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Maize (*Zea mays* L., 1753.) evapotranspiration and crop coefficient in semi-arid region of Ethiopia

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Abstract. Maize (*Zea mays* L.,1753.) plays an important role in the economy of maize-growing nations. Supplying the right amount of water to a crop based on its needs is the main agenda for implementing water-saving agriculture. Non-weighting lysimeters were used to determine the actual crop evapotranspiration and crop coefficient of maize at the experimental farmland of the Melkassa Agricultural Research Center, Ethiopia. Soil-water balance approaches were applied to obtain actual crop evapotranspiration, while the Penman-Monteith technique was used to compute reference evapotranspiration. The growth stages-wise crop coefficient was calculated as the ratio of the actual crop evapotranspiration ratio to the reference evapotranspiration. The total seasonal maize actual crop evapotranspiration during the 2017 and 2018 experimental years was 503.7 and 511.06 mm, respectively. The 2-year average maize actual crop evapotranspiration was 507.4 mm. The mean locally developed actual crop coefficient values of 0.55, 1.19, and 0.56 were observed for the initial, mid, and end seasons, respectively. The FAO-adjusted crop coefficient for the mid-season was 1.15. The developed Kc values differed considerably from the FAO-adjusted Kc values. Therefore, the determination of actual crop evapotranspiration and crop coefficients for crop growth under local climatic conditions is vital for decision-making concerning agricultural water management in areas where irrigation is practiced.

Keywords: maize, crop coefficient, crop evapotranspiration, soil-water balance, reference evapotranspiration, non-weighing lysimeter.

1. INTRODUCTION

Currently, there is competition for water among various sectors, such as industrial, municipal, and agricultural. Globally, agriculture is a major consumer of water. It accounts for more than 80% of the available water (Dingre & Gorantiwar, 2020). Nevertheless, this share continually decreases in developing countries because of the increasing demand for industries and domestic water supply (Dingre & Gorantiwar, 2020; Hamdy *et al.*, 2003). Technical and economic limitations, the expense of developing new water resources, and the occurrence of extreme events due to climate change are other factors that reduce the share of existing water resources. This is a major challenge for the agricultural sector regarding food production. Therefore, the precise use of irrigation water is crucial for reducing water scarcity in global agriculture.

Maize (*Zea mays* L.,1753.) is an important food crop in Ethiopia. It covered about 2.53 million hectares of land. With this mass of land, a total yield of 1055709.36 tons was produced, with an average yield of 4.179 tons/ha (Haile *et al*., 2022). The yields of these crops are affected by inadequate water supply and inappropriate irrigation scheduling. Knowledge of crop evapotranspiration and stage-wise crop coefficients is crucial for enhancing crop production in agricultural fields. This information is vital for enhancing irrigation water management under both full and limited irrigation scenarios. Crop evapotranspiration is a crucial variable in agricultural research. Accurate measurement of actual crop evapotranspiration (ETa) is essential for managing irrigation water during the growing season, water resource allocation, and conducting hydrologic balance analyses, especially in arid and semiarid areas (Djaman & Irmak, 2013). Therefore, it is important to quantify the ETa under different climatic conditions, irrigation techniques, and agronomic practices.

