A FINAL REPORT

on

DETERMINATION OF CROP COEFFICIENTS FOR MAJOR CROPS BY LYSIMETRIC STUDIES

funded by

NANAJI DESHMUKH KRISHI SANJEEVANI PRAKALP,

(PROJECT ON CLIMATE RESILIENT AGRICULTURE)

GOVERNMENT OF MAHARASHTRA

at

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING,

DR. PANJABRAO DESHMUKH KRISHI VIDYAPEETH AKOLA- 444104 (MAHARASHTRA)

(2021-2024)

Phase X
Final Report
on
Crop Kc, Water Requirement of Summer Greengram, Summer Sesame, Kharif Cotton and Kharif Pigeon Pea

"Determination of crop coefficients for major crops by Lysimetric studies"

Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola.

Title of the Project: Determination of crop coefficients for major crops by Lysimetric studies" at Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola.

Location: **Department of Irrigation and Drainage Engineering, Dr. Panjabrao Deshmukh Krishi Vidyapeeth Akola.**

Duration: **Three years.**

Total outlay: **Rs. 38.38 lakhs.**

Investigators:

Principal Investigator	:	Dr. M.M. Deshmukh, Associate Professor and Head, Department of Irrigation and Drainage Engineering Dr. PDKV, Akola.
Co-Principal Investigator	:	Dr. A.N. Mankar, Assistant Professor, Department of Irrigation and Drainage Engineering Dr. PDKV, Akola.
Coordinator for the project for three universities **(MPKV, Rahuri; Dr PDKV, Akola and VNMKV, Parbhani)**	:	Dr. S.D. Gorantiwar, PI CAAST-CSAWM and Head, Deptt. of Agril. Engg., MPKV, Rahuri.

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1. INTRODUCTION

Nanaji Deshmukh Krishi Sanjeevani Prakalp (NDKSP), Government of Maharashtra earlier referred as Project on Climate Resilient Agriculture (PoCRA) a World Bank Funded Project and Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola signed a MoU on January 17, 2020 at Mumbai by Project Director, PoCRA and the Director of Research, Dr. PDKV, Akola in presence of ADG (NRM), ICAR, New Delhi; Director, ICAR-CRIDA, Hyderabad; NDKSP Authorities and PI of the project from MPKV, Rahuri and VNMKV, Parbhani. The project is being executed at Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola.

Water is very critical natural input for agricultural production and plays a versatile role in crop growth and development which directly and indirectly results the yield and productivity of the crops. But due to population growth, urbanization, climate change the competition for water resources is expected to increase day by day with the negative impact on agriculture field. Currently Indian agriculture farmers tackle the different problems such as climate change, Famines & Droughts, Extreme precipitation and flooding, Hurricanes, Tornados, and Cyclones, Extreme Temperature and dryspell having the negative impacts on the Indian agriculture. Drought resilience is intricately related to the crop water requirements of different crops grown in the region, with the determination of local crop coefficients playing a pivotal role in optimizing irrigation strategies. 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 small pores (stomata) in the leaves.

The major component of the crop water requirement is the crop evapotranspiration. The estimation of crop evapotranspiration is, therefore, necessary for appropriate management of irrigation water for irrigation, water budgeting and matching demand and supply. The water requirement comprised mainly of evapotranspiration varies as per crop, its growth stage and prevailing weather conditions. Thus, crop evapotranspiration is the function of crop characteristics and weather characteristics. 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.

Currently most of the studies consider the crop coefficient values documented by FAO based on the average values all over the world. Therefore, consideration of the global averages of crop coefficient does not result in appropriate estimation of crop evapotranspiration and hence leads to inappropriate application of water, resulting in under or over irrigation and finally either in decreased productivity and/ or increased wastage of scarce water resources. FAO also cautioned to use the values documented by them carefully, as those values are average of values over different regions of 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. 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.

Objectives:

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 Dr. Panjabrao Deshmukh Krishi Vidyapith, Akola 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 AND AWS INSTALLATION

Weighing type Digital Lysimeters were 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, drainage 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 Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola; four Lysimeters were installed after procurement by Nanaji Deshmukh Krishi Sanjeevani Prakalp (formerly PoCRA) centrally.

Three Lysimeters were delivered on dated 18/07/2021 from M/s. Pratik enterprises, Sahakar Nagar, Parvati, Pune (Challan No.21104) which were installed at the Experimental farm of AICRP on Weed Management; Department of Agronomy, Dr. PDKV, Akola under the project on dated 18/11/2021.

