FINAL COMPREHENSIVE REPORT

on

DETERMINATION OF CROP COEFFICIENTS FOR MAJOR CROPS USING LYSIMETRIC STUDIES

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Location	**:**	Department of Irrigation & Drainage Engineering, College of Agricultural Engineering Research Field, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani
Duration	**:**	Three years
Total outlay	**:**	Rs. 38.38 lakhs
Investigators	**:**	
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CONTENTS

1. INTRODUCTION

The Government of Maharashtra's implementation of the Nanaji Deshmukh Krishi Sanjeevani Prakalp (NDKSP) under the Department of Agriculture, with support from the World Bank, marks a significant step towards enhancing climate resilience and profitability for smallholding farmers in drought-prone regions. Covering approximately 4,000 villages across 15 districts, the project aims to achieve this by promoting climate-resilient technologies and commodity value chains. The NDKSP holds the potential to not only improve livelihoods and food security but also strengthen rural economies and reduce vulnerability to climate-related shocks, thereby contributing to broader socio-economic development in Maharashtra.

Crop water requirements i.e. crop evapotranspiration refers to the combined water loss from two main processes in crops: evaporation from the soil surface and transpiration from the plants. Evaporation is the process by which water in the soil is converted into water vapour and released into the atmosphere, primarily driven by solar radiation and environmental conditions. Transpiration, on the other hand, is the movement of water from the plant roots, through the plant, and into the atmosphere through stomata in the leaves.

The role of crop evapotranspiration in crop water requirement is crucial for efficient irrigation management and understanding the water needs of crops. It represents the total amount of water that a crop utilizes during its growth cycle. Factors influencing crop evapotranspiration include climate conditions, crop type, growth stage, and the availability of soil moisture. Understanding and managing crop evapotranspiration helps optimize water use efficiency, reduce water wastage, and enhance overall agricultural productivity. It is a key parameter in determining the irrigation needs of crops, contributing to sustainable water management practices in agriculture.

Reference crop evapotranspiration, which is the evapotranspiration of reference crop, that is fully grown and never short of water takes care of the weather characteristics. The crop evapotranspiration is then related to reference crop evapotranspiration through a factor called crop coefficient which varies over the growth period of crop. Thus the reference crop evapotranspiration and crop coefficient values are essential for estimating the crop water requirement.

Crop coefficient, denoted as Kc, is a factor in the crop's growth stage and guide the adjustment of reference evapotranspiration to estimate actual evapotranspiration. Currently most of the studies consider the crop coefficient values documented by FAO based on the average values all over the world. As the evapotranspiration values are influenced by local climatic conditions, crop evapotranspiration values need to be measured locally and hence crop coefficient values need to be estimated locally. Though there is considerable variation in Kc values but there is no specific trend of variation between locally developed and FAO documented values, which translate in to 8 to 12% variation in the crop yield. Thus for the estimation of accurate crop water requirement, it is necessary to determine the crop coefficient values locally over the crop growth season for different crops of the regions. Moreover, locally developed Kc values provide the accurate values and thus the confidence amongst the users for estimating water requirement based on Kc values.

Weighing Lysimeters are extensively used to estimate and study crop water use patterns throughout crop growth and thereby standardize reference evapotranspiration models for the localized area to estimate crop-coefficient data for specific crops. The amount of water, which cultivated areas in a field require for evapotranspiration, might be precisely measured using a weighing Lysimeter. The applicability of Lysimeter for estimating the crop coefficient of various crops has been widely reported worldwide. Thus, considering the importance of determining local crop coefficients of different crops in the region, Nanaji Deshmukh Krishi Sanjeevani Prakalp (formerly PoCRA) granted a project on **"Determination of Crop coefficients for Major Crops by Lysimetric Studies"** to Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani with following objectives:

1. To estimate the values of crop coefficients of important field crops over their growth period by using Lysimetric study.
2. To estimate water requirement of different field crops for efficient irrigation water management.

2. LYSIMETER & ITS INSTALLATION

Digital Weighing type Lysimeter was used to measure crop water used by measuring the change in mass of an isolated volume of soil. Lysimeters are used to calculate the water balance of the enclosed system. The water balance involves accounting for all the inputs and outputs of water, such as precipitation, irrigation, runoff, and changes in soil moisture. The primary objective of a Lysimeter is to establish a favorable and controlled environment that is identical to field conditions for the measurement of water balance. Evapotranspiration, which combines water evaporation from the soil surface and transpiration from plants, is a critical parameter measured by Lysimeter. This information is valuable for understanding the water requirement of crops.

In the project on "Determination of crop coefficients for major crops by Lysimetric studies" at Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, four Lysimeters were to be installed after procurement by Nanaji Deshmukh Krishi Sanjeevani Prakalp (formerly PoCRA) centrally.

Three Lysimeters are installed at the Experimental farm of Department of Irrigation and drainage Engineering, CAET, VNMKV, Parbhani under the guidance of Principal investigator and Co-Principal Investigator of the PoCRA project during 4-5th December, 2021. The geographical location of Lysimeter at 19.242938°N and 76.788385°E was done on 15 -16th November, 2021.

Fourth Lysimeter was supplied on 07th April 2023 and successfully installation was done on 7-8th April 2023 at Experimental Farm.

Specifications of various components of digital weighting type Lysimeter and their function are given in the Table 1.

