindrical was used to measure the drainage depth (D) in the underground room. Changes in soil moisture (ΔS) were calculated by subtracting the moisture content acquired today from the previous day.

$$\mathrm{P_{eff}} = \left(0.6 * \mathrm{P}\right) - \frac{10}{3} \ \text{for } \mathrm{P_{month}} \leq 70\,\mathrm{mm} \tag{3}$$

$$\mathrm{P_{eff}} = \left(0.8 * \mathrm{P}\right) - \frac{24}{3} \ \text{for } \mathrm{P_{month}} > 70\,\mathrm{mm} \tag{4}$$

where; P_{eff} is effective rainfall (mm); and P is total precipitation in the crop growing season (mm).

The evapotranspiration rate from a reference surface that is not short of water is called reference evapotranspiration and is denoted as ETo. Using the FAO Penman-Monteith equation, the cropwat8.0 model was employed to compute daily reference evapotranspiration (ETo). The model inputs consisted of weather data including daily minimum and maximum air temperatures, wind speed at a height of 2 m, relative humidity, and sunshine hours.

Table 1. Hydrological Water Balance Components (cm) for Tomatoes During the 2022 and 2023 Experimental Seasons.

YEAR		2022					2023						AVERAGE			
STAGES	DAYS	PEFF	*I*	*D*	ETO	ETC	DAYS	PEFF	*I*	*D*	ETO	ETC	PEFF	*I*	*D*	ETC
Initial	12	5.84	23	—	74.7	28.84	12	76.7	—	50.9	43.1	25.82	41.27	23	509	27.33
Development	26	126.7	63.5	50.6	163.4	143.1	24	64	50.7	21.3	105.5	93.4	95.36	57.1	35.95	118.21
Mid-season	39	—	318.9	—	244.9	311.5	37	146.3	91.1	31.4	176.9	206.1	146.3	228.4	—	258.8
End-season	28	—	107	—	173.4	107	27	14.2	73.9	—	153.6	88.1	14.16	133	—	173.5
Total	105	132.6	512.4	50.6	656.4	590.4	100	301.2	216	103.6	479.1	413.3	216.9	364.1	77.1	501.83

Note. ETc = crop evapotranspiration; ETo = reference evapotranspiration; *I* = applied irrigation water; Peff = effective rainfall; *D* = drainage water.

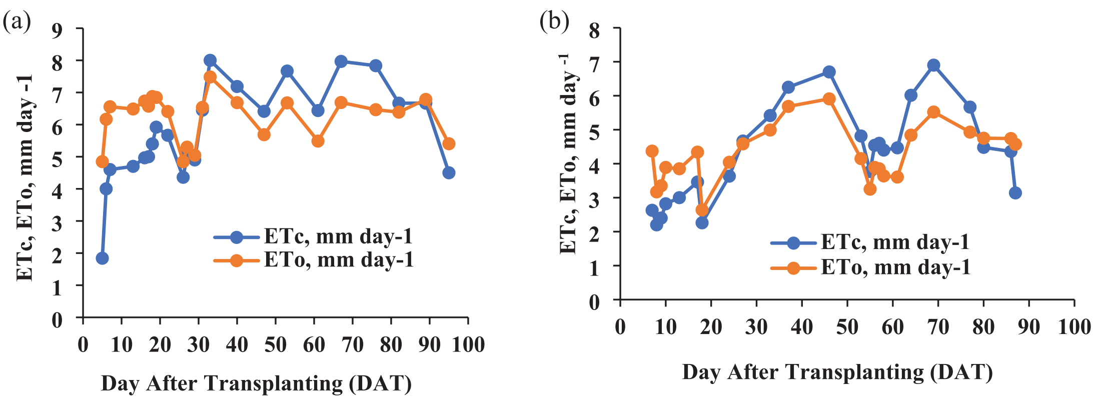

Figure 4. Crop evapotranspiration (ETc) as a function of days after transplanting for tomato during (a) 2022 and (b) 2023.

