Determination of Crop Coefficient and Water Requirement of Okra Crop by using Lysimeter for Parbhani District, Maharashtra

Onkar P. Bhoje[1*]; Dr. Vishal K. Ingle[2]; Dr. Uday M. Khodke[3]; Dr. Harish W. Awari[4]; Dr. Sumant B. Jadhav[5]

[*1]M.Tech Student Dept. of Irrigation and Drainage Engineering, CAET, VNMKV, Parbhani
[2,5]Assistant Professor Dept. of Irrigation and Drainage Engineering, CAET, VNMKV, Parbhani, 431402
[3]Associate Dean & Principal CAET, VNMKV, Parbhani, 431402
[4]Head Dept. of Irrigation and Drainage Engineering, CAET, VNMKV, Parbhani, 431402
*Corresponding Author

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Abstract— *Water is a finite and vital resource, making its efficient utilization particularly critical in irrigation, especially during the summer months when water scarcity is most acute. Summer okra (Abelmoschus esculentus), a key vegetable crop in India, depends on precise irrigation scheduling to ensure optimal yields. To address this need, a field experiment was conducted over the summer seasons of 2023 and 2024 at Vasantrao Naik Marathwada Krishi Vidyapeeth (VNMKV), Parbhani, situated in the semi-arid Marathwada region of Maharashtra, India. The study utilized a weighing-type lysimeter to estimate crop coefficient (Kc) values for okra, which are crucial for determining accurate irrigation schedules. In 2023, the Kc values for the okra crop were recorded as follows across different growth stages: initial stage (12 to 14 MW) – 0.63, development stage (15 to 18 MW) – 1.05, mid-season stage (19 to 23 MW) – 1.42, and late season stage (24 to 26 MW) – 0.76. In 2024, the Kc values were slightly different: initial stage (13 to 15 MW) – 0.60, development stage (16 to 19 MW) – 0.99, mid-season stage (20 to 24 MW) – 1.33, and late season stage (25 to 26 MW) – 0.75. The seasonal water requirement for okra was calculated to be 579.18 mm in 2023 and 529.38 mm in 2024. These Kc estimates provide valuable insights for optimizing irrigation management, facilitating more accurate water demand predictions and resource planning. The study's findings contribute to improving water use efficiency in the Marathwada region, where conserving water is vital for sustainable agricultural practices.*

Keywords— Crop coefficient, FAO-56 Penman Monteith method, lysimeter, okra, reference evapotranspiration, crop evapotranspiration, water requirement.

I. INTRODUCTION

Okra (Abelmoschus esculentus L. Moench) is a highly valued crop, particularly for its mucilaginous pods that, due to their soluble fiber content, impart a distinctive slimy texture when cooked. The pods are versatile, consumed in various forms such as cooked, pickled, raw, or added to salads. In developing nations, okra plays a significant role in addressing malnutrition and food insecurity. Nutritionally, raw okra comprises approximately 90% water, 7% carbohydrates, 2% protein, and is a rich source of dietary fiber, vitamin C, and vitamin K (Gemede, 2015). While okra exhibits relative tolerance to water stress, it performs optimally when soil moisture is well-maintained, especially during germination and for achieving high yields. Varughese et al. (2014) emphasize the importance of fertigation with 100% of the recommended fertilizer dose delivered through drip irrigation for optimizing water use and crop yield. Thokal et al. (2020) recommend specific agronomic practices, including a crop spacing of 1200-450 x 150 mm, 100% RDF fertigation, 80% ET_x drip irrigation, and the use of silver-black mulch to enhance productivity and water efficiency, particularly in the lateritic soils of the Konkan region.

Crop water requirements vary throughout the growing season, influenced by changes in canopy structure, climatic conditions, cropping practices, and irrigation methods (Hamdy and Lacirignola, 1999; Katerji and Rana, 2008).

Evapotranspiration (ET), encompassing both soil evaporation and plant transpiration, constitutes approximately 99% of the water uptake by plants. Therefore, measuring daily crop evapotranspiration (ETc) throughout the growth cycle is crucial for determining precise water requirements. Accurate estimation of ETc is essential for effective water management, as misestimating water needs can adversely affect economic, social, and environmental outcomes (Shideed et al., 1995; Katerji and Rana, 2008).