Actual crop evapotranspiration (ETa) can be measured using the soil water balance technique with the help of a lysimeter. Lysimeters are devices, typically tanks or containers, that define a specific boundary to contain soil water and permit the measurement of either the soil-water balance or the volume of water percolating vertically. It can measure the major components of the hydrological water balance. Lysimeters can be broadly classified into two types: weighing and non-weighing. Both can serve the purpose of determining the soil-water balance, vertical percolation flux (drainage), and chemistry of percolating water. Non-weighing lysimeters may be installed to determine the vertical soil-water flux (drainage) within the soil at a defined boundary. It can be used with a soil-water profile measurement method to estimate water use in evaporative processes. Weighing lysimeters permit the mass or volumetric soil water content change to be determined by weighing the lysimeter and determining its mass change over time. A non-weighing-type Lysimeter can measure long-term ETa 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 ETa values for short periods; however, their installation and maintenance costs are high (Srinivas & Tiwari, 2018). Moreover, actual crop evapotranspiration (ETa) can be estimated by utilizing a two-step method that relates the crop-specific coefficient Kc to ETo. This method is highly convenient for computing ETa and is primarily employed in real-world scenarios by technicians and irrigation professionals. Nevertheless, to facilitate irrigation planning, the crop coefficient (Kc) is necessary when utilizing the measured ETa. The crop coefficient (Kc) signifies the crop's unique water consumption, which varies throughout the growing period and is attributable to physiological changes in the crop. In 1968, Jensen introduced the crop coefficient methodology for ETa estimation, which was further improved by various researchers (Doorenbos and Pruitt, 1977; Allen *et al*., 1998). Kc is developed with a ratio of actual crop evapotranspiration (ETa) to reference evapotranspiration (ETo). Numerous approaches are available to calculate reference evapotranspiration. In 1948, Penman introduced the original reference evapotranspiration (ETo) equation, which was subsequently modified by several researchers (Doorenbos and Pruitt, 1977; Hargreaves and Samani, 1985; Watson and Burnett, 1995; Allen *et al*., 1998). The FAO-56 Penman-Monteith technique, after modification, is the only standardized approach capable of yielding satisfactory ETo outcomes across diverse climatic scenarios.

Globally, many researchers have reported maize crop coefficients. For instance, Doorenbos & Kassam (1979) proposed Kc values for maize range between 0.3 – 0.5, 0.7 – 0.85, 1.05 – 1.2, 0.8 – 0.9, and 0.55 – 0.6 for initial, development, mid-season, late-season, and harvesting, respectively. Nevertheless, these values depend on the global average Kc. The authors emphasized the importance of local calibration of Kc under given climate conditions. Allen *et al*. (1998) further proposed maize Kc values at standard climate conditions (RHmin = 45% and u2 = 2 m s^{-1}) of kc_{ini} = 0.3, kc_{mid} = 1.2, and kc_{end} = 0.35 – 0.6 (the lower value is maize harvested after complete filed drying and the upper-value harvesting at high grain moisture). They also recommended a local adjustment of Kc based on a given climatic condition when the wind speed and RHmin differed from 2 m s^{-1} and 45%, respectively, Rosa *et al*. (2012) and Zhang *et al*. (2013) developed a mid-stage maize basal crop coefficient of 1.05 and 1.15, respectively using the SIMDualKc model. Suyker & Verma (2009) obtained Kc values for maize of 0.27, 1.03, and 0.33 during the initial, mid, and end seasons, respectively, using the eddy covariance method in eastern Lincoln, Nebraska, USA. In lysimeter studies, Abedinpour (2015) in New Delhi, India, obtained maize seasonal Kc values of 0.5, 0.75, 1.2, and 0.6 for the initial, development, mid, and late seasons, respectively. Similarly, Piccinni *et al*. (2009) reported maize Kc values in the range of 0.2–1.2 from the initial to mid-stages in the Wintergarden region of Texas, USA.

The studies mentioned above indicate a critical need for the development of Kc for local weather conditions because the scales at which the climate and its effects on crops are experienced vary. The crop coefficient for computing maize evapotranspiration was not obtained for the semi-arid region of Ethiopia; therefore, this study was conducted. This study aimed to determine the actual crop evapotranspiration (ETa) and crop coefficient (Kc) of maize under local climatic conditions using a non-weighting lysimeter.

2. MATERIAL AND METHODS

2.1. Study site

The field trial was conducted at the Melkassa Agricultural Research Center, Ethiopia. It is located at 8^0 24'N latitude and 39^0 21'E longitude at an elevation of 1550 m a.s.l (Figure 1). The climate of the study area is classified as semi-arid, with irregular and unequal rainfall patterns. Between January 01, 1977, and December 31, 2018, the average daily minimum and maximum temperatures varied from 13.8 °C to 28.7 °C. The area receives a mean annual rainfall of 825 mm during the same period. July, August, and September received the highest rainfall. From January 01, 1977, to December 31, 2018, the area's average daily wind speed and ETo ranged between 0.3 - 2.71 m s^{-1} and 3.8 - 5.42 mm day^{-1}, respectively. The daily trends and monthly climate parameters for the maize growing periods of 2017 and 2018 are presented in Figure 2 and Table 1, respectively. The soil in the study area belongs to the clay loam soil