Crop coefficient (Kc)

Crop coefficient (*Kc*) signifies the crop's unique water consumption, which varies throughout the growing period attributable to physiological changes in the crop. Equation (5) was used to compute the stage-wise tomato *Kc* values:

$$Kc = \frac{\mathrm{ETc}}{\mathrm{ETo}} \tag{5}$$

Where: *Kc* is crop coefficient (dimensionless); ETc is crop evapotranspiration (mm day^{-1}), and ETo is reference evapotranspiration (mm day^{-1}).

Adjustment of FAO crop coefficient using local climate

In FAO-56, tomato *Kc* values for the initial, mid, and end seasons are reported as 0.6, 1.15, and 0.7 to 0.9, respectively. These values were derived under conventional climatic conditions (RHmin = 45% and u_2 = 2 m s^{-1}). These numbers must be modified to account for the local climate, where the wind speed and RHmin differ by 2 m s^{-1} and 45%, respectively. The *Kc* values greater than 0.45 for the mid and end-season were adjusted to account for the climatic conditions of the area and plant height as follows (Allen et al., 1998):

$$Kc_{\mathrm{mid-FAO}} = Kc_{\mathrm{mid}}\left(\mathrm{Tab}\right) + \left[0.04\left(\mathrm{u}_2 - 2\right) - 0.004\left(\mathrm{RH}_{\mathrm{min}} - 45\right)\right]*(\mathrm{h}/3)^{0.3} \tag{6}$$

Where $Kc_{\mathrm{mid-FAO}}$ = FAO-adjusted *Kc* for the midseason, $Kc_{\mathrm{mid}}\left(\mathrm{Tab}\right)$ = *Kc* tabulated for the midseason gained from FAO-56, u_2 = Mean wind speed at 2 m height during the midseason (m s^{-1}), RHmin = Mean relative humidity during the midseason (%), and *h* = Mean plant height during the midseason (m). $Kc_{\text{-end-FAO}}$ was calculated using some method. More justification for the correction in the above equations is explained by (Allen et al., 1998).

Results

Crop evapotranspiration and reference evapotranspiration

Accurate measurement of crop evapotranspiration (ETc) based on crop growth stage, root depth, soil water-holding capacity, and precipitation data is essential for managing irrigation water in agricultural fields. The seasonal evapotranspiration (ETc) and the developed hydrological water balance components (cm) of tomato are presented in Table 1. The average daily evapotranspiration and ETo for the 2022 and 2023 tomato experimental periods are also shown in Figure 4.