The crop coefficient (Kc), a critical factor in irrigation management, represents the ratio of ETc to reference evapotranspiration (ET_0). Kc values fluctuate during different growth stages and must be calibrated locally to ensure precise irrigation scheduling (Doorenbos and Pruitt, 1977; Milla et al., 2016). While generalized Kc values are available, region-specific data is imperative for effective irrigation planning at the local level.

In Maharashtra, characterized by arid and semi-arid climatic conditions, erratic rainfall patterns present significant challenges to agricultural productivity. The Marathwada region typically cultivates okra during June-July, September-October, and February-March, with the winter-sown crop demanding the highest water input. Given the increasing importance of okra cultivation in the region, a field experiment is proposed to quantify the water requirements and crop coefficients of okra. This research aims to facilitate improved irrigation planning and water resource management in the Marathwada region.

With rising global water demand, irrigation is becoming an increasingly significant cost factor in agriculture. Effective irrigation scheduling, which is key to maximizing yields and enhancing water productivity, requires a solid understanding of crop water needs (Dabhi et al., 2020). One of the most commonly used methods to estimate crop water requirements is the FAO-56 Penman-Monteith (PM) method. This method calculates reference crop evapotranspiration (ETo) and multiplies it by crop coefficients (Kc) to determine crop evapotranspiration (ETc), with Kc values adjusted to account for the specific characteristics of different crops and their growing environments (Allen et al., 1998). Studies by Gul et al. (2018) highlighted the influence of water table depths on okra's water usage and overall productivity, while Nyatuame et al. (2019) emphasized the importance of applying the right amount of water to maximize the efficiency of limited freshwater resources. Similarly, James et al. (2017) used a mini-lysimeter to measure water use in okra, further demonstrating the importance of developing irrigation systems that are specifically tailored to the needs of different crops.

Due to the highly site-specific nature of Kc values, determining them locally is crucial for optimizing irrigation management (Ramachandran et al., 2021). Although generalized Kc values, such as those found in FAO's Irrigation and Drainage Paper No. 24 (Doorenbos and Pruitt, 1977), are widely applied, they can lead to substantial inaccuracies if not calibrated to local conditions. For instance, Vu et al. (2005) discovered a 17% error when using standard Kc values in paddy fields, which highlighted the need for local calibration. Awari et al. (2023) conducted a key study that determined Kc values for okra in the semi-arid Marathwada region of Maharashtra using a weighing-type lysimeter. Additionally, Awari and Khodke (2018) developed modified Kc values for gram in the Parbhani district, which differed significantly from FAO recommendations due to regional climate and farming practices.

Kc values are central to precision irrigation scheduling, as they are derived by dividing ETc by ETo. In a study by Hawari et al. (2023) in the Marathwada region, Kc values for okra ranged between 0.61 and 1.41, with the highest values observed around the 10th week. Their research provided Kc values of 0.64, 1.07, 1.33, and 0.86 for the initial, developmental, mid-season, and late stages of okra growth. These data are essential for developing more efficient irrigation strategies in similar climates.

In sub-humid regions, Patil et al. (2018) examined how subsurface drip irrigation, both with and without plastic mulch, affected okra's water use. Their research showed that plastic mulch reduced total evapotranspiration from 403 mm to 363 mm, as opposed to 512 mm and 468 mm without mulch. Furthermore, Kc values were found to be lower when using plastic mulch (ranging from 0.31 to 0.77) compared to without mulch (0.51 to 0.93). This illustrates how plastic mulch can reduce irrigation demands, lower evaporation losses, and improve crop yields.

Several studies have highlighted the variability of Kc values across different crops and climates. For example, Sagar et al. (2022) used a smart weighing lysimeter to calculate Kc values for Chrysanthemum grown in a greenhouse, with Kc values ranging from 0.43 to 1.27 depending on the crop's growth stage. Similarly, Nigusi Abebe et al. (2021) developed Kc values for onions in Ethiopia using non-weighing lysimeters and found significant differences between local Kc values and FAO-56 recommendations. These findings underline the importance of site-specific calibration in water management. Environmental factors, such as elevated temperatures and vapor pressure deficits, can influence regional Kc values, as noted by Piccinni et al. (2009), reinforcing the need to account for local conditions when determining Kc.

This study aims to determine the water requirements and crop coefficients for okra in Maharashtra's semi-arid Parbhani district using a weighing-type lysimeter. The results will provide more accurate crop water requirement estimates, aiding in reliable crop production and promoting sustainable water use practices in similar regions.