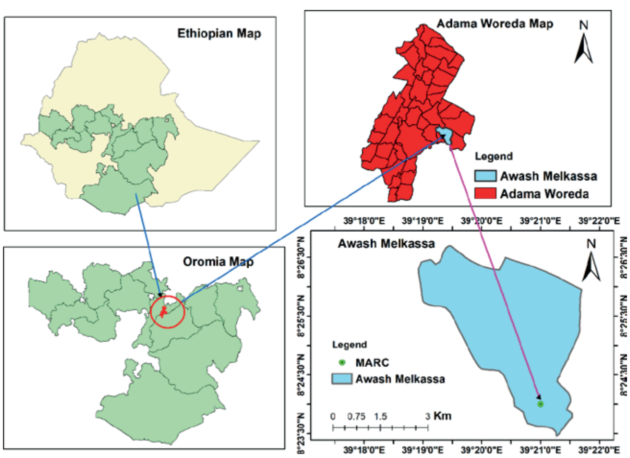

Figure 1. Study area map.

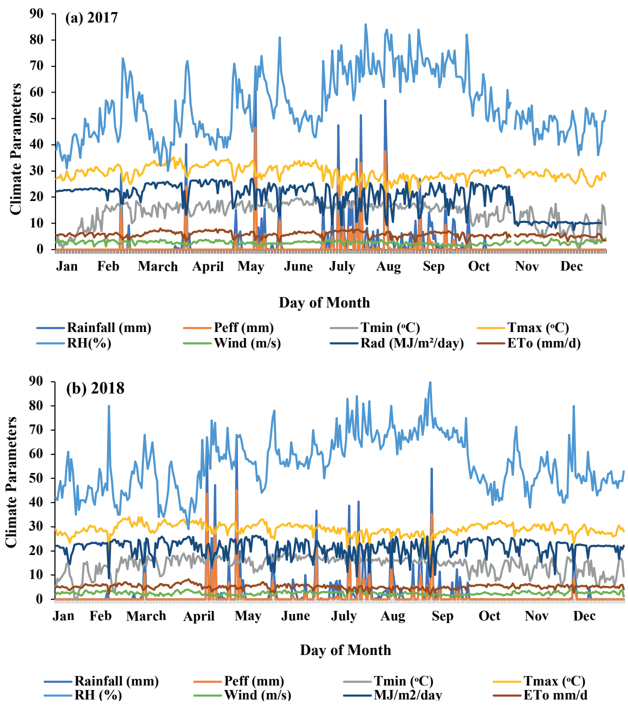

Figure 2. Daily trends of climate parameters during (a) 2017, and (b) 2018 maize growing seasons.

texture class. The soil had an average bulk density of 1.13 g cm^{-3}, field capacity (FC) of 0.32 m^3 m^{-3}, and permanent wetting point (PWP) of 0.22 m^3 m^{-3}. The average soil pH and electrical conductivity (EC) were 6.50 and 1.64 dS m^{-1}, respectively. The total nitrogen content was 0.09%.

2.2. The Experimental setup

Two lysimeters (non-weighing-type) were used to measure ETa and Kc for maize. The first lysimeter had an internal planting area of 2 m^2, whereas the second had a larger planting 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 1 m layer, 0.2 m of rock, 0.2 m of gravel, and 0.2 m of sand pack underneath. The total area of the lysimeter was 36 m^2 (6 × 6 m), including the internal area. To drain excess water, each lysimeter access chamber was linked to an underground steel pipe. 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 to an effective root depth of 1 m to monitor the soil moisture level inside the lysimeters.