Fourth lysimeter was delivered on dated 06/04/2023 from M/s. Pratik enterprises, Sahakar Nagar, Parvati, Pune (Challan No.23109) and it was installed at the Experimental farm of AICRP on Weed Management; Department of Agronomy, Dr. PDKV, Akola on dated 11/05/2023.

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

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

Sr. No.	Component	Specifications	Functions
1.	Inner box	1.5 x 1.5 x 1.00 m	To grow crop in an isolated environment.
2.	Outer box	1.6 x 2.1 x 1.25 m	To separate isolated mass of soil from surrounding environment.
3.	Weighing Scale	Size: 1.5 x 1.5 m 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	0.4m×0.38m×0.26m. Made of corrosion free material.	Shows the weight of Soil water in inner tank & drain water in drain tank
6.	GI Pipe	Length 2 m	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	0.6 X 0.3 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

LYSIMETER INSTALLATION PROCEDURE:

The installation procedure of lysimeters 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 14.

1. **Site Selection:** A central location within the agricultural field was identified and selected for Lysimeter installation. The site was ensured to be easily accessible and cleared of potential interference.
2. **Prepare the Site:** The selected area was cleared of vegetation and debris. The central point of the field was established, and the exact location for Lysimeter installation was marked.
3. **Digging the Pit:** A pit was manually excavated at the chosen location to the size of the inner tank (1.5 × 1.5 × 1 m). During excavation, soil was systematically set aside in layers of 20 cm thickness. Then, the pit was expanded with heavy machinery (JCB) to the size of the outer tank of the Lysimeter (1.6 × 2.1 × 1.25 m).
4. **Laying Foundation:** The bottom of pit was levelled using a Water Level for precision. A layer of bricks was placed at the base to establish a solid foundation for the Lysimeter.
5. **Lysimeter Installation:** The Lysimeter (consisting of the outer tank, inner tank, and weighing frame) was carefully lowered into the pit with the help of Crane, ensuring it was leveled and securely positioned.
6. **Back filling of Soil:** The inner tank was backfilled with the soil layers kept separate during excavation to maintain soil structure. The last-excavated layer was placed on the perforated plate inside the inner tank first, and the initial layer was placed last. Temperature and moisture sensors were inserted at 30, 60, and 90 cm from the soil surface.
7. **Installation of Accessories:** The Drain Tank, Control Panel, battery, and Solar Panel were installed. Wires connecting the load cells to the Data Logger and GSM module were properly fitted.
8. **Calibration:** The Lysimeter was calibrated to ensure precise measurements, including weight sensor calibration and the setup of data logging systems.

Plate 1. Layout of digging site

Plate 2. Digging of pit and heave of soil from pit

Plate 3. Layer wise heaves of soil

Plate 4. 1 m × 1 m pit from which soil was excavated layer wise to fill in inner tank of Lysimeter

Plate 5. Bricks foundation below Lysimeter as levelled platform

Plate 6. Lysimeter placed on the foundation in pit

Plate 7. Placing of mesh and soil moisture sensor at the bottom of inner tank to prevent washing out of soil through drain

Plate 8. Layer wise soil refilling & compaction and sensor installation in the inner tank of Lysimeter

Plate 9. Completion of Soil filling in the inner tank of Lysimeter

Plate 10. Final installation of Lysimeter and control panel

Plate 11. Saturated Lysimeter after successful installation and calibration

INSTALLATION OF AUTOMATIC WEATHER STATION:

The Automatic Weather Station (AWS10W) has been received as per specifications in good condition from Origin Instruments and Analytics. The following table 2 shows materials received and installed by Origin Instruments and Analytics.

Table 2. Details of AWS received and installed at experimental site

Sr. No.	Material Description	Quantity
1	Data logger, AWS10W (Serial no. 86DTF22)	1
2	Weather Proof Enclosure with key	1
3	Wind direction sensor with cable	1
4	Temperature with humidity sensor with cable	1
5	Wind speed sensor with cable	1
6	B P sensor with cable	1
7	Solar Radiation sensor with cable	1
8	Rain gauge sensor with cable	1
9	USB pen drive	1
10	Software CD including JRE	1
11	User manual of software and data logger	1
12	Warranty Certificate and calibration certificate	1
13	Tool kit, screw driver, adjustable spanner, allen key 3/16 one each	1
14	Tripod stand and accessories	1

INSTALLATION SITE OF AWS:

AWS was installed on the experimental farm of AICRP on Weed Management; Department of Agronomy, Dr. PDKV, Akola under this project on date 13/10/2022.