II. MATERIAL AND METHODS

2.1 Study Area:

The experiment on Okra crop cultivation was conducted at the Department of Irrigation and Drainage Engineering, C.A.E.T., V.N.M.K.V., Parbhani, during the years 2022-2023 and 2023-2024. Meteorological data for the study was collected from the IMD-recognized weather station at Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani.

2.2 Climate:

The climate of the Marathwada region can be classified as semi-arid. The region experiences hot and dry summers, cold dry winters, and wet, humid monsoon seasons with medium rainfall. The mean annual precipitation is approximately 649.34 mm, mostly received between June and October from the southwest monsoon. Winter rains are scant and uncertain. The mean maximum temperature ranges from 28.6°C in winter (December) to about 41.2°C in summer, while the mean minimum temperature ranges from 10.9°C in winter to 25.6°C in summer. The relative humidity varies between 31% to 62% for minimum and 85% to 96% for maximum throughout the year.

2.3 Soil Data:

The soil in the experimental field was classified as clay, with a field capacity of 26% and a bulk density of 1.4 g/cm³. The variety of Okra used for the lysimeter experiment was Parbhani Kranti (OH/517). Seeds were sown in a 1.5 x 1.5 x 1m weighing-type lysimeter platform at a spacing of 0.25 x 0.50 m on March 24, 2023, and March 26, 2024. To simulate similar growing conditions, the same okra crop was planted around the lysimeter tanks, ensuring a uniform cropping environment.

2.4 Experimental Set-Up:

FIGURE 1: Technical Specifications of Weighing Type Digital Lysimeter

Lysimeter Size; 1.5M X 1.5 M X 1.0 M.

A weighing-type lysimeter, with a platform size of 1.5 x 1.5 x 1 m, was installed in the field as part of a study to measure the actual evapotranspiration of okra by recording the applied water and the amount of water lost through evapotranspiration. The lysimeter consisted of an outer and inner box with a drainage system and a weighing mechanism based on load cells connected to a data logger for recording time-varying water loss due to evapotranspiration and drainage (Schmidt et al., 2013). To install the lysimeter, a pit of 1.5 × 1.5 × 1.0 m was manually dug, with the soil removed in five layers of 200 mm depth each and set aside for backfilling in the same order. The bottom of the pit was compacted, leveled with burnt bricks, and the outer tank was placed with load cells fixed at the base. The inner tank, resting on the load cells, was filled layer-wise with the excavated soil, and its weight was automatically monitored by the load cell assemblies. Moisture sensors were installed at intervals of 200 mm in perforated PVC pipes at a depth of 200 mm below the soil surface to record soil moisture. Field calibration was conducted in 2023, following the methodology of Wheller and Ganji (2010), by recording output from loading and unloading known weights. To replicate field conditions and maintain a controlled environment for water balance measurement, the same crop was grown surrounding the lysimeter to ensure similar micro-environment, nutrient availability, soil moisture, and soil–plant interactions. Additionally, 20 random soil samples were collected from the experimental plot, mixed, and analyzed for physical properties at the Department of Soil Science and Agriculture Chemistry, VNMKV, Parbhani.

2.5 Estimation Parameters:

2.5.1 Calculation of Crop coefficient:

Jensen (1968) introduced the concept of the crop coefficient (Kc) for estimating actual evapotranspiration, which has since been further developed by researchers such as Amayreh and Al-Abed (2005), Fisher (2012), Awari and Khodke (2018), Awari et al. (2019), and Nigusi Abebe et al. (2021). The crop coefficient is defined as the ratio of crop evapotranspiration to reference evapotranspiration, with the latter estimated over a reference grass surface of standard height and with no scarcity of available water (Allen et al., 1998).

$$Kc = ETc / ETo \tag{1}$$

Where,

ETc is the actual crop evapotranspiration (mm day-1)

ETo is the reference crop evapotranspiration (mm day-1)

2.5.2 Determination of crop evapotranspiration (ETc):

Evapotranspiration of the okra crop was measured using the soil water balance method, which considers changes in soil water content within the lysimeter area, including inputs from rainfall and irrigation. The water applied from the lysimeter area served as input data. Crop evapotranspiration was calculated for each growth stage based on the soil water balance equation. This equation estimates evapotranspiration by comparing the soil moisture measured each day against previous measurements. The water balance equation for each successive day during the study period was used to determine the daily crop evapotranspiration.

$$ETc = R+I-DP \pm \Delta S \tag{2}$$

Where,

ETc is crop evapotranspiration,

I= irrigation, mm,

R is rainfall,

DP is deep percolation loss

ΔS is change in storage of soil moisture and all are in mm,

The change in soil moisture (ΔS) was determined by subtracting the moisture content recorded on each day from that of the previous day, with measurements taken from sowing through to the final harvest. Crop evapotranspiration was calculated for different growth stages initial, development, mid-season, and late-season using the appropriate equation. The crop evapotranspiration was estimated based on the water balance equation, considering the daily soil moisture measurements throughout the study period.