2.3. Crop agronomic practice

Maize (*Zea mays* L., 1753.), Melkassa II variety, was sowed on July 13, 2017, and July 16, 2018, within the lysimeter and in the surrounding area. Plant densities of 24 and 168 plants were sown inside and outside the lysimeter, respectively, with a lysimeter having an internal area of 4 m^2. Plant densities of 12 and 180 plants were sown inside and outside the lysimeter, respectively, with a lysimeter having an internal area of 2 m^2. The spacing between rows and plants was 75 and 25 cm, respectively. All recommended agronomic practices (fertilization, weed management, pest control, etc.) were consistently applied within the lysimeter as well as in the surrounding area. The plot was fertilized with urea at a split rate of 50 kg ha^{-1} and diammonium phosphate (DAP) at a rate of 100 kg ha^{-1}. The first application of urea and DAP was at the time of sowing (July 13, 2017, and July 16, 2018), and the second application of urea was on August 16, 2017, and August 19, 2018, when the crop reached knee height. Other agronomic practices, such as weed management and pest control, were applied based on the occurrence of weeds and pests. Over two successive experimental seasons, maize was harvested on November 9, 2017, and November 13, 2018.

2.4. Irrigation application and soil moisture monitoring

Before and after each irrigation, soil moisture was measured within the lysimeter at intervals of 15–100 cm. A neutron moisture meter (CPN503) was utilized to measure the soil moisture at depths ranging from 15 to 100 cm in the lysimeter. The gravimetric (oven method) was employed to quantify the soil moisture level in the top 0 –15 cm of the soil. The 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 (TASW) was computed by subtracting the permanent wilting point (PWP) from the field capacity (FC) after measuring the soil water content at Fc and PWP using a pressure plate apparatus. Irrigation water was provided to the crop when the main rooting layer had depleted 55 % of the available soil water. A watering can was used to apply a known volume of irrigation water to the crops. Irrigation was stopped when the crop showed signs of maturity. The following (equation (1) Brouwer *et al.*, 1985) was used to compute the volume of applied irrigation water to the crop:

$$V = A * D \tag{1}$$

where: V = Quantity of applied water (m^3); A = Lysimeter area (m^2); and D = Applied depth (m).

2.5. Crop evapotranspiration and reference evapotranspiration

The following soil water balance approach (equation (2) Jensen *et al.*, 1990) was employed to calculate the daily crop evapotranspiration.

$$ETa = \left[\frac{I + P - D \pm \Delta S}{\Delta t}\right] \tag{2}$$

where: ETa = Actual crop evapotranspiration (mm day^{-1}), P = effective rainfall (mm), I = applied irrigation depth (mm), D = drainage depth (mm), and t = time between two consecutive observations in days. ΔS = Change in soil moisture storage (mm), ΔS for a specific period at a specific depth (d_z) was computed as:

$$\Delta S_2 = (\theta_{z,\, final} - \theta_{z,\, initial}) * d_z \tag{3}$$

where: $\theta_{z,\, initial}$ and $\theta_{z,\, final}$ are the initial and final water content in the soil profile in a discrete time interval. Graduated cylindrical was used to measure the drainage depth (D) in the underground room. The amount of irrigation depth needed to fill the root zone to field capacity was equal to the moisture deficit in the soil when no precipitation was anticipated and the soil was not saline. The following (equation (4) Mishra and Ahmed, 1990) was used to calculate the moisture deficit (d) in the effective root zone of the crop.

$$d = \sum_{i=1}^{n} \frac{(Fci - Pwi)}{100} * ASi * Di \tag{4}$$

where: Fci = Field capacity on a weight basis; Pwi = Actual soil moisture on a weight basis; ASi = apparent specific gravity; Di = depth of i^{th} layer and, n = number of layers in the root zone.

The cropwat8.0 model was employed to compute daily ETo using the FAO Penman-Monteith equation. 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.

2.6. Crop Coefficient (Kc)

The following equation (5) was used to compute the stage-wise maize Kc values:

$$Kc_{act} = \frac{ETa}{ETo} \quad (5)$$

where: Kc_{act} = actual crop coefficient (dimensionless); ETa = actual crop evapotranspiration (mm day^{-1}), and ETo = reference evapotranspiration (mm day^{-1}).