In order to install the AWS, a concrete platform of 2m x 2m was constructed to install AWS at an experimental field under Project on "Determination of crop coefficients for major crops by Lysimetric studies" at AICRP on Weed Management; Department of Agronomy, Dr. PDKV, Akola. The electricity supply for AWS is provided at the corner of the field near AWS platform. Also, as per needs, a SIM with 1GB data per month with voice call enabled for AWS Modem is provided. The tripod stand has been fixed to the AWS platform with cement concrete material at each leg of the tripod.

All the installed sensors were connected to data logger to store and display the weather data. The modem is connected to data logger to update the weather data to online server. The installation of Automatic Weather Station is done successfully and it's working in good condition.

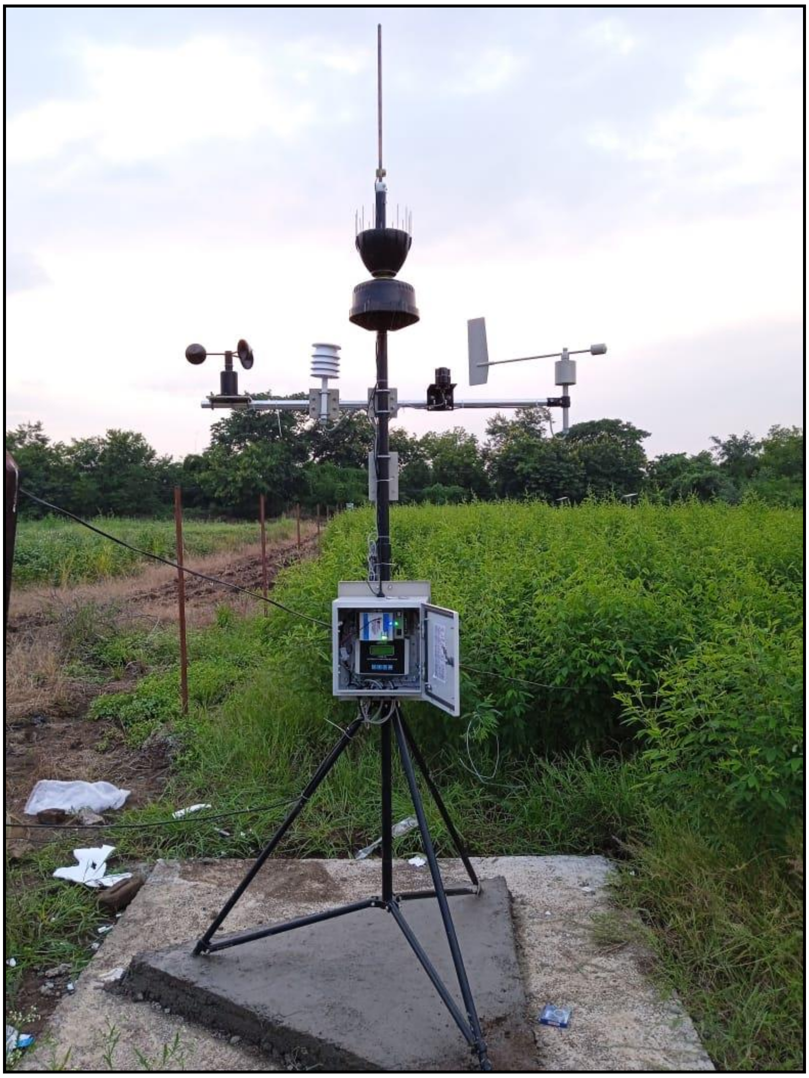

Plate 12. AWS Installed at Experimental Site

3. MODIFIED CROP COEFFICIENTS (FAO) OF SUMMER GREENGRAM, SUMMER SESAME, KHARIF COTTON & KHARIF PIGEON PEA

Terminologies:

i. 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).

ii. Reference Evapotranspiration (ETo):

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).

iii. 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).

iv. Crop Coefficient (Kc):

The crop coefficient, Kc, is the ratio of the crop evapotranspiration (ETc) to the reference evapotranspiration (ETo), 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).