2.5.3 Calculation of reference evapotranspiration (ETo):

Reference crop evapotranspiration (ETo) was calculated using the FAO-56 Penman-Monteith method through the DSS-ET version-1, a decision support system developed by the Department of Agricultural and Food Engineering at the Indian Institute of Technology, Kharagpur (George et al., 2002; Bandyopadhyaya et al., 2012). The necessary meteorological data for this calculation were obtained from the weather station at VNMKV, Parbhani.

The FAO Penman Monteith equation is expressed as:

$$ET_0 \frac{[0{\cdot}408\Delta(\mathrm{Rn}-\mathrm{G})+\gamma(900\backslash \mathrm{T}+273)\mathrm{u2}(\mathrm{es}-\mathrm{ea})]}{\Delta+\gamma\,1+0.34\,u_2}$$

where,

ETO - potential evapotranspiration (mm day-1),
Rn - net radiation at the crop surface (MJ m-da1), G - soil heat flux density (MJ m-2 day-1),
T - mean daily air temperature at2m height(°C), u2 - wind speed at 2 m height (m s-1),
es - saturation vapour pressure (kPa), ea - actual vapour pressure (kPa)
es - ea - saturation vapour pressure deficit (kPa), Δ - slope vapour pressure curve (kPa °C-1),
γ - psychrometric constant(kPa°C1).

The total growing period for the okra variety was 98 days in 2023 and 93 days in 2024. During the experiment, the crop growth periods were divided into four stages: initial (21 days), crop development (28 days), mid-season (35 days), same in both year 2023&2024, and late-season (17 days) in 2023 and (12 days) in 2024, based on recommendations from Vasantaro Naik Krishi Vidyapeeth, Parbhani (Holsambare, 1988; Anon., 2021). Real-time weather data was collected daily from an Automatic Weather Station and stored via a cloud server for input into the software. Power for the system was supplied by a storage battery, which was charged by an overhead solar panel installed at the lysimeter's software and data storage panel. These recorded data were used to compute ETo using the FAO-56 Penman-Monteith method. Daily ETo values were logged at regular intervals (every 60 minutes) and averaged to obtain daily values. From these daily averages, ETc and Kc values were calculated. Both daily ETo and Kc values were then averaged on a weekly basis for the crop period.

2.5.4 Soil Parameters:

Soil moisture and temperature were recorded at depths of 200 mm, 400 mm, and 600 mm using in-situ moisture and temperature sensors installed in the lysimeter.

2.5.5 Crop Growth Parameters:

Crop height, number of branches, leaves, flowers, and fruits were recorded manually after 30, 45, 60,75, 90 daysduring study.

III. RESULTS AND DISCUSSION

3.1 Soil analysis of the experimental plot and lysimeter:

The physical properties of the soil were analyzed in 10 cm layers down to 80 cm depth within the lysimeter. The estimated water holding capacity of the experimental soil averaged 25%. It was observed that moisture content increased from the top layer to the bottom of the lysimeter. Field capacity ranged from 23% to 26%, while bulk density varied between 1.37 and 1.41 g/cm^3, being higher at the 75 cm depth. The soil type significantly influences water availability to the crop, as the water holding capacity is determined by the amount of moisture retained by the soil particles. The particle size distribution, showing higher clay content in the five layers, contributes to the increased water holding capacity of the soil.

3.2 Crop growth parameters

The crop growth parameters recorded during the experimentation for the lysimeter and field plots are presented in Table 1, 2&3.