In FAO-56 (Table 12), the maize Kc values for the initial, mid, and end seasons were 0.3, 1.2, and 0.35 - 0.6, 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, when the wind speed and RHmin are different from 2 m s^{-1} and 45%, respectively. The Kc values > 0.45 for the mid and end seasons were adjusted to account for the climatic conditions of the area and plant height, as follows (Allen *et al*., 1998).

$$Kc_{mid\text{-}FAO} = Kc_{mid}\,(Tab) + [0.04\,(u_2 - 2) - 0.004\,(RH_{min} - 45)] * (h/3)^{0.3} \quad (6)$$

where $Kc_{mid\text{-}FAO}$ = FAO-adjusted Kc for the mid-season, Kc_{mid} (Tab) = tabulated Kc for the mid-season gained from FAO-56, RHmin = average relative humidity during the mid-season (%), u_2 = average wind speed at 2 m height during the mid-season (m s^{-1}), and h = Mean plant height during the mid-season (m). $Kc_{-end\text{-}FAO}$ was calculated using some method.

3. RESULTS AND DISCUSSIONS

3.1. Climate parameters

Climate parameters such as mean air temperature, relative humidity (RH%), wind speed (u2), solar radiation (Rs), rainfall, and ETo for the 2017 and 2018 study seasons are presented in Table 1. These climate variables were similar to some extent in both growing seasons, except for some differences in rainfall distribution. For instance, the average temperature was 21.3°C in 2017 and 21.4°C in the 2018 maize growing season. The mean values of relative humidity (RH%), wind speed, solar radiation, and ETo were also comparable in both growing periods (Table 1). Total accumulated effective rainfall amounts of 460.1 mm in 2017 and 344.4 mm in 2018 were observed. Higher rainfall amounts were observed in July (201.12 mm) and August (146.32 mm) in 2017, while 150.9 mm of rainfall was received in August 2018 (Table 1). The total amount of rainfall recorded in 2018 was less than 25.84% of that recorded in 2017. The daily ETo values over the maize growing season ranged from 2.18 to 6.54 mm day^{-1} in 2017 and from 1.92 to 6.51 mm day^{-1} in 2018 (Figure 3).

3.2. Maize actual crop evapotranspiration

The Maize Melkassa II variety could take approximately 120 days to mature under Melkassa climate

Table 1. Selected Weather Variables for the Maize Growing Periods of 2017 and 2018.

Month	Mean Temperature (°C)	Mean Relative humidity, RH (%)	Average wind speed, u2 (m s^{-1})	Average Radiation, RS (MJ m^2 day^{-1})	Effective Rainfall (mm)	Average reference evapotranspiration, ETo (mm day^{-1})
2017						
July	21.98	68.9	2.88	17.2	201.12	4.48
August	21.47	72.1	2.36	17.3	146.32	4.26
September	21.80	69.57	1.82	18.6	91.04	4.42
October	21.37	55.06	2.36	20.9	7.20	5.29
November	19.94	47.93	2.81	22.4	14.4	5.54
Average	21.3	62.7	2.4	19.3	-	4.80
Total					**460.1**	
2018						
July	21.6	69.0	2.9	20.07	141.6	4.63
August	21.3	71.0	2.2	20.08	150.9	4.35
September	21.5	71.0	2.2	22.29	44.8	4.96
October	21.6	50.0	2.5	22.75	3.68	5.62
November	21.1	48.0	2.8	22.81	3.40	5.56
Average	**21.4**	**61.8**	**2.5**	**21.60**	-	**5.02**
Tota1					**344.4**	

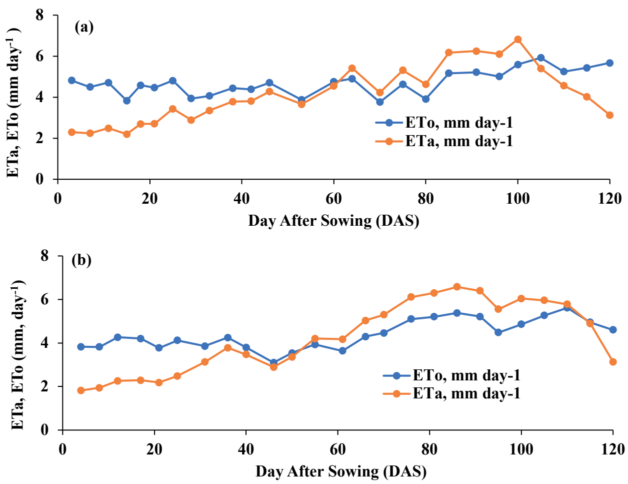

Figure 3 Actual Crop Evapotranspiration (ETa) Vs. Day After Sowing (DAS) for Maize during (a) 2017 and (b) 2018.