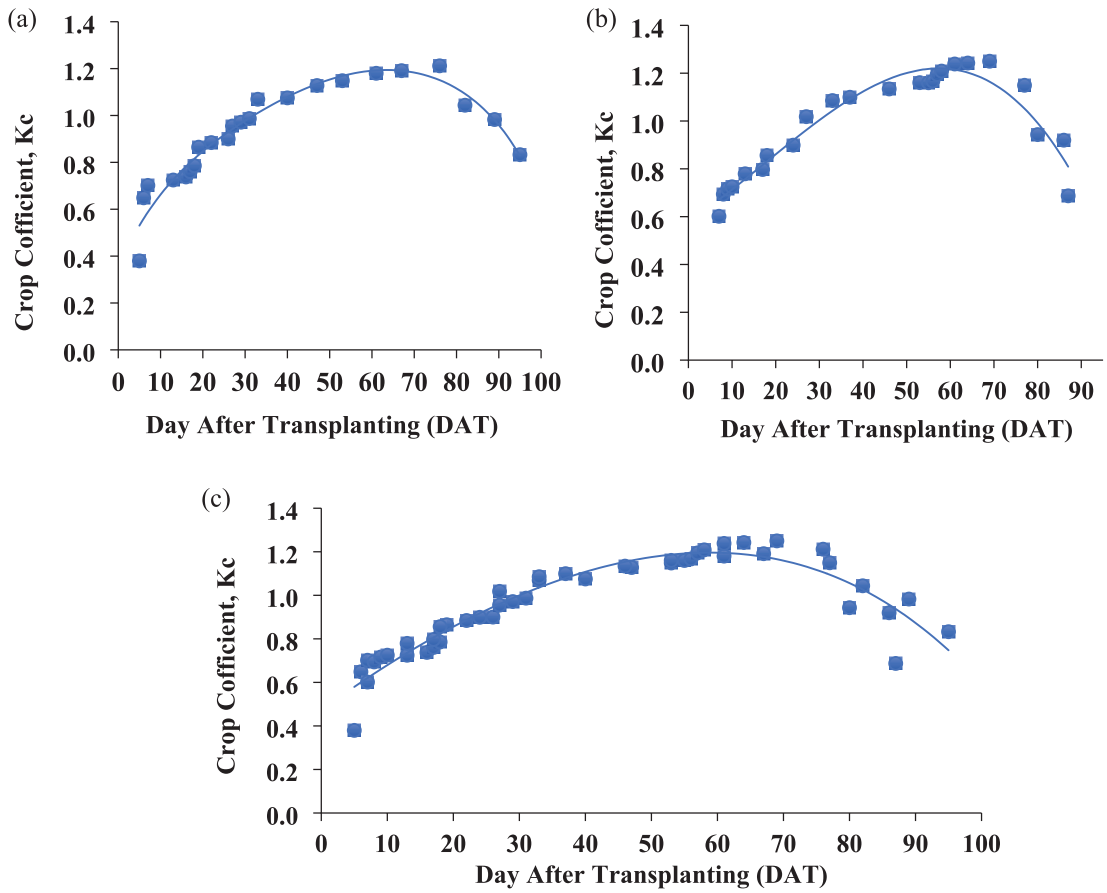

Figure 5. Crop coefficient (*Kc*) versus days after transplanting for tomato growing seasons (a) 2022, (b) 2023, and (c) two seasons pooled data.

Table 2. Measured *Kc*-Values for Tomato in the 2022 and 2023 Experimental Years.

MEASURED *KC*			
EXPERIMENTAL YEAR	*KC*-INI-MEASURED	*KC*-MID- MEASURED	*KC*-END- MEASURED
2022	0.58	1.16	0.95
2023	0.68	1.19	0.92
Average *Kc*	0.63	1.18	0.94

*Locally measured and FAO adjusted tomato crop coefficient (*Kc*)*

Figure 5 shows the developed daily actual crop coefficient values for the tomato growing periods of 2022 and 2023, as well as the combined data from the two seasons. The results show that *Kc* values gradually increased from the start of the season, peaked in the mid of the season, and then began to fall at the end. This outcome is consistent with the trend described for FAO-56. The Measured and the FAO-adjusted *Kc* values for the 2022 and 2023 experiment periods are also presented in Tables 2 and 3 respectively.

Discussions

As presented in Table 1, the seasonal tomato evapotranspiration (ETc) for the 2022 and 2023 experimental periods was 590.35 and 413.3 mm, respectively. An average ETc value of 501.83 mm was recorded over the two experimental years (Table 1). In the 2022 and 2023 experimental years, daily tomato ETc values ranged from 1.84 to 8.0 mm day^{-1} and 2.2 to 6.90 mm day^{-1}, respectively (Figure 4). The seasonal ETo value of 656.43 mm was observed in the 2022 tomato growth season, while 479.1 mm was in 2023. Average daily ETo values ranged from 4.84 to 7.48 mm day^{-1} in 2022 and 2.64 to 5.91 mm day^{-1} in 2023 (Figure 4). The Tomato seasonal crop evapotranspiration measured in this study was within the range of previous reports, 400 to 600 mm (Doorenbos & Kassam, 1979) and 300 to 600 mm (Schwab et al., 1993). Other researchers have also reported tomato evapotranspiration in different parts of the world using different irrigation methods. Abebe and Kebede (2020) Werer, Middle Awash Valley of

Table 3. FAO-Adjusted and Measured *Kc*-Values for Tomato in the 2022 and 2023 Experimental Seasons.