TABLE 1
PLANT GROWTH PARAMETERS OF SUMMER OKRA IN LYSIMETER DURING SUMMER 2023&2024

S.No.	Parameter	30 DAS		45 DAS		60 DAS		75 DAS		90 DAS		AT Haevest	
		2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
1	Height, cm	30.7	20.1	69.3	61.09	91.06	90.6	106.1	101.4	111.9	111.8	120.5	111.8
2	Branches, Nos	2.1	1.7	2.3	2.2	3.6	3.2	4.8	3	5.1	3.7	5.5	3.7
3	Leaves, Nos	11.8	9	21.3	14.2	30.4	20.6	33.8	24.7	35.3	23	34	29
4	Flowers, Nos	5	1	3.4	2	2.8	2	4.4	2.6	1.3	0.9	1.1	0.3
5	Fruits, Nos	0	0	5.3	2.3	9.9	4.5	8.7	5.3	5.6	2.9	7.3	3.2
6	Avg yield	**2023- 118.34 gm plant^{-1}, 2024-94.39gm plant^{-1}**											

TABLE 2

PLANT GROWTH PARAMETERS OF SUMMER OKRA IN THE FIELD PLOT-1 OF THE YEAR 2023 AND 2024

Field plot-1	Parameter	30 DAS		45 DAS		60 DAS		75 DAS		90 DAS		AT Haevest	
Sr.no.		**2023**	**2024**	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
1	Height, cm	19.8	19.6	58.2	51.09	80.8	71.32	92.8	83.1	98.9	96.2	102.5	96.2
2	Branches, Nos	1.5	1.3	1.7	1.7	3.1	2.9	3.9	2.4	4.2	3.1	4.6	3.1
3	Leaves, Nos	10.8	7.8	16.9	11	21.8	16	24.8	23.5	25.5	20	24.5	24.5
4	Flowers, Nos	3.4	0.8	2.7	1.6	2.4	1.9	2.8	2.6	1.2	0.6	1	0.4
5	Fruits, Nos	0	0	4.8	1.7	7.7	3.6	6.4	4.2	3.5	2.6	4.6	2.5
6	Avg yield	**2023- 101.27 gm plant^{-1}, 2024-80.20 gm plant^{-1}**											

TABLE 3

PLANT GROWTH PARAMETERS OF SUMMER OKRA IN THE FIELD PLOT-2 OF THE YEAR 2023 AND 2024

Field plot-2	Parameter	30 DAS		45 DAS		60 DAS		75 DAS		90 DAS		AT Haevest	
Sr.no.		**2023**	**2024**	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
1	Height, cm	21.3	18.2	57.9	44.26	77.4	65.15	100.4	78.4	104.1	92.8	106	92.8
2	Branches, Nos	1.2	1.2	1.6	1.9	2.9	2.2	3.3	2.6	3.9	2.7	4.1	2.7
3	Leaves, Nos	11.3	8.8	17.4	14.3	19.9	19	23.1	21.7	24.3	17.8	23.2	22
4	Flowers, Nos	4.3	0.3	3	1.5	2.8	1.7	3	1.9	0.5	0.7	0.5	0.3
5	Fruits, Nos	0	0	4.7	1.2	7.1	2.9	6.2	3.1	3.9	2.7	4.2	2.1
6	Avg yield	**2023- 102.20 gm plant^{-1}, 2024 -74.49 gm plant^{-1}**											

Table 1 represented the growth parameters of summer okra measured in a lysimeter during the summer of 2023 and 2024 at different stages of development, recorded at 30, 45, 60, 75, and 90 days after sowing (DAS), as well as at harvest. In 2023, okra plants showed a greater height, reaching 120.5 cm at harvest compared to 111.8 cm in 2024. Similarly, the number of branches in 2023 peaked at 5.5, whereas in 2024, the maximum was only 3.7. The number of leaves followed a similar trend, with 35.3 leaves in 2023 and 29.0 in 2024 at harvest. Flower production also differed significantly, with a notable reduction in 2024 (only 0.3 flowers at harvest compared to 1.1 in 2023). Fruit production was higher in 2023, with 7.3 fruits at harvest compared to 3.2 in 2024, indicating better overall plant growth and productivity in 2023 than in 2024.