conditions, as presented in Table 2. At the study site, the division of maize growth stages depended on the number of plant leaves. The initial stage (Kc_{ini}) is from planting until the seedling is visible above the soil surface, the crop development stage (Kc_{dev}) is from four to five leaf numbers to tassel, the mid-season stage (Kc_{mid}) is from the initiation of ears (8-10 leaf stage) to flowering, and the late-season stage (Kc_{late}) is from full development to harvest. The seasonal maize crop evapotranspiration (ETa) during the 2017 and 2018 experimental years were 503.7 mm and 511.06 mm, respectively, with an average of 507.4 mm (Table 2). In the 2017 and 2018 experimental years, the maximum average maize daily ETa was 6.83 mm day^{-1} and 7.2 mm day^{-1}, respectively, whereas, the minimum average maize daily ETa was 2.2- and 1.82-mm day^{-1}, respectively (Figure 3). The maximum average daily crop evapotranspiration was observed at 100 DAS in 2017 and 95 DAS (midseason) in 2018, whereas the minimum mean daily ETa was observed at 15 DAS and 4 DAS (initial stages) in 2017 and 2018, respectively (Figure 3). The pattern of the average daily ETa for each maize growing season observed in the study area was comparable to the trend described in FAO-56. This trend generally shows a gradual increase in ETa from the initial value, reaching a peak at midseason and starting to decline toward the end of the season. The variation in ETa was due to the combined effects of crop development, changes in the evaporative demand of the atmosphere, and differences in energy absorption characteristics. The increase in ETa from the initial to the crop development stages can be explained by changes in evaporative demand and rapid crop growth. The decline in ETa toward the end-season stage was due to senescence and less physiological activities of the leaves because of aging (Allen *et al*., 1998). Researchers have reported actual maize evapotranspiration in different parts of the world using different irrigation methods. Kang *et al*. (2003) obtained a maize ETa value of 424 mm under surface irrigation conditions in northwestern China. Similar studies by Zhao & Nan (2007) reported a maize ETa value of 611.5 mm using a dual-crop coefficient in northwestern China. Djaman & Irmak (2013) recorded average seasonal evapotranspiration values of 530 mm and 627 mm under rainfall and full irrigation conditions, respectively. Similarly, Suyker & Verma (2009) reported average maize season ETa values of 548 and 482 mm under surface-irrigated and rainfed conditions, respectively, in eastern Nebraska, USA. Piccinni *et al*. (2009), in South Texas, USA, reported actual maize evapotranspiration in the range of 441–609 mm under sprinkler irrigation using a weighing lysimeter. Similarly, Abedinpour (2015) observed a maize ETa value of 411 mm using a weighing lysimeter. In another study, Trout *et al.* (2018) reported an average maize ETa value of 666 mm under drip irrigation conditions in the west-central Great Plain, USA. Udom & Kamalu (2019) in Port Harcourt, Nigeria recorded a maize ETa value of 456.9 mm using Blaney-Criddle and Standard Class A Pan Evaporation data. Tariq & Usman (2009) reported an actual maize evapotranspiration of 451 mm under farmer irrigation.