v. Penman Monteith Method

The FAO Penman Monteith Method has been recommended as the sole standard method for calculating reference crop evapotranspiration. It is a method with strong likelihood of correctly predicting ETr in a wide range of locations (Allen et. al., 1998). By defining the reference crop as a hypothetical crop with assumed height of 0.12 m having a surface resistance of 70 s m-1 and an albedo of 0.23, closely resembling the evaporation of an extensive surface of green grass of uniform height, actively growing and adequately watered, the FAO Penman Monteith Method was developed as presented by following equation.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where, ETo - Reference Evapotranspiration (mm day^{-1})

Δ - Slope of saturation vapour curve (kPa $^0C^{-1}$)

R_n - Net radiation at the crop surface (MJ m^{-2} day^{-1})

G - Soil heat flux density (MJ m^{-2} day^{-1})

γ - Psychometric constant (kPa $^0C^{-1}$)

T - Mean air temperature (^{0}C)

u_2 - Wind speed at 2.0 m height (ms^{-1})

e_a - Actual vapour pressure (kPa)

e_s - Saturation vapour pressure (kPa)

(e_s- e_a) - Saturation vapour pressure deficit (kPa)

COMPUTATION OF MODIFIED FAO Kc VALUES FOR VIDARBHA REGION

Crop water requirement (ETc) was determined by the crop coefficient approach whereby the effect of the various weather conditions are incorporated into reference crop evapotranspiration (ETo) and the crop characteristics into the crop coefficient (Kc):

$$ETc = Kc \times ETo$$

Crop water requirement for major crops i.e. Summer Greengram, Summer Sesame, Cotton and Pigeon Pea were determined using the historical meteorological data of 30 years. Daily meteorological data were downscaled and downloaded for the period 1992 - 2021 (30 years) for 118 tehsils of Vidarbha from website (power.larc.nasa.gov) of The POWER Project supported by NASA Earth Science for prediction of worldwide energy resources. Data pertaining to maximum temperature (^{o}C) at 2 m (Tmax), minimum temperature (^{o}C) at 2 m (Tmin), relative humidity (%) at 2 m (RH), wind speed (ms^{-1}) at 2 m (WS) and all sky surface shortwave downward irradiance (MJ m^{-2} day $^{-1}$) i.e. Solar radiation (Rs) are available free to download from that website and data of these parameters was downloaded. Then, mean weekly averages of all above meteorological data was determined, by averaging it, according to standard meteorological weeks. Other parameters like geographic locations viz., latitude, longitude and altitude were also obtained.

I) Reference Crop Evapotranspiration

Weekly reference crop evapotranspiration was determined by converting daily climatic data into weekly, according to standard meteorological weeks (SMW). Estimation of weekly reference evapotranspiration (ETo, mm day^{-1}) was carried out by using FAO Penman-Monteith method for all eleven districts of Vidarbha region.

The determined weekly reference crop evapotranspiration (ETo) for 30 years (1992-2021) was averaged to get average weekly ETo for 52 standard meteorological weeks for each station (Tehsil) of all eleven districts in Vidarbha region. The obtained ETo values for each taluka were used to extract district wise and Tehsil wise average ETo values for respective tehsil and district using GIS software. The extracted ETo values for each district and taluka were used to determine the crop water requirement for the respective station by multiplying crop coefficient values.

II) Modified Crop Coefficients

FAO has given the crop coefficient values for various crops and climatic conditions; these values can be used to calculate the crop evapotranspiration after modifying according to our local climatic conditions. Crop coefficient values were determined by modifying the FAO crop coefficients for local climatic conditions to determine the crop evapotranspiration. The Kc values were modified for the four crops i.e. summer sesame, summer greengram, cotton and pigeon pea. The calculation modification of FAO crop coefficients consists of:

1. Identifying the crop growth stages, determining their lengths, and computing the corresponding crop coefficients;

2. Constructing the crop coefficient curve (To predict Kc values from graph plotted for the growing period); and

3. Calculating ETc as the product of ETo and Kc.

1. Identifying the crop growth stages and their lengths for local varieties of respective crops: Identifying and determining the length of growth stages was done by selecting the general lengths for the four distinct growth stages and the total growing period for local climatic conditions. This information is summarized in Table 3.