Table 2&3 summarize the growth parameters of summer okra grown in two field plots during 2023 and 2024, with measurements taken at various stages (30, 45, 60, 75, and 90 days after sowing, as well as at harvest). In Field Plot 1, the plants in 2023 generally outperformed those in 2024. The maximum plant height at harvest was 102.5 cm in 2023, compared to 96.2 cm in 2024. Branch and leaf numbers were also higher in 2023, with 4.6 branches and 24.5 leaves compared to 3.1 branches and 24.5 leaves in 2024. Flower and fruit production followed the same pattern, with 4.6 fruits in 2023 compared to 2.5 in 2024. Similarly, Field Plot 2 showed better results in 2023, with plants reaching a height of 106 cm at harvest, while in 2024 they only reached 92.8 cm. The number of branches, leaves, flowers, and fruits were also higher in 2023, with 4.1 branches, 23.2 leaves, and 4.2 fruits compared to 2.7 branches, 22.0 leaves, and 2.1 fruits in 2024. Overall, the data indicates that okra plants showed more vigorous growth and productivity in 2023 compared to 2024 across both field plots.

3.3 Reference Crop Evapotranspiration, Actual crop evapotranspiration, Crop coefficients:

Tables 4 and 5 summarize the weekly average values of reference evapotranspiration (ETo), crop evapotranspiration (ETc), and crop coefficient (Kc) for okra during the 2023 and 2024 growing seasons. In 2023, ETc ranged from 2.26 mm/day during the first week, peaking at 8.71 mm/day in the 8th week, with fluctuations observed until the 15th week. The highest ETc occurred during the 19th standard meteorological week (SMW). In 2024, ETc values ranged from 2.15 mm/day to a maximum of 7.63 mm/day, with the highest recorded during the 20th SMW.

ETo exhibited a rising trend in 2023, starting at 4.34 mm/day and reaching 6.87 mm/day by the 17th SMW. Similarly, in 2024, ETo increased from 4.70 mm/day to 6.49 mm/day, fluctuating due to varying weather conditions. The crop water demand was low in the initial growth stage, increased during mid-season, and decreased in the late season.

Lysimetric Kc values for okra, presented in Figure 3, showed similar patterns for both years. In 2023, Kc values ranged from 0.52 to 1.49, decreasing to 0.65 by the 26th SMW. In 2024, Kc ranged from 0.46 to 1.45, falling to 0.64 by the end of the season. The Kc values for the Parbhani Kranti variety in 2023 were 0.63, 1.05, 1.42, and 0.76 for the initial, development, mid-season, and late-season stages, respectively. In 2024, these values were 0.60, 1.0, 1.33, and 0.75 for the same stages.

The stage-wise Kc values align with findings from previous studies in India, though some variation is noted due to differences in agro-climatic conditions. For instance, Hawari et al. (2023) reported Kc values of 0.64, 1.07, 1.33, and 0.86 for Maharashtra, while Sharma et al. (2021) recorded values ranging from 0.4 to 1.2 for Udaipur, and Patil and Tiwari (2018) reported values between 0.51 and 1.12 for Kharagpur. These variations underscore the importance of developing location-specific Kc values for precise irrigation scheduling.

TABLE 4
WEEKLY LYSIMETRIC ESTIMATED ETc, ETO and Kc VALUES FOR THE OKRA CROP IN 2023

Crop Week	SMW	Crop Growth stage	ETc (mm/day)	ETo (mm/day)	Kc values	Stage Wise kc values
1	12	(21 Days) Initial	2.26	4.34	0.52	0.64
2	13		3.62	5.29	0.68	
3	14		3.44	4.86	0.71	
4	15	(28 Days) Development	4.44	5.31	0.83	1.05
5	16		5.95	6.22	0.96	
6	17		7.89	6.87	1.15	
7	18		7.96	4.43	1.26	
8	19	(35 Days) Mid-season	8.71	6.37	1.37	1.42
9	20		8.53	4.96	1.49	
10	21		8.35	5.64	1.48	
11	22		7.26	4.95	1.45	
12	23		6.21	4.71	1.32	
13	24	(15 Days) Late season	5.08	6.32	0.9	0.76
14	25		2.88	4	0.72	
15	26		2.11	3.25	0.65	

TABLE 5
WEEKLY LYSIMETRIC ESTIMATED ETc, ETO and Kc VALUES FOR THE OKRA CROP IN 2024

Crop Week	SMW	Crop Growth stage	ETc (mm/day)	ETo (mm/day)	Kc values	Stage Wise kc values
1	13	(21 Days) Initial	2.15	4.7	0.46	0.6
2	14		3.57	5.5	0.65	
3	15		3.65	5.27	0.69	
4	16	(28 Days) Development	4.38	5.6	0.78	1
5	17		5.83	6.49	0.9	
6	18		6.21	5.75	1.08	
7	19		7.41	6.09	1.22	
8	20	(35 Days) Mid-season	7.63	5.53	1.38	1.33
9	21		7.52	5.2	1.45	
10	22		7.48	5.6	1.34	
11	23		7.4	5.8	1.28	
12	24		5.95	4.9	1.21	
13	25	(10 Days) Late season	4.11	4.73	0.87	0.75
14	26		3.3	5.23	0.63	