3.3. Maize crop coefficient (Kc)

The computed daily actual crop coefficient values expressed as a function of the day after sowing (DAS) for the maize growing seasons of 2017 and 2018 are presented in Figure 4. The result indicates a gradual increase in Kc values from the initial, reaching a peak at the midseason and starting to decline toward the end of the season. This result was similar to the trend described in FAO-56. The seasonal Kc values during the initial (0.57), midseason (1.17), and end season (0.55) were recorded in 2017, while Kc values of 0.53, 1.2, and 0.56 for initial, mid, and end-season, respectively were obtained in 2018 (Table 3). The average maize seasonal Kc values over the two experimental years were 0.55, 1.19, and 0.56 for the initial, mid, and end-season, respectively (Table 3). The evolution of Kc values reflected crop growth, development, and physiology effects on ETa. As the crop develops and shades the ground to the effective full cover and reaches full size, the amount of water abstraction increases, increasing the ETa. The maximum Kc value of 1.17 and 1.2 was obtained during the mid-season of 2017 and 2018, respectively when ETa reached its highest

Table 2. Water balance components (cm) for maize growth periods observed at the experimental site in a semi-arid area of Ethiopia.

Crop stages	Days	2017					2018					Average				
		Pe	I	D	ΔS	ETa	Pe	I	D	ΔS	ETa	Pe	I	D	ΔS	ETa
Initial	25	186.1	5.8	124.3	-3.1	64.5	98	13.5	29.2	-28	54.3	142.1	9.7	76.8	-15.6	59.4
Development	36	105.5	70.5	9.9	-29.2	136.9	131.6	55.2	22.6	-40.6	123.6	118.6	62.9	16.3	-34.9	130.3
Mid-Season	39	57.9	172	5.1	8.4	216.7	20.8	214.5	-	-	235.3	39.4	193.4	2.6	4.2	226.0
End-Season	20	0.16	85.4	-	-	85.6	0.2	97.7	-	-	97.9	0.2	96.1	-	-	91.7
Total	120	349.7	334	139.3	-23.9	503.7	250.6	380.9	51.8	-68.6	511.06	300.2	358.5	94	-47.7	507.4

Note: ETa = actual crop evapotranspiration; I = applied irrigation depth; Pe = effective rainfall; D = drainage depth; S = change in soil moisture; and t = the amount of time between two observations in days.

Table 3. Locally Developed Kc-Values for Maize in the 2017 and 2018 experimental years.

Experimental Year	Kc-ini-Local	Kc-mid-Local	Kc-end-Local
Year I -2017	0.57	1.17	0.55
Year II -2018	0.53	1.20	0.56
Average Kc	0.55	1.19	0.56

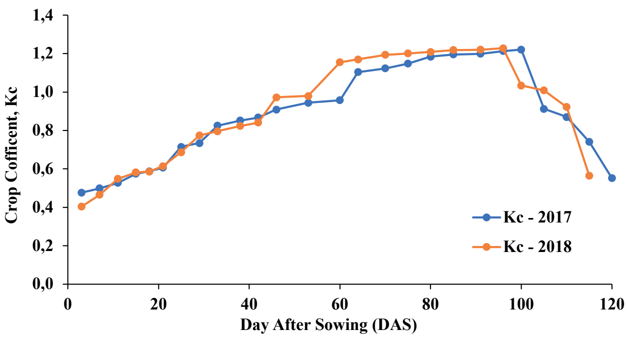

Figure 4. Crop Coefficient (Kc) Values Vs. Days After Sowing (DAS) for 2017, and 2018 maize growing periods.

demand. The Kc-mid value recorded in 2017 was lower than the Kc-mid value recorded in 2018.