Table 1: Specification and function of various components of digital weighting type Lysimeter

Sr. No.	Component	Specifications	Use
1.	Inner box	1500 x 1500 x 1000 mm	To grow crop in an isolated environment.
2.	Outer box	1600 x 2200 x 1250 mm	To separate isolated mass of soil from surrounding environment.
3.	Weighing Scale	Size: 1500 x 1500 mm High precision type, class II weighing scale indicator, capacity of 1000 kg and least count of 10 g.	Attached with 4 load cells which works on strain gauge principle which measures the weight of inner tank.
4.	Perforated plate	Corrosion resistant chicken type stainless steel mesh screen of 2 mm thickness (grade 304 SS) at about 10 cm from bottom.	To prevent washing out of soil along with drain water.
5.	Control Panel Box	400 ×380 ×260 mm. Made of corrosion free material.	Shows the weight of Soil water in inner tank & drain water in drain tank
6.	GI Pipe	Length 2000 mm	For fitting for Solar panel and Control Panel
7.	Solar Panel Frame	Frame made of MS angle for fitting the Solar panel for the electric supply for data collection and data transmission.	For electric supply to charge battery which is required for data transmission & display.
8.	Drain tank	600 X 300 m MS tank	Measures the weight of drainage water from inner tank
9.	GSM Module	Sim Card and Device	To transmit data to web based application

Procedure for the Installation of Lysimeter

The installation procedure involved meticulous site preparation, pit excavation, foundation laying, Lysimeter placement, back filling with soil layers, installation of accessories, and calibration to guarantee accurate and reliable measurements for subsequent studies.

Step wise procedure followed for installation of Lysimeter is as given below. Photographs captured during installation of Lysimeter are shown in plates 1 to 10.

- ### Site preparation

Plate 1: Field layout

Plate 2: Manual excavation of pits and measurement of the depth

In order to install the lysimeters, three dug-out (1.5m x 1.5m x 1.0m) excavations were made in the experimental field. The soil was manually withdrawn from the dugouts. During excavation, the soil was carefully removed in five layers each of 20 cm depth and placed aside separately on plastic sheet for backfilling. Each soil layer was placed in separate pile with a care of non-mixing without disturbing with each other. For easy identification, excavated soil of each layer was labeled as L1, L2, L3, L4 and L5.

- ### Pit excavation

After the achievement of desired dimension of holes to match the inner tank of lysimeter, a pit sufficiently larger and deeper than the lysimeter outer tank was dug by machine. The accurate measurement of inner tank pit was taken.

Plate 3: layer wise soil collection

Plate 4: layer wise soil collection

- **Foundation laying and Lysimeter placement**

After enlarging and widening of the pit for the outer tank, a sand layer approximately 2-3 cm thick was sprayed at the bottom of the pit and then burnt brick layer was placed on it. On these foundation lysimeter box was placed.

Plate 5: Sand and bricks layer laid at bottom of pit

Plate 6: Installation of outer tank in pit

- **Back filling with soil layers**

The outer tank was placed in the pit by using crane machine and there after the inner tank was placed in the outer tank by maintaining 5-10 cm spacing between inner and outer tank from all four sides. The soil was filled around the outer tank of Lysimeter.

Plate 7: Installation of outer tank in pit

Plate 8: Steel net installation at bottom of inner tank

- ## Installation of accessories

Steel net was placed at bottom of inner tank in order to prevent soil loss along with drainage water. After successful installation of outer and inner tank, the soil moisture sensors were placed at 20, 40 and 60 cm depth respectively and the marking was done in the inner tank at every 20 cm depth, for filling the soil exactly in the same manner in which it was excavated. The undisturbed soil was filled in inner tank of the lysimeters to match the natural soil profile. The inner tank of each lysimeter was filled layer by layer with maintaining its original homogeneity and bulk density.

Plate 9: Installation of moisture and temperature sensor

Plate 10: Installation of solar panel

Additionally, the soil of each layer was slightly compacted to match the soil density in the lysimeters to that in the field.

- ## Calibration

All the accessories of lysimeter were assembled after that. A small surplus of top soil was added in the inner tank later. Continuous watering lowered the soil surface in inner tank sufficiently. Finally, Lysimeters were calibrated in the field using standard loads of known mass.

3. METHODOLOGY

3.1 Important Terminologies:

- **Reference Crop Evapotranspiration (ETr):**

Evapotranspiration from the reference surface i.e. hypothetical grass i.e. reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s/m and an albedo of 0.23 (Allen et al, 1998).

- **Evapotranspiration (ET):**

Evapotranspiration is the combined process of water evaporation from the soil surface and transpiration from plant surfaces into the atmosphere (Allen et al, 1998).

- **Crop Evapotranspiration (ETc):**

Evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions (Allen et al, 1998).

- **Crop Coefficient (Kc):**

The crop coefficient, Kc, is the ratio of the crop evapotranspiration (ETc) to the reference evapotranspiration (ETr), and it represents an integration of the effects of four primary characteristics (crop height, albedo, canopy resistance and evaporation from soil) that distinguish the crop from reference grass (Allen et al, 1998).

3.2 Estimation of Reference Crop Evapotranspiration

Reference crop evapotranspiration (ET_r) during the crop growing season is estimated by using the Penman-Monteith method [Eq (3.1)].

$$ET_r = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad \ldots (3.1)$$

Where,

ET_r = Reference evapotranspiration [mm/day],

R_n = Net radiation at the crop surface [MJ/ m^2 day],

G = Soil heat flux density [MJ/ m^2 day],

T = Mean daily air temperature at 2 m height [°C],

u_2 = Wind speed at 2 m height [m/ s],

e_s = Saturation vapour pressure [kPa],

e_a = Actual vapour pressure [kPa],

e_s - ea = Saturation vapour pressure deficit [kPa],

 = Slope of vapour pressure curve [kPa/ °C],

g = Psychrometric constant [kPa / °C].

3.3 Methodology for modification of FAO-56 Crop Coefficients for local conditions

For modification of Kc values at local condition it is required to have the data related to soil type, wetting event and crop height at mid and end growth stage. Figure 3.1 shows the flow chart of methodology used for modification of Kc at initial, mid and end stages during crop growth period.

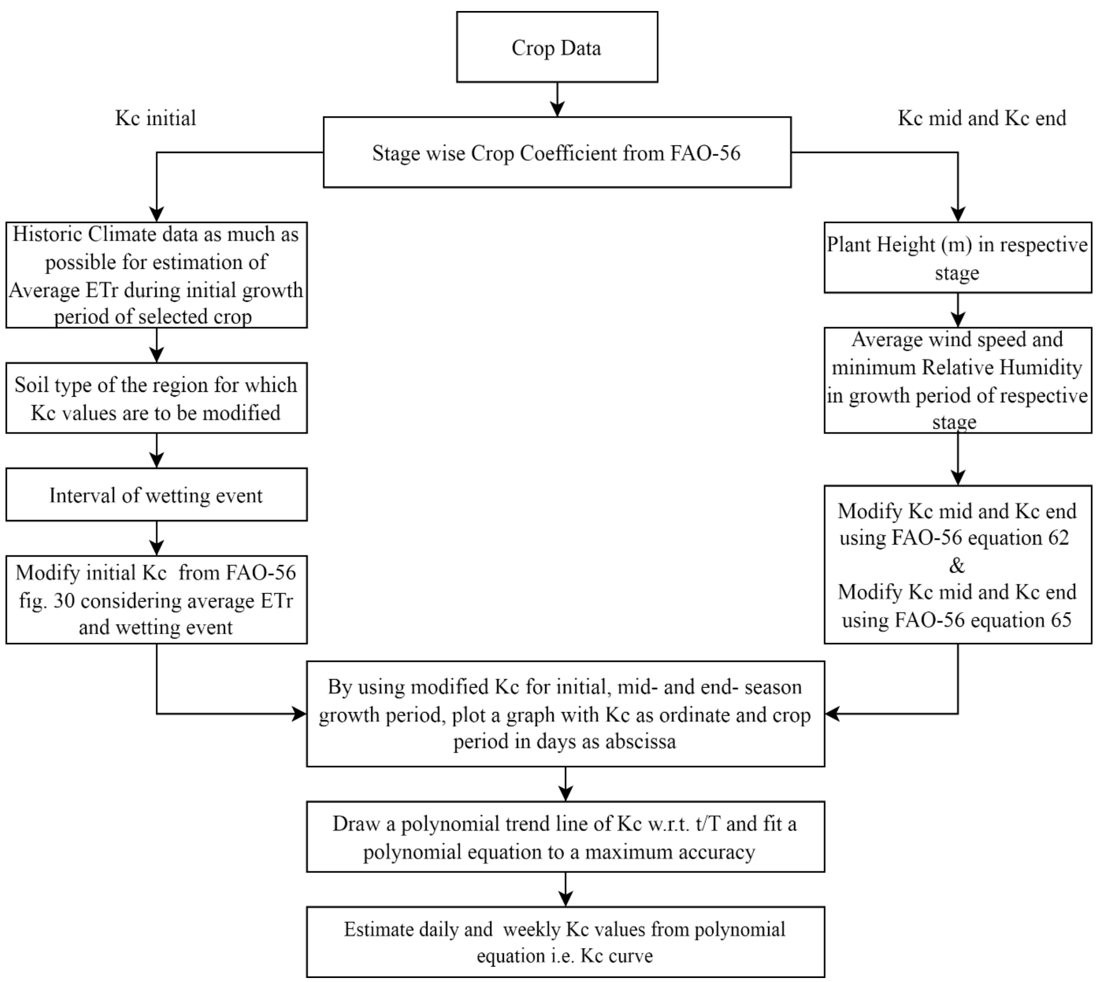

Figure 3.1: Methodology flowchart for modification of K_c

- **Modification of Kc (initial)**

The soil type of Parbhani region where the experiments were conducted is having fine and medium texture, therefore the irrigation interval was considered as 10 days. Kc_{ini} is taken from Kc vs ETr graph (Figure 3.2) provided in FAO-56 paper using averaged ETr value for previous 47 years, soil type/ texture and wetting event for initial growth period. Average Kc_{ini} as related to the level of ETr and the interval between irrigation greater than or equal to 40 mm per wetting event, during the initial growth stage for medium and fine textured soils is determined using figure 3.2.

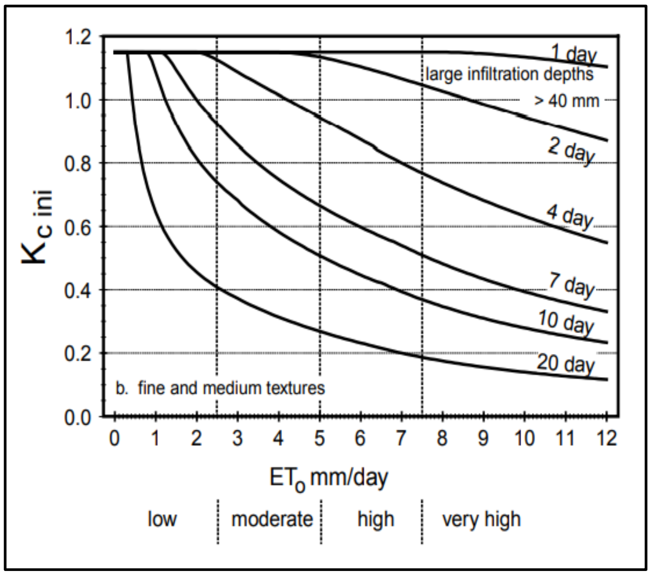

Figure 3.2: Kc vs ETr graph provided in FAO-56 paper for Medium and Fine Soil

- **Modification of Kc mid:**

The following equation is used for estimation of K_c mid:

$$K_c\ mid = K_c(mid)_{FAO56} + [0.04(U_2-2) - 0.004(RH_{min}-45)](h/3)^{0.3} \quad \text{……(3.2)}$$

- **Modification of Kc end:**

The following equation is used for estimation of K_c end:

$$K_c\ end = K_c(end)_{FAO56} + [0.04(U_2-2) - 0.004(RH_{min}-45)](h/3)^{0.3} \quad \text{……(3.3)}$$

Where,

$K_c\ (mid)_{FAO56}$ = value of K_c mid taken from FAO-56,

$K_c\ (end)_{FAO56}$= value of K_c end taken from FAO-56,

U_2= Mean value for daily wind speed at 2 m height, m/s

RH_{min}= Mean value for daily minimum relative humidity during the end season growth stage,

h = Mean plant height during end-season (m)

The crop height, minimum relative humidity and wind speed at 2 m height required for estimation of Kc for mid and end season stages, was recorded and stage wise Kc values were modified. The weekly Kc values were developed by linear interpolation of Kc initial, Kc mid and Kc end. The curve of weekly Kc Vs t/T, where't' is day after sowing and 'T' is total crop growth period in days, was plotted and a polynomial equation was fitted with maximum accuracy. Using developed polynomial equation, the daily Kc values for the crop were calculated.