Table 3. Length of growth Stages for selected crops

Sr. No.	Name of Crop	Length of Growth Stage (Days)				
		Initial	Development	Mid	End	Total
1	Summer Greengram	10	21	26	13	70
2	Summer Sesame	15	28	42	20	105
3	Cotton (Kharif)	22	38	52	48	160
4	Pigeon Pea (Kharif)	24	52	58	46	180

Determination of Crop coefficient for the initial stage (Kc ini)

The crop coefficient for the initial growth stage was derived by taking reference of FAO, irrigation and drainage paper No.56. FAO has given the procedure to select the initial Kc value by graphical method. The average reference crop evapotranspiration values were used to determine the Kc initial using FAO graphical method. Whereas the wetting events for determining the Kc initial for all four crops were selected by general irrigation intervals during summer for greengram and sesame and during Kharif for cotton and pigeon pea. Figure 1. is given by FAO-56 which is used for heavy wetting events when infiltration depths are greater than 40 mm, such as for when wetting is primarily by periodic irrigation such as by sprinkler or surface irrigation.

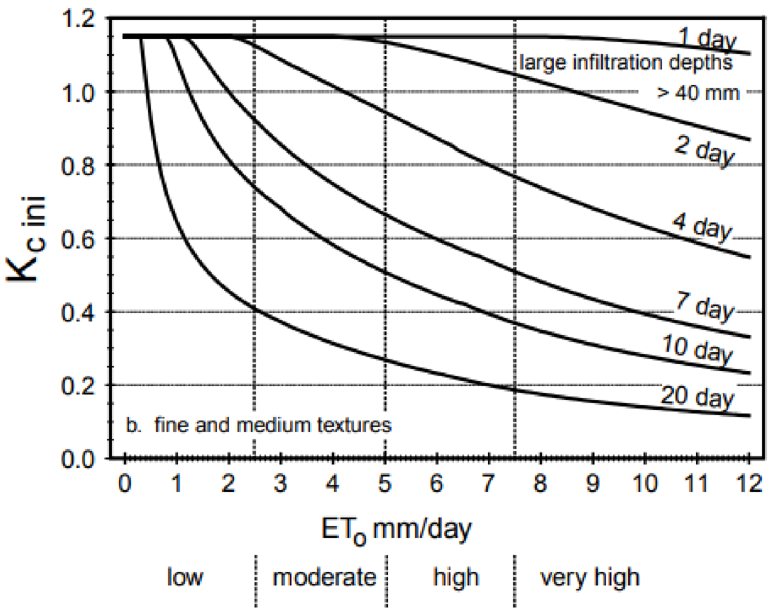

Figure 1. Average Kc ini as related to the level of ETo and the interval between irrigations greater than or equal to 40 mm per wetting event, during the initial growth stage for a) coarse textured soils; b) medium and fine textured soils

Determination of Crop coefficient for the mid stage (Kc mid)

The computation of Kc mid was done for specific adjustment in climates where mean value of daily minimum relative humidity during mid-stage of growth stage and mean daily wind speed during the mid-stage of growth stage was considered by following the procedure given by FAO, Irrigation and drainage paper. The mean plant height and mean relative humidity during the mid-season stage for all four crops were collected from previous experimental data of university for determining Kc mid as well as Kc end. The mean daily wind speed value was used to determine both Kc mid and Kc end. Following equation was used to estimate Kc mid:

$$K_C\ mid = K_{C\ mid\ (FAO)} + [0.04(u_2 - 2) - 0.004\ (RH_{min} - 45)]\ (h/3)^{0.3}$$

Where,

$Kc_{\ mid\ (FAO)}$ -	Value for Kc mid 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 mid-season growth stage (%),
h -	Mean plant height during the mid-season stage (m)

Determination of Crop coefficient for the end stage (Kc end)

The computation of Kc end is similar to Kc mid where mean value of daily minimum relative humidity during end-stage of growth stage and mean daily wind speed during the end-stage of growth stage was considered by following the procedure given by FAO, Irrigation and drainage paper. Following equation was used to estimate Kc end:

$$K_C\ end = K_{C\ end\ (FAO)} + [0.04(u_2 - 2) - 0.004\ (RH_{min} - 45)]\ (h/3)^{0.3}$$

Where,

$Kc_{\ end\ (FAO)}$ -	Value for Kc 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 the end-season stage (m)

2. Constructing the crop coefficient curve (To determine Kc values for weekly crop coefficient during the growing period)

The calculated crop coefficient values were plotted against time of season (days) for respective crop growth stages to get weekly Kc values for all four crops and eleven districts of Vidarbha region. Only three-point values of Kc are required to describe and to construct the Kc curve. The curve was constructed using the following three steps:

1. Divided the growing period into four general growth stages that describe crop phenology or development (initial, crop development, mid-season, and late season stage), determined the lengths of the growth stages, and identified the three Kc values that correspond to Kc ini, Kc mid and Kc end.