3.4. Comparison with FAO Adjusted and other studies

Table 4 presents the Kc values of mid and end-season for maize, which have been adjusted by FAO and locally developed. It is clear that for these maize growth stages, the mean locally derived Kc values of the two seasons were different from the FAO-adjusted Kc (Table 4) and those reported in other publications. In comparison, the Kc_{-mid-}FAO-adjusted value of 1.15 was less than the average locally developed value of 1.19. The average $Kc_{-mid-local}$ for this study was also lower than the reported maize Kc_{-mid} values of: 1.2, 1.26, 1.43, and 1.21 by Allen *et al.* (1998); Li *et al.* (2003); Ding *et al.* (2013); and Abedinpour (2015), respectively. The mean locally developed $kc_{-mid-local}$ values were greater than the Kc_{-mid} values 1.16, 1.0, 1.13, and 1.15 reported by Gao *et al.* (2009); Facchi *et al.* (2013); Martins et al. (2013) and Giménez *et al.* (2016), respectively. However, the $Kc_{-mid-local}$ value of 1.19, observed in this study, was comparable to the Kc_{-mid} of 1.18 obtained by Miao *et al.* (2016). The average $Kc_{-end-local}$ value over two years was 0.56 and was greater than the Kc_{-end-}FAO-56. The maize's mean $Kc_{-end-local}$ values, produced locally, were found to be comparable to the Kc values reported by Irmak & Irmak (2008) and Ding *et al.* (2013), which were Kc_{-mid} = 0.54 and 0.6, respectively. The $Kc_{-ini-local}$ value developed in this study, with a mean of 0.55, is higher than the Kc_{-ini} values reported by Allen *et al.* (1998); Piccinni *et al.* (2009); Suyker & Verma (2009); Gao *et al.* (2009) which were 0.3, 0.27, 0.2, and 0.37, respectively. Nonetheless, it is comparable to the Kc initial value of (kc-ini = 0.5) developed by Li *et al.* (2003). In general, this variation of Kc values between the locally developed, the FAO adjusted and other stud-

Table 4. FAO-adjusted and Locally Developed Kc-Values for Maize in the 2017 and 2018 experimental periods.

Experimental Year	$Kc_{-mid-(Local)}$ ($Kc_{-mid(adj)}$)	$Kc_{-end-(Local)}$ ($Kc_{-end(adj)}$)
Year I (2017)	1.17 (1.13)	0.55 (**)
Year II (2018)	1.20 (1.17)	0.56 (**)
Average Kc	1.19 (1.15)	0.56 (**)

Note: ($Kc_{-mid(adj)}$) and $Kc_{-end\ (adj)}$ represent the FAO adjusted Kc for the mid and end-season, respectively, when wind speed and RHmin differ from 2 m s^{-1} and 45%. $Kc_{-mid-Local}$ and $Kc_{-end-Local}$ refer to locally developed Kc for the mid and end-season, respectively. (**) is a non-adjusted value of Kc because the maize end-season kc value found in FAO-56 was 0.35, which was less than 0.45. Therefore, it could not be adjusted to the local climate conditions. For more information refer to section 2.6 in this paper.

ies could be attributable to the difference in local climatic conditions, growing window, soil texture, and management practice.

4. CONCLUSIONS

Maize plays an important role in the economy of maize-growing nations. Underestimating actual crop evapotranspiration might result in yield penalties attributable to water stress, whereas overestimation can lead to excessive water application, thereby lowering the available water for other uses. Knowing the stage-specific Kc of maize is crucial because Kc is a critical factor in the computation of ETa for any crop. To enhance irrigation practices in the semi-arid region of Ethiopia, this study produced knowledge-based data on maize ETa and Kc using the water balance technique and a non-weighing lysimeter under local climate conditions. In 2017 and 2018, seasonal maize ETa values were 503.7 mm and 511.06 mm, respectively, with an average of 507.4 mm. In 2017, the developed maize Kc values for the initial, mid, and end seasons were 0.57, 1.17, and 0.55, respectively. In contrast, the Kc values for the initial, mid, and end of the season in 2018 were 0.53, 1.20, and 0.56, respectively. The average seasonal maize Kc values for the initial, mid, and end seasons across the two experimental years were 0.55, 1.19, and 0.56, respectively. Throughout the growth period, the Kc values obtained locally were higher than the FAO-adjusted Kc values. Using FOA-adjusted Kc values may result in an underestimation of maize irrigation scheduling in the semi-arid region of Ethiopia. The actual water use of maize can be corrected using the Kc values developed in this study. In general, this study provides useful information on the exact water applications and efficient management of irrigation water for countries that cultivate maize in semiarid areas of the world.

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AUTHORS CONTRIBUTIONS

Tatek Wondimu Negash: Field data collection, data analysis, methodology, writing original draft, writing-review, and editing. Abera Tesfaye Tefera: Field Data collection, writing- review and editing. Gobena Dirirsa Bayisa: Writing- review and editing.

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