3.4 Estimation of Crop Evapotranspiration Using Lysimeter

Lysimeter is used to measure crop evapotranspiration where the crop is grown in isolated tanks filled with soil. Weighing Lysimeters measure crop water used by measuring the change in mass of an isolated volume of soil. Irrigation and precipitation add water and increase the weight of the soil volume and drainage and evapotranspiration removes water and decrease the weight. Water input and output is measured by Water Balance Method and then crop evapotranspiration is calculated using water balance method [Eq. (3.4)].

$$ETc = P + I - S - D \quad \ldots (3.4)$$

Where,

ET_c	=	Crop Evapotranspiration, mm;
P	=	Precipitation, mm;
I	=	Irrigation, mm;
□S	=	Change in water storage, mm;
D	=	Drainage, mm.

3.5 Estimation of Crop Coefficient and Development of Kc Curve

The Kc values were estimated for given crop as the ratio of crop evapotranspiration (ETc) to the reference evapotranspiration (ETr) estimated by Penman-Monteith method over crop growth period using Eq (3.5).

$$K_c = ET_c / ET_o \quad \dots (3.5)$$

Where,

K_c = Crop Coefficient

ET_c = Crop Evapotranspiration, mm

ET_o = Reference Crop Evapotranspiration, mm

The polynomial equations of second, third, fourth and fifth orders are fitted to calculate daily K_c, with K_c as the dependent variable and (t/T) as the independent variable. The best fit polynomial equation is selected based on maximum R^2.

General equation for K_{ct} can be written as:

$$K_{ct} = \sum_{n=0}^{5} a_{(n)} \left(\frac{t}{T}\right)^n$$

The different forms of second, third, fourth and fifth order polynomial equation are as below:

$$Kc_t = a_o\left(\frac{t}{T}\right)^0 + a_1\left(\frac{t}{T}\right)^1 + a_2\left(\frac{t}{T}\right)^2$$

$$Kc_t = a_o\left(\frac{t}{T}\right)^0 + a_1\left(\frac{t}{T}\right)^1 + a_2\left(\frac{t}{T}\right)^2 + a_3\left(\frac{t}{T}\right)^3$$

$$Kc_t = a_o\left(\frac{t}{T}\right)^0 + a_1\left(\frac{t}{T}\right)^1 + a_2\left(\frac{t}{T}\right)^2 + a_3\left(\frac{t}{T}\right)^3 + a_4\left(\frac{t}{T}\right)^4$$

$$Kc_t = a_o\left(\frac{t}{T}\right)^0 + a_1\left(\frac{t}{T}\right)^1 + a_2\left(\frac{t}{T}\right)^2 + a_3\left(\frac{t}{T}\right)^3 + a_4\left(\frac{t}{T}\right)^4 + a_5\left(\frac{t}{T}\right)^5$$

Where,

Kc_t = Crop Coefficient of t^{th} day.

a_0, a_1, a_2….= Constants of equations.

t = Day considered after sowing.

T = Total crop growth period from sowing to harvesting (days)

4. CROP COEFFICIENTS OF *SUMMER* GROUNTNUT, *SUMMER* OKRA, *KHARIF* SOYBEAN, *KHARIF* GREENGRAM AND *RABI* SORGHUM

In the project titled "Determination of Crop Coefficient for Major Crops by Lysimetric Studies" conducted at Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. The primary objective was to assess and establish crop coefficients for major five crops: *Summer* Groundnut and Okra, *Kharif* Soybean and Greengram and *rabi* Sorghum

Lysimeters provide direct and accurate data on evapotranspiration, allowing researchers to quantify how much water the crops use at different growth stages. These measurements contribute to the determination of crop coefficients. The experiments involved monitoring and recording various parameters such as weather conditions, crop development stages, and water usage.

By conducting Lysimetric studies on Groundnut, Okra, Soybean, Greengram, Sorghum the research aimed to determine crop coefficients specifically for these crops under the local conditions of Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. Timeline of the experiments conducted are given in the table 4.1. The outcomes of these experiments are presented in this chapter.

Table 4.1: Details of the experiments conducted under the project

Sr. No.	Experiment	Year
	First Year Study (Feb.2022-23)	
1.	Determination of Crop Coefficient of *Summer* Groundnut and Okra	Feb. 2022
2.	Determination of Crop Coefficient of *Kharif* Soybean and Greengram	June 2022
3.	Determination of Crop Coefficient of *rabi* Sorghum	Oct. 2022
	First Year Study (Feb.2023-24)	
4.	Determination of Crop Coefficient of summer Groundnut and Okra	Feb. 2023
5.	Determination of Crop Coefficient of *Kharif* Soybean and Greengram	July 2023
6.	Determination of Crop Coefficient of *rabi* Sorghum	Oct. 2023

4.1 Crop Coefficient for *Summer* Groundnut

The computed Kc values for *Summer* Groundnut was averaged based on two year data From this data initial, development, mid and end stages crop coefficient were found to be 0.50, 0.74, 1.17 and 0.74 respectively. The maximum values of crop coefficient were estimated during mid-stage mainly because of higher canopy. Fig. 4.1 represents the stagewise lysimetric Kc curve during crop growth period of *Summer* Groundnut. Data presented in Table 4.2 represents stagewise lysimetric crop coefficient values for *Summer* Groundnut. From table it is also observed that lysimetric Kc values are slightly more than FAO Kc values. Whereas modified Kc values were found to be higher than the FAO-56 and lysimetric Kc for all the crop growth stages.

Table 4.2: Stage wise crop average coefficient developed for *Summer* Groundnut

Stage	Duration (Days)	Modified Kc	Lysimetric Kc	FAO Kc	Weightage (%)
Initial	20	0.62	0.50	--	16.67
Development	35	0.84	0.74	--	29.17
Mid	45	1.35	1.17	1.15	37.50
End	20	1.1	0.74	0.60	16.67

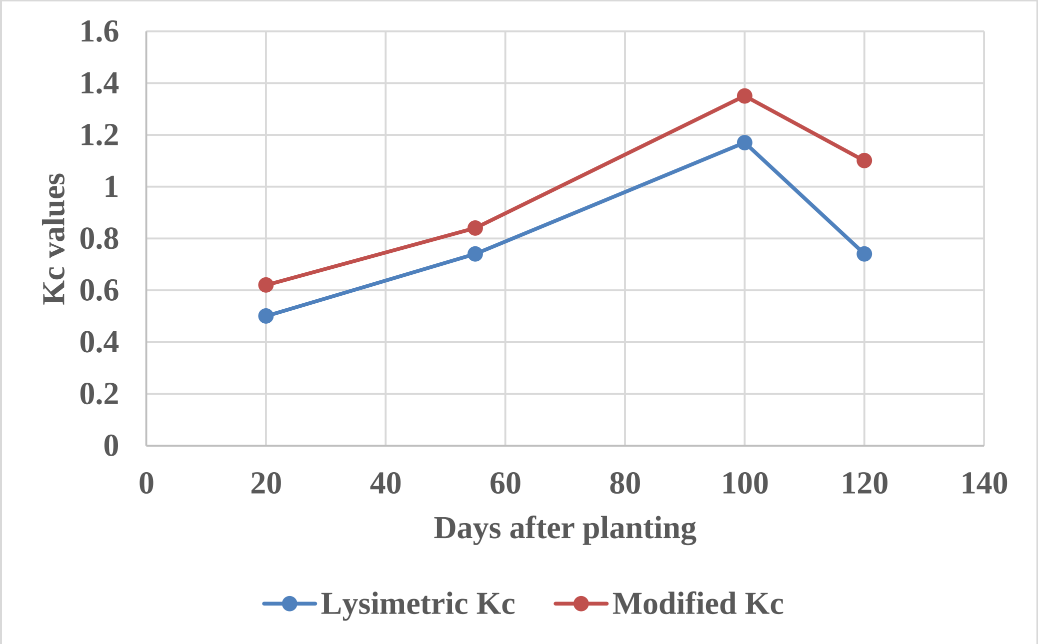

Fig. 4.1: Stagewise Kc curve for *Summer* Groundnut

4.2 Crop Coefficient for *Summer* Okra

For *Summer* Okra, from two years averaged crop coefficient data, the average Kc values are found to be 0.66, 1.09, 1.34 and 0.78 during initial, development, mid-stage and end stages, respectively. The average Kc value was low during initial stage due to low canopy cover, indicating that major loss may constitute through evaporation from bare soil. Data presented in Table 4.3 represents lysimetric crop coefficient values for *Summer* Okra.

Graphical representation for comparison of modified and lysimetric Kc is shown in figure 4.2. From the table and fig it is observed that modified Kc values are at par with lysimetric Kc values. Specifically for Okra crop there is no reference Kc values calculated by FAO.

Table 4.3: Stage wise average crop coefficient developed for *Summer* Okra

Stage	Duration (Days)	Modified Kc	Lysimetric Kc	Weightage (%)
Initial	20	0.65	0.66	16.67
Development	35	1.07	1.09	29.17
Mid	45	1.33	1.34	37.50
End	20	0.89	0.78	16.67

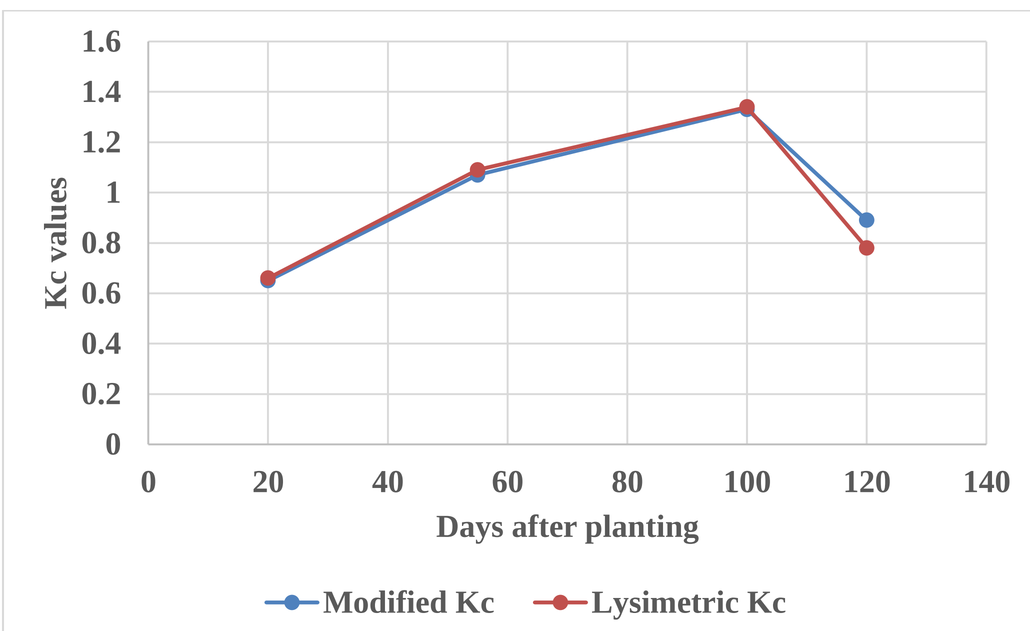

Fig. 4.2: Average Weekly Kc curve for *Summer* Okra

4.3 Crop Coefficient for *Kharif* Soybean

The two year average stage wise Kc values for *Kharif* Soybean during initial, development, mid and end stages were observed 0.55, 0.66, 1.02 and 0.62 respectively. The maximum Kc value was found during mid-season stage indicating the higher water requirement and lowest Kc value was found during initial stages. Indicating that modified Kc values was slightly higher than lysimetric Kc values and nearly equal with FAO Kc values. Table 4.4 represents the stage wise comparison of modified, lysimetric and FAO-56 Kc.

In the case of *Kharif* Soybean, the maximum weightage is 37.50 %, indicating longest growth stage of crop. The graphical representation of this K values are shown in fig. 4.3. Except end stage of soybean lysimetric Kc values are less than FAO kc values indicating that require less water than FAO standard

Table 4.4: Stage wise average crop coefficient developed for *Kharif* Soybean

Stage	Duration (Days)	Modified Kc	Lysimetric Kc	FAO - Kc	Weightage (%)
Initial	20	0.57	0.55	--	16.67
Development	35	0.76	0.66	--	29.17
Mid	45	1.13	1.02	1.15	37.50
End	15	0.55	0.62	0.50	16.67

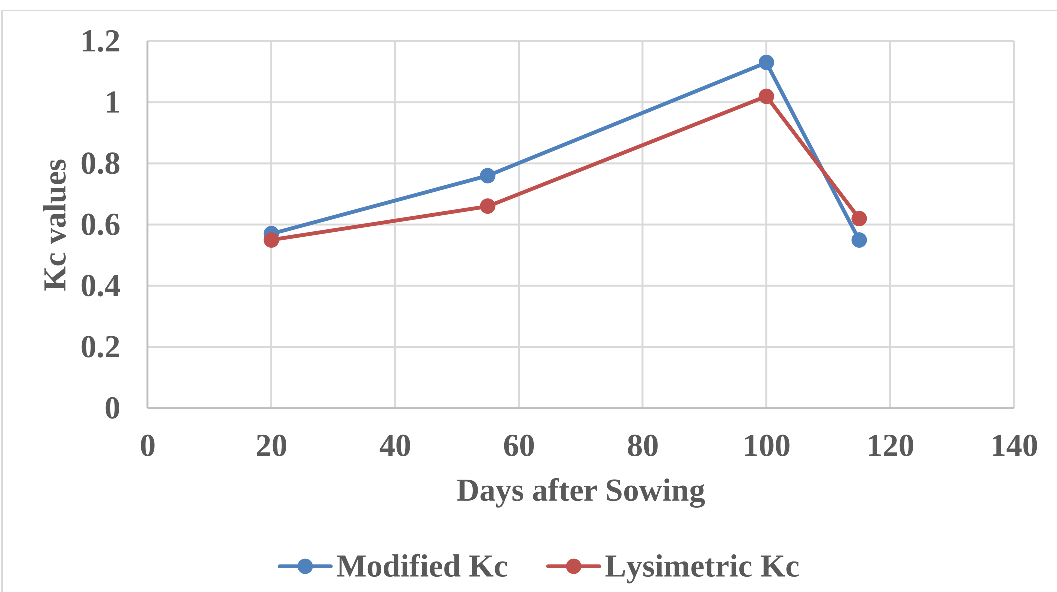

Fig. 4.3: Kc curve of *Kharif* Soybean during crop growth period

4.4 Crop Coefficient for *Kharif* Greengram

The table 4.5 provides a comparison of two year average crop coefficients (Kc) for different growth stages, namely Initial, Development, Mid, and End, along with the corresponding duration, between the FAO-56 standard and modified crop coefficients.

From table, it is observed that the lysimetric crop coefficients for *Kharif* Greengram were found lower than FAO standard Kc values. In simpler terms, it is indicate that, Kharif Greengram requires slightly lower water than FAO-56 standard.

Table 4.5: Stage wise average crop coefficient developed for *Kharif* Greengram

Stage	Duration (Days)	Modified Kc	Lysimetric Kc	FAO Kc	Weightage (%)
Initial	15	0.6	0.53	--	18.75
Development	25	0.9	0.98	--	31.25
Mid	25	1.07	0.88	1.05	31.25
End	15	0.45	0.48	0.60	18.75

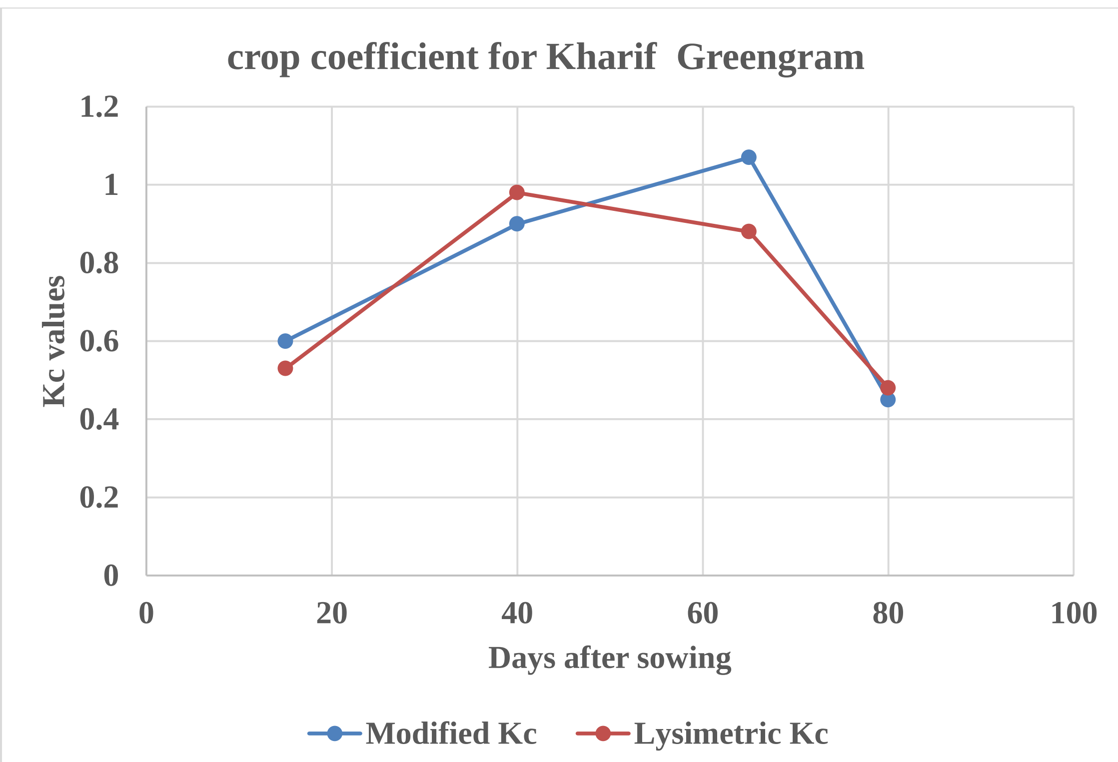

Fig. 4.4: Kc curve of *Kharif* Greengram during crop growth period

4.5 Crop Coefficients (Kc) for *Rabi* Sorghum

The Parbhani Jyoti (CSV-18) variety of sorghum was used for estimation of crop Kc. The computed two year average Kc values for *Rabi* Sorghum during initial, development, mid and end stages were 0.5, 0.8, 1.2 and 0.7 respectively. The maximum Kc value was found during mid-season stage, suggesting that increase in water demand for *Rabi* Sorghum with having higher weightage of crop duration in the local climate and lowest Kc was found during initial stages. Table 4.6 showing comparative stage wise average crop coefficient developed for *Rabi* Sorghum Fig. 4.6 represents the lysimetric Kc curve during crop growth period of *Rabi* Sorghum. This indicating very small difference between modified and lysimetric Kc. In which modified Kc values are slightly higher Kc values than FAO standard thus indicating the higher water requirement.

Table 4.6: Stage wise average crop coefficient developed for *Rabi Sorghum*

Stage	Duration (Days)	Modified Kc	Lysimetric Kc	FAO - Kc	Weightage (%)
Initial	20	0.45	0.5	--	16.67
Development	35	0.81	0.8	--	29.17
Mid	45	1.25	1.2	1.1	37.50
End	20	0.88	0.7	0.55	16.67

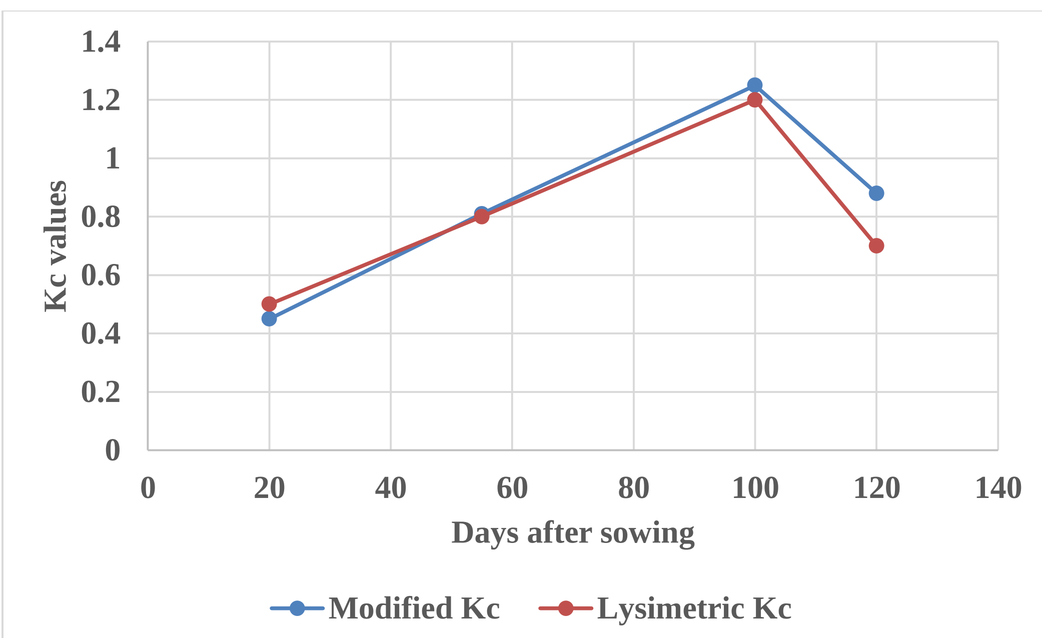

Fig. 4.4: Kc curve of *Rabi Sorghum* during crop growth period

5. CROP & IRRIGATION WATER REQUIREMENT FOR MARATHWADA

To compute Taluka wise Crop and Irrigation Water Requirement for Marathwada following procedure was followed.

1. **Data Collection:**

   Meteorological data collected from Automatic Weather Station and IMD Weather Station which is located near the lysimetric research field in VNMKV, Parbhani.

2. **Reference Evapotranspiration:**

   Reference crop evapotranspiration was calculated using the Penman- Monteith Method by using DSS_ET and Phule Jal software, using minimum and maximum temperature, and latitude of the stations.

3. **Spatial Interpolation:**

   Daily Reference evapotranspiration values were converted into weekly values. Weekly values were spatially interpolated over the entire Marathwada region using the Inverse Distance Weight (IDW) method in ArcMap.

4. **Crop Coefficient Multiplication:**

   The interpolated values were multiplied by the respective crop coefficients obtained from Lysimetric Studies for Groundnut, Okra, Soybean, Greengram and Sorghum.

5. **Weekly Maps of Crop Water Requirement:**

   Weekly maps of crop water requirement were developed for Marathwada based on the multiplied values.

6. **Shading Factor Consideration:**

   For Groundnut, Okra, Soybean, Greengram and Sorghum, close-growing row crops, the shading factor was considered as 1 during the calculation of crop water requirement.

7. **Geo-statistical Analysis:**

   Geo-statistical Analysis tools in ArcMap were utilized to extract taluka-wise weekly crop water requirements using preloaded locations of all the taluka in Marathwada region.

8. **Irrigation Water Requirement:**

Taluka-wise weekly crop water requirement was converted into irrigation water requirement. Different efficiencies were considered for surface irrigation (40%, 50%, and 60%), sprinkler irrigation (80% and 85%), and drip irrigation (90% and 95%).

To calculate irrigation water requirement by different irrigation methods at different efficiency levels, crop water requirement for given crop in given week was divided by efficiency factor. Different irrigation methods, efficiency levels and efficiency factors are given in table 5.1.

9. **Regional Overview:**

Taluka-wise crop water requirement and irrigation water requirement considering two year averaged lysimetric Kc values were compiled for 8 districts in Marathwada, namely Aurangabad, Beed, Hingoli, Jalna, Latur, Nanded, Osmanabad and Parbhani and given in appendices.

Table 5.1: Different irrigation methods, efficiency levels and efficiency factors

Sr. No.	Irrigation Method	Efficiency Level	Efficiency factor
1.	Surface Irrigation	40%	0.4
		50%	0.5
		60%	0.6
2.	Sprinkler Irrigation	80%	0.8
		85%	0.85
3.	Drip Irrigation	90%	0.9
		95%	0.95

6. SUBMISSION OF DELIVERABLES

Sr. No	Particulars	Phase	Date of Submission	Status of Grant
1.	Inception Report	I.	01/07/2020	Yes
2.	Lysimeter Installation Report	II.	08/06/2022	Yes
3.	● Normalized Kc Values using FAO calculations for Kharif Soybean, Kharif Greengram, Rabi Sorghum, Summer Groundnut and Okra ● Taluka wise weekly Crop Water Requirement and Irrigation Water Requirement of Kharif Soybean, Kharif Greengram, Rabi Sorghum, Summer Groundnut and Okra based on Modified Kc Values	III.	17/11/2022	Yes
4.	● Lysimetric Kc values Summer Groundnut and Okra (first year) ● Taluka wise weekly Crop Water Requirement and Irrigation Water Requirement of Summer Groundnut and Okra	IV.	14/03/2023	Yes
5.	● Kc values of Kharif Soybean and Kharif Greengram (first year) ● Taluka wise weekly Crop Water Requirement and Irrigation Water Requirement of Kharif Soybean and Kharif Greengram	IV.	28/04/2023	Yes
6.	● Lysimetric Kc values of Rabi Sorghum (first year) ● Taluka wise weekly Crop Water Requirement and Irrigation Water Requirement of Rabi Sorghum	VI.	16/06/2023	Yes
7.	● Lysimetric Kc values of Summer Groundnut and Okra (Second year) ● Taluka wise weekly Crop Water Requirement and Irrigation Water Requirement of Summer	VII.	03/08/2023	Yes

	Groundnut and Okra ● Comprehensive report for the first Year			
8.	● Lysimetric Kc values of Kharif Soyabean and Kharif Greengram (Second year) ● Taluka wise weekly Crop Water Requirement and Irrigation Water Requirement of Kharif Soyabean and Kharif Greengram	VIII.	21/02/2024	No
9.	● Lysimetric Kc values of Rabi Sorghum (Second year) ● Taluka wise weekly Crop Water Requirement and Irrigation Water Requirement of Sesame ● Comprehensive Report for the second year	IX.	18/03/2024	No
10	● Final comprehensive report on determination of crop coefficient for major crops using lysimetric studies	X	22/03/2024	No

7. APPENDICES

List of Appendices to be attached

Appendix	Details	
A	I	Weekly Kc Values of *Summer* Groundnut
	II	Weekly Kc Values of *Summer* Okra
	III	Weekly Kc values of *Kharif* Soybean
	IV	Weekly Kc values of *Kharif* Greengram
	V	Weekly Kc values of *Rabi* Sorghum
B	Crop and Irrigation Water Requirement of *Summer* Groundnut for Marathwada region	
	I	Taluka wise irrigation water requirement of *Summer* Groundnut by surface irrigation at 40, 50 and 60 percent efficiency
	II	Taluka wise irrigation water requirement of *Summer* Groundnut by sprinkler irrigation at 80 and 85 percent efficiency
	III	Taluka wise irrigation water requirement of *Summer* Groundnut by drip irrigation at 90 and 95 percent efficiency
C	Crop and Irrigation Water Requirement of *Summer* Okra for Marathwada region	
	I	Taluka wise irrigation water requirement of *Summer* Okra by surface irrigation at 40, 50 and 60 percent efficiency
	II	Taluka wise irrigation water requirement of *Summer* Okra by sprinkler irrigation at 80 and 85 percent efficiency
	III	Taluka wise irrigation water requirement of *Summer* Okra by drip irrigation at 90 and 95 percent efficiency
D	Crop and Irrigation Water Requirement of *Kharif* Soybean for Marathwada region	
	I	Taluka wise irrigation water requirement of *Kharif* Soybean by surface irrigation at 40, 50 and 60 percent efficiency
	II	Taluka wise irrigation water requirement of *Kharif* Soybean by sprinkler irrigation at 80 and 85 percent efficiency
	III	Taluka wise irrigation water requirement of *Kharif* Soybean by drip irrigation at 90 and 95 percent efficiency
E	Crop and Irrigation Water Requirement of *Kharif* Greengram for Marathwada region	
	I	Taluka wise irrigation water requirement of *Kharif* Greengram by surface irrigation at 40, 50 and 60 percent efficiency
	II	Taluka wise irrigation water requirement of *Kharif* Greengram by sprinkler irrigation at 80 and 85 percent efficiency
	III	Taluka wise irrigation water requirement of *Kharif* Greengram by drip

		irrigation at 90 and 95 percent efficiency
F	Crop and Irrigation Water Requirement of *Rabi* Sorghum for Marathwada region	
	I	Taluka wise irrigation water requirement of *Rabi* Sorghum by surface irrigation at 40, 50 and 60 percent efficiency
	II	Taluka wise irrigation water requirement of *Rabi* Sorghum by sprinkler irrigation at 80 and 85 percent efficiency
	III	Taluka wise irrigation water requirement of *Rabi* Sorghum by drip irrigation at 90 and 95 percent efficiency

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