2. Constructed a curve by connecting straight line segments through each of the four growth stages. Horizontal lines were drawn through Kc ini in the initial stage and through Kc mid in the mid-season stage. Diagonal lines were drawn from Kc ini to Kc mid within the course of the crop development stage and from Kc mid to Kc end within the course of the late season stage.

3. After plotting horizontal and diagonal curve for all growth stages, the possible best fitting soft curve has been drawn manually on graph paper for whole growing season of respective crop and for respective district. Then the weekly Kc values has been read from that soft curve for the whole growing season.

4. The obtained weekly Kc values for all four crops were plotted against crop weeks in Microsoft Excel to determine the daily values of crop coefficient by obtaining curve fitting equation. Then estimated daily Kc values were averaged to get modified weekly crop coefficients more exactly.

Following tables 4, 5, 6 and 7 represents the modified FAO Kc values for summer greengram, summer sesame, kharif cotton and pigeon pea respectively.

Table 4. Modified FAO Crop Coefficient values for Summer Greengram

Week No.		Akola	Amravati	Bhandara	Buldhana	Chandrapur	Gadchiroli	Gondia	Nagpur	Wardha	Washim	Yavatmal
MW	CW											
11	1	0.52	0.50	0.54	0.53	0.54	0.54	0.54	0.54	0.53	0.53	0.52
12	2	0.62	0.60	0.64	0.64	0.64	0.60	0.64	0.64	0.64	0.63	0.63
13	3	0.79	0.77	0.80	0.79	0.79	0.70	0.80	0.81	0.79	0.79	0.79
14	4	0.95	0.95	0.96	0.95	0.95	0.82	0.96	0.97	0.95	0.95	0.96
15	5	1.08	1.09	1.09	1.08	1.07	0.91	1.09	1.09	1.07	1.08	1.10
16	6	1.16	1.17	1.16	1.15	1.14	0.95	1.16	1.16	1.15	1.15	1.17
17	7	1.17	1.18	1.18	1.17	1.15	0.92	1.17	1.17	1.16	1.16	1.18
18	8	1.11	1.12	1.12	1.12	1.10	0.83	1.11	1.11	1.10	1.10	1.12
19	9	0.99	0.99	0.99	1.00	0.97	0.67	0.99	0.98	0.98	0.97	0.99
20	10	0.78	0.80	0.78	0.81	0.77	0.43	0.78	0.78	0.78	0.77	0.80
21	11	0.76	0.78	0.76	0.79	0.75	0.42	0.76	0.76	0.76	0.76	0.78

*MW = Meteorological Week

*CW = Crop Week

Table 5. Modified FAO Crop Coefficient values for Summer Sesame

Week No.		Akola	Amravati	Bhandara	Buldhana	Chandrapur	Gadchiroli	Gondia	Nagpur	Wardha	Washim	Yavatmal
MW	CW											
6	1	0.58	0.57	0.61	0.59	0.60	0.64	0.63	0.60	0.59	0.60	0.58
7	2	0.63	0.63	0.67	0.64	0.65	0.69	0.68	0.66	0.65	0.65	0.64
8	3	0.72	0.72	0.75	0.73	0.74	0.76	0.76	0.75	0.73	0.73	0.73
9	4	0.83	0.83	0.85	0.84	0.84	0.85	0.86	0.85	0.83	0.83	0.83
10	5	0.94	0.95	0.96	0.95	0.94	0.94	0.96	0.96	0.94	0.94	0.95
11	6	1.05	1.06	1.06	1.06	1.05	1.04	1.06	1.06	1.04	1.04	1.06
12	7	1.15	1.16	1.15	1.16	1.14	1.12	1.15	1.16	1.13	1.13	1.15
13	8	1.22	1.23	1.22	1.23	1.20	1.18	1.22	1.23	1.20	1.20	1.23
14	9	1.26	1.27	1.26	1.27	1.24	1.21	1.26	1.27	1.23	1.24	1.27
15	10	1.26	1.27	1.27	1.28	1.24	1.21	1.26	1.27	1.24	1.25	1.27
16	11	1.22	1.23	1.23	1.23	1.20	1.17	1.22	1.23	1.19	1.21	1.22
17	12	1.13	1.13	1.13	1.14	1.11	1.08	1.13	1.13	1.10	1.12	1.13
18	13	0.98	0.99	0.99	1.00	0.96	0.94	0.98	0.98	0.96	0.97	0.98
19	14	0.78	0.78	0.78	0.80	0.75	0.73	0.77	0.78	0.76	0.76	0.78
20	15	0.52	0.52	0.50	0.53	0.49	0.46	0.48	0.50	0.49	0.49	0.52
21	16	0.50	0.50	0.48	0.51	0.46	0.44	0.46	0.48	0.47	0.46	0.50