3.4 ETc and ETo during crop growing period:

Reference evapotranspiration (ET_0) and crop evapotranspiration (ETc) during the growing season are presented in the Fig. 2 for year 2023 and 2024. In ETc curve, the fluctuation is regulated by crop growth and development, while in ET_O curve the fluctuation is regulated by weather parameter values.

As shown in the Figure 2 the crop evapotranspiration (ETc) exceeded ET_O at the development stage and midseason stage, whereas in the rest stages ET_O higher than ETc during cropping season. This indicates that during the midseason stage, the crop water demand is high because of the fully developed crop canopies and high evaporative demand to flower, fruit formation and filling.

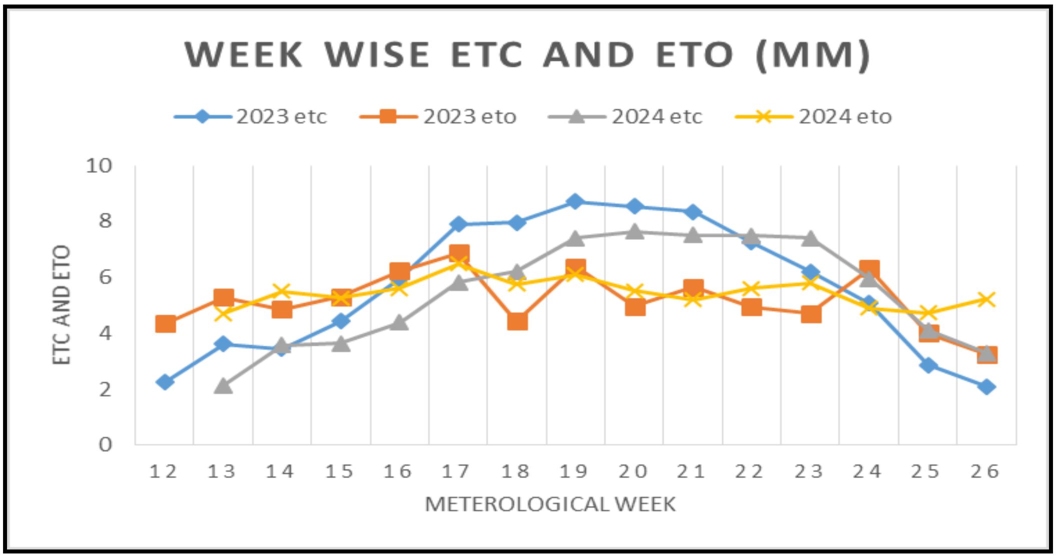

FIGURE 2: Seasonal ETc and ET_O of okra crop as a function of days after sowing

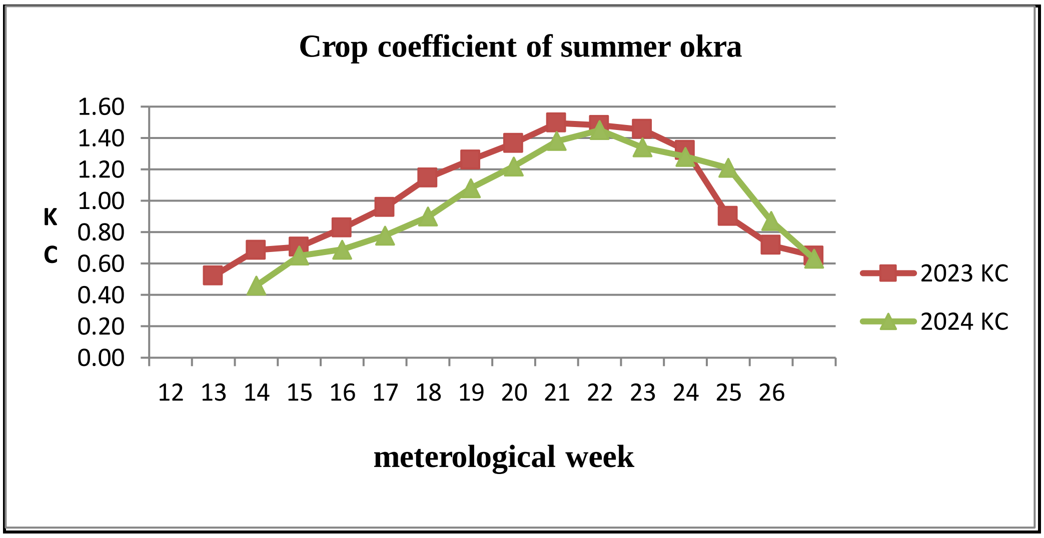

FIGURE 3: Weekwise crop coefficient of summer Okra crop

3.5 Stage-wise water requirement for summer Okra:

The stage-wise crop water requirement of summer Okra at Parbhani presented in the Fig. 4 for year 2023 and 2024, for The initial stage demands of water approximately 65.22 mm 65.57 mm in the year 2023 & 2024 respectively, into the developmental stage, there is a substantial increase in water requirements, totaling 182.66 mm in 2023 where as 166.81 mm in 2024, During the midseason stage it was 273.38 mm of water in 2023 while in 2024 it was ranges 253.20 mm, during late season stage, the water requirement decreases