EXPERIMENTAL YEAR	$KC_{\text{-MID-(MEASURED)}}$ $KC_{\text{-MID(ADJ)}}$	$KC_{\text{-END-(MEASURED)}}$ $KC_{\text{-END(ADJ)}}$
2022	1.16 (1.17)	0.95 (0.92)
2023	1.19 (1.07)	0.92 (0.83)
Average *Kc*	1.18 (1.12)	0.94 (0.86)

Note. $Kc_{\text{-mid(adj)}}$ and $Kc_{\text{-end(adj)}}$ = FAO adjusted *Kc* values for mid and end-season, respectively, where wind speed and RH_{min} differ from 2 m s^{-1} and 45%; $Kc_{\text{-mid-(Measured)}}$ and $Kc_{\text{-end-(Measured)}}$ = locally measured *Kc* values for mid and end-season, respectively. All values in the brackets are the FAO-adjusted *Kc* values.

Ethiopia reported tomato ETc of 552 and 584 mm during the cool and main cropping seasons, respectively using a non-weighing lysimeter. Kifle (2019), Hadero Tunto Zuria Woreda, Ethiopia, reported tomato evapotranspiration in the 495.5 to 619.3 mm range under furrow irrigation using different irrigation treatments. Ahmed et al. (2020), Kaduna State, Nigeria reported tomato ETc of 386 mm using metrological data. Hembram et al. (2020) also reported 480 mm using web-based software in the north-central plateau zone of Odisha. Reddy et al.(2023), also obtained tomato ETc in the 375.65 to 548.36 mm range using a weighing type lysimeter in the Raichur Region.

As shown in Table 2, the mean tomato *Kc* values over the two experimental seasons were 0.63 for initial, 1.18 during mid, and 0.94 during the end season. In 2022, the *Kc* values were 0.55 at the initial, 1.16 at the mid, and 0.95 at the end of the season. However, the *Kc* values for the initial, mid, and end seasons in 2023 were 0.68, 1.19, and 0.92, respectively. The *Kc*-mid value recorded in 2022 was lower than that in 2023 (Table 2). The *Kc* values of the tomato's mid and end seasons, which were locally measured and FAO-adjusted are presented in Table 3. The $Kc_{\text{-mid-FAO-adjusted}}$ value of 1.12 was less than the locally measured average $Kc_{\text{-mid-measured}}$ of 1.18. The average $Kc_{\text{-mid-measured}}$ for this study was less than the tomato $Kc_{\text{-mid}}$ values of 1.22 reported by Reddy et al. (2023) and Abebe and Kebede (2020). The mean locally measured $Kc_{\text{-mid-measured}}$ was greater than the $Kc_{\text{-mid}}$ values of 0.82, 1.13, and 1.15 reported by Amayreh and Al-abed (2005); Dirirsa et al. (2017) and (Allen et al., 1998) respectively. The mean $Kc_{\text{-end-local}}$ value over two years was 0.94, greater than the $Kc_{\text{-end-FAO-adjusted}}$ value of 0.86. The details of FAO-adjusted and locally measured *Kc*-values for tomatoes are presented in Table 3. It is clear that for these tomato growth stages, the mean locally derived *Kc* values of the two seasons differed from the FAO-adjusted *Kc* values. This can generally be attributed to variations in plant height and climatic conditions, specifically relative humidity and wind speed. In general, this study determined tomatoes' crop evapotranspiration (ETc) and crop coefficient (*Kc*) by monitoring soil moisture at a minimum interval of three days. This frequent monitoring allowed for an accurate assessment of the water dynamics within the soil, reflecting the plants' water consumption and the effects of irrigation and environmental conditions. To ensure accurate determination of crop coefficient (*Kc*) and crop evapotranspiration (ETc) for tomatoes, further studies are recommended to include daily monitoring of soil moisture. This approach will provide more precise data, capturing the dynamic changes in soil moisture levels influenced by various environmental factors such as temperature, humidity, and irrigation practices.

Conclusions

This study underscores the importance of developing crop evapotranspiration and crop coefficient in the semi-arid region. As water becomes increasingly scarce owing to competition across various sectors, precise water allocation in irrigated agriculture is imperative for achieving optimal crop yields and conserving water resources. Underestimating crop evapotranspiration might result in yield penalties attributable to water stress, while overestimation can lead to excessive water application, thereby lowering the available water for other uses. Knowing the stage-specific *Kc* of tomatoes is crucial because *Kc* is a critical factor in the computation of ETc for any crop. This study produced knowledge-based data on tomato ETc and *Kc* using a non-weighing lysimeter by applying the water balance technique. In 2022 and 2023, seasonal tomato ETc values were 590.4 and 413.3 mm, respectively, with a mean of 501.83 mm. In 2022, the developed tomato *Kc* values for the initial, mid, and end of the season were 0.58, 1.16, and 0.95, respectively. In contrast, the *Kc* values for the initial, mid, and end of the 2022 season were 0.68, 1.19, and 0.92, respectively. The average seasonal tomato *Kc* values for the initial, mid, and end seasons across the two experimental years were 0.63, 1.18, and 0.94, respectively. When comparing these locally developed *Kc* values with the FAO-adjusted *Kc* values throughout the growth period, the locally gained *Kc* values were higher. This shows that FOA-adjusted *Kc* values would result in an underestimation of the scheduling of tomato irrigation in a semi-arid region of Ethiopia and similar agroecology. The actual water use of tomatoes can be corrected using the *Kc* values acquired in this study. In general, this study provides useful information on the exact water applications and efficient irrigation water management for countries that cultivate tomatoes in semi-arid areas.

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Authors Contributions

Tatek Wondimu Negash: Data analysis, methodology, and writing the original draft. **Abera Tesfaye Tefera, Gebeyehu Ashami, and Ketema Tezera Bizuneh:** data collection and editing. **Tigist Worku Awulachew, and Aynalem Gurms**

Dinku: field data collection and feedback on the revised version of the manuscript.

Declaration of Conflicting Interests

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Data Availability

All data are available on the paper itself

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REFERENCES

Abebe, N., & Kebede, E. (2020). Determination of crop coefficients and water requirement of tomato at werer, middle awash valley of Ethiopia. *International Journal of Agriculture and Biosciences*, 9(4), 152–155.

Ahmed, A., Oyebode, M. A., Igbadun, H. E., & Ezekiel, O. (2020). Estimation of crop water requirement and crop coefficient of tomato crop using meteorological data in pampaida millennium village, Kaduna state, Nigeria. *Fudma Journal of Sciences*, 4(3), 538–546.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration* (Guidelines for computing crop water requirements, FAO Irrig. Drain. Paper 56). FAO. http://www.fao.org/docrep/x0490e/x0490e00.htm.

Amayreh, J., & Al-abed, N. (2005). Developing crop coefficients for field-grown tomato (Lycopersicon esculentum Mill.) under drip irrigation with black plastic mulch. *Agricultural Water Management*, 73, 247–254. https://doi.org/10.1016/j.agwat.2004.10.008

Anastacia, M. A. O., Thomas, K. K., & Hilda, W. N. (2011). Evaluation of tomato (Lycopersicon esculentum L.) variety tolerance to foliar diseases at Kenya Agricultural Research Institute Centre-Kitale in North west Kenya. *African Journal of Plant Science*, 5(11), 676–681. http://www.academicjournals.org/AJPS

Brouwer, C., Goffeau, A., & Heibloem, M. (1985). *Irrigation water management: Training manual no.1* (Draft document. 1). FAO (Food and Agriculture Organization) of the United Nations, Rome, Italy.

Dingre, S. K., & Gorantiwar, S. D. (2020). Determination of the water requirement and crop coefficient values of sugarcane by field water balance method in semi-arid region. *Agricultural Water Management*, 232, 106042. https://doi.org/10.1016/j.agwat.2020.106042

Dirirsa, G., Hordofa, T., & Bekele, D. (2017). Crop coefficient and water requirement of tomato (Melka Shola Variety) at Melkassa, Central Rift Valley of Ethiopia. *Academic Research Journal of Agricultural Science and Research*, 5(September), 336–340. https://doi.org/10.14662/ARJASR2017.039

Doorenbos, J., & Kassam, A. H. (1979). *Yield response to water* (Irrigation and Drainage Paper, 33, 257).

Doorenbos, J., & Pruitt, W. O. (1977). *Crop water requirements*. FAO irrigation and drainage paper, 24.

EIAR. (2004). *Sustainable highland rivers management*. Ethiopian Institute of Agricultural Research. http://www.eiar.gov.rt/about.eiar.

Engida, M. (2000). A desertification convention based on moisture zones of Ethiopia. *Journal of Natural Resources*, 2, 1–9.

ESS. (2022). *Area and production of major crops* (Survey report, I, 132). Ethiopian Statistics Service, Agricultural Sample Surver.

Food and Agricultural Organization (FAO). (2005). *AQUASTAT.FAO's information system on water and agriculture*. http://www.fao.org/ag/agl/aglw/aquastat/countries/ethiopia/index.stn.

Hargreaves, G. H., & Samani, Z. A. (1985). Reference crop evapotranspiration from temperature. *Applied Engineering in Agriculture*, 1(2), 96–99.

Hembram, P., Suibudhi, C. R., & Suibudhi, R. (2020). Water and irrigation requirement for tomato (*Solanum Lycopersicum*) crop of north central plateau zone of Odisha. *Journal of Bio Innovation*, 9(5), 701–710.

Intergovernmental Authority for Development (IGAD) and Food and Agricultural Organisation (FAO). (1995). *Agro-meteorology working paper series no. 10* (Draft document). Crop Production System Zones of the IGAD sub-region. FAO, Rome, Italy.

Kifle, T. (2019). Evaluation of irrigation regime on tomato (Lycopersicon Esculentum), at Hadero Tunto Zuria Woreda, Ethiopia. *Global Journal of Science Frontier Research*, 19(6), 27–31.

Negash, T. W., Dirirsa Bayisa, G., Tefera, A. T., Tezera Bizuneh, K., Dinku, A. G., Awulachew, T. W., & Ashemi Bikela, G. (2023). Evapotranspiration and crop coefficient of sorghum (*Sorghum Bicolor* L.) at Melkassa Farmland, semi-arid area of Ethiopia. *Air, Soil and Water Research*, 16(May), 11786221231184206. https://doi.org/10.1177/11786221231184206

Reddy, G. V., Ayyanagoudar, M. S., Babu, B. M., Ajayakumar, M. Y., & Meena, M. K. (2023). Determination of crop water requirement and crop coefficient at different growth stages of tomato by using weighing type lysimeter in raichur region. *International Journal of Environment and Climate Change*, 13(8), 964–972. https://doi.org/10.9734/ijecc/2023/v13i82034

Schwab, G. O., Fangmeier, D. D., Elliot, W. J., & Frevert, R. K. (1993). *Soil and water conservation engineering* (4th ed.). Wiley and Sons Inc.

Srinivas, B., & Tiwari, K. N. (2018). Determination of crop water requirement and crop coefficient at different growth stages of green gram crop by using non-weighing lysimeter. *International Journal of Current Microbiology and Applied Sciences*, 7(9), 2580–2589. https://doi.org/10.20546/ijcmas.2018.709.321

Watson, I., & Burnett, A. (1995). *Hydrology: An environmental approach*. CRC Press.

Yang, L., Liu, H., Tang, X., & Li, L. (2022). Tomato evapotranspiration, crop coefficient and irrigation water use efficiency in the winter period in a sunken chinese solar greenhouse. *Water*, 14(15), 2410. https://doi.org/10.3390/w14152410

Zheng, J., Huang, G., Jia, D., Wang, J., Mota, M., Pereira, L. S., Huang, Q., Xu, X., & Liu, H. (2013). Responses of drip irrigated tomato (*Solanum Lycopersicum* L.) yield, quality, and water productivity to various soil matric potential thresholds in an arid region of Northwest China. *Agricultural Water Management*, 129, 181–193.