Table 6. Modified FAO Crop Coefficient values for Cotton

Week No.		Akola	Amravati	Bhandara	Buldhana	Chandrapur	Gadchiroli	Gondia	Nagpur	Wardha	Washim	Yavatmal
MW	CW											
25	1	0.47	0.47	0.51	0.45	0.51	0.54	0.53	0.51	0.49	0.51	0.41
26	2	0.50	0.49	0.53	0.48	0.53	0.56	0.55	0.52	0.51	0.53	0.44
27	3	0.55	0.54	0.58	0.53	0.58	0.60	0.59	0.57	0.55	0.57	0.49
28	4	0.61	0.60	0.63	0.60	0.64	0.66	0.65	0.63	0.61	0.62	0.56
29	5	0.68	0.68	0.70	0.68	0.71	0.72	0.72	0.70	0.68	0.68	0.64
30	6	0.76	0.76	0.78	0.76	0.78	0.79	0.79	0.77	0.76	0.75	0.73
31	7	0.84	0.84	0.85	0.84	0.85	0.86	0.86	0.85	0.84	0.81	0.82
32	8	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.91	0.86	0.91
33	9	0.98	0.99	0.98	0.99	0.98	0.97	0.98	0.98	0.97	0.91	0.98
34	10	1.04	1.04	1.03	1.04	1.03	1.02	1.03	1.04	1.02	0.95	1.05
35	11	1.08	1.09	1.07	1.09	1.07	1.05	1.07	1.08	1.06	0.98	1.09
36	12	1.11	1.12	1.09	1.11	1.09	1.07	1.09	1.11	1.09	1.00	1.12
37	13	1.12	1.13	1.10	1.12	1.10	1.08	1.10	1.12	1.10	1.00	1.14
38	14	1.12	1.12	1.10	1.12	1.09	1.08	1.09	1.11	1.09	0.98	1.13
39	15	1.10	1.10	1.08	1.10	1.07	1.06	1.07	1.09	1.07	0.95	1.11
40	16	1.07	1.07	1.05	1.06	1.04	1.03	1.04	1.06	1.04	0.92	1.08
41	17	1.06	1.06	1.04	1.05	1.03	1.02	1.03	1.05	1.03	0.91	1.07
42	18	1.02	1.02	1.00	1.01	0.99	0.98	0.99	1.01	0.99	0.86	1.02
43	19	0.97	0.96	0.94	0.95	0.93	0.92	0.94	0.95	0.93	0.80	0.96
44	20	0.90	0.89	0.88	0.89	0.87	0.86	0.88	0.89	0.86	0.73	0.89
45	21	0.84	0.82	0.82	0.82	0.80	0.80	0.81	0.82	0.80	0.66	0.82
46	22	0.72	0.70	0.70	0.70	0.68	0.68	0.70	0.69	0.67	0.51	0.70
47	23	0.68	0.67	0.66	0.66	0.63	0.63	0.65	0.65	0.63	0.46	0.67
48	24	0.68	0.66	0.65	0.66	0.62	0.63	0.65	0.65	0.63	0.45	0.66

Table 7. Modified FAO Crop Coefficient values for Pigeon Pea

Week No.		Akola	Amravati	Bhandara	Buldhana	Chandrapur	Gadchiroli	Gondia	Nagpur	Wardha	Washim	Yavatmal
MW	CW											
25	1	0.48	0.49	0.51	0.47	0.51	0.58	0.54	0.51	0.50	0.53	0.44
26	2	0.49	0.49	0.51	0.48	0.52	0.58	0.55	0.52	0.50	0.54	0.44
27	3	0.51	0.52	0.54	0.51	0.55	0.60	0.57	0.55	0.53	0.56	0.47
28	4	0.56	0.56	0.58	0.55	0.58	0.63	0.60	0.59	0.56	0.59	0.51
29	5	0.61	0.61	0.63	0.61	0.63	0.67	0.65	0.64	0.61	0.64	0.57
30	6	0.67	0.67	0.69	0.67	0.69	0.72	0.70	0.70	0.67	0.69	0.64
31	7	0.74	0.74	0.75	0.73	0.75	0.77	0.76	0.76	0.73	0.75	0.71
32	8	0.81	0.81	0.81	0.80	0.81	0.83	0.82	0.82	0.79	0.81	0.78
33	9	0.88	0.87	0.87	0.87	0.87	0.88	0.87	0.88	0.86	0.87	0.85
34	10	0.94	0.93	0.93	0.93	0.92	0.93	0.93	0.94	0.91	0.93	0.92
35	11	0.99	0.99	0.98	0.98	0.97	0.98	0.98	0.99	0.96	0.98	0.98
36	12	1.04	1.03	1.03	1.03	1.01	1.01	1.02	1.03	1.01	1.02	1.03
37	13	1.07	1.07	1.06	1.06	1.05	1.04	1.05	1.07	1.04	1.05	1.07
38	14	1.10	1.09	1.08	1.09	1.07	1.06	1.07	1.09	1.07	1.08	1.10
39	15	1.11	1.10	1.10	1.10	1.08	1.07	1.08	1.10	1.08	1.09	1.11
40	16	1.11	1.10	1.09	1.10	1.08	1.07	1.08	1.09	1.08	1.09	1.11
41	17	1.10	1.09	1.08	1.09	1.07	1.05	1.06	1.08	1.06	1.07	1.10
42	18	1.07	1.06	1.05	1.06	1.04	1.03	1.04	1.05	1.04	1.05	1.07
43	19	1.03	1.02	1.01	1.02	1.00	0.99	1.00	1.01	1.00	1.01	1.03
44	20	0.98	0.97	0.96	0.97	0.95	0.94	0.95	0.96	0.95	0.96	0.98
45	21	0.91	0.91	0.90	0.91	0.89	0.88	0.89	0.90	0.88	0.89	0.91
46	22	0.84	0.84	0.83	0.84	0.82	0.81	0.82	0.83	0.81	0.82	0.84
47	23	0.76	0.75	0.74	0.75	0.73	0.72	0.74	0.74	0.72	0.73	0.75
48	24	0.66	0.65	0.64	0.65	0.62	0.62	0.64	0.64	0.62	0.62	0.65
49	25	0.57	0.55	0.54	0.56	0.52	0.51	0.55	0.54	0.51	0.51	0.55
50	26	0.51	0.48	0.48	0.49	0.44	0.44	0.49	0.48	0.44	0.44	0.49
51	27	0.51	0.48	0.47	0.48	0.43	0.43	0.48	0.47	0.44	0.43	0.48
52	28	0.50	0.47	0.46	0.48	0.43	0.43	0.47	0.46	0.43	0.42	0.47

4. CROP COEFFICIENTS SUMMER SESAME, SUMMER GREENGRAM, KHARIF COTTON AND KHARIF PIGEON PEA USING LYSIMETRIC STUDIES

In the project titled "Determination of Crop Coefficient for Major Crops by Lysimetric Studies" conducted at, Dr. Panjabrao Deshmukh Krishi Vidyapith, Akola, the primary objective was to assess and establish crop coefficients for four major crops using lysimeters: Summer Sesame, Summer Greengram, Kharif Cotton and Kharif Pigeon Pea.

Table 8: Details of the experiments/trials conducted under the project

Sr. No.	Crop	Season	Year	Date Of Sowing	Date of Harvesting
1	Summer Greengram	1	2022	28-03-2022	03-06-2022
2	Summer Sesame	1	2022	11-02-2022	25-05-2022
3	Kharif Cotton	1	2022	24-06-2022	10-12-2022
4	Kharif Pigeon pea	1	2022	24-06-2022	20-12-2022
5	Summer Greengram	2	2023	03-03-2023	30-05-2023
6	Summer Sesame	2	2023	13-02-2023	18-05-2023
7	Kharif Cotton	2	2023	28-06-2023	12-12-2023
8	Kharif Pigeon pea	2	2023	30-06-2023	28-12-2023

Cultivation of Summer