to 57.86 mm and 43.80 mm in 2023 & 2024 respectively. Similar results are in confirmatory with result obtained by Aliku et al. (2022), Ademiju et al. (2017), Hashim et al. (2012), Dahr et al. (2021), Lima et al. (2021), Mehta and Pandey (2016).

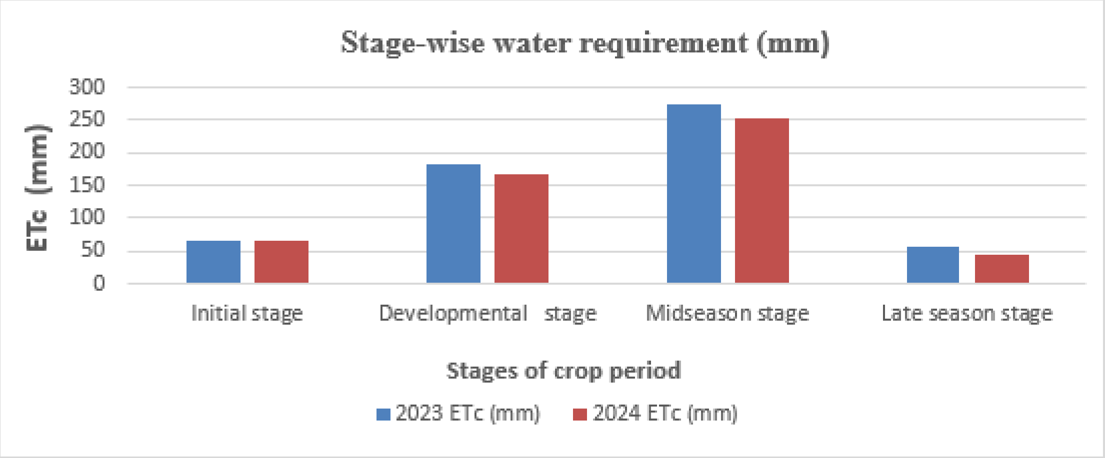

FIGURE 4: Stage-wise water requirement (mm)

IV. CONCLUSION

The study concluded that the total actual evapotranspiration (ETc) for summer Okra was 579.18 mm in 2023 and 529.38 mm in 2024, with the highest water demand observed during the mid-season stage. The reference evapotranspiration (ETo) varied based on climatic conditions, totaling 547.71 mm in 2023 and 513.93 mm in 2024. Stage-wise crop water requirements also fluctuated, with the initial stage requiring approximately 65 mm, while the mid-season had the highest demand, reaching 273.38 mm in 2023 and 253.20 mm in 2024, before decreasing in the late season.

The estimated crop coefficients (Kc) for summer Okra varied across growth stages, with higher values recorded in the mid-season. In 2023, the Kc values were 0.63, 1.05, 1.42, and 0.76 for the initial, developmental, mid-season, and late stages, respectively, while in 2024, they were slightly lower. Notably, the lysimeter-derived Kc values were higher than those recommended by FAO-56, and polynomial crop coefficient equations developed from lysimeter data can be applied to estimate daily or weekly Kc values for different Okra varieties and crop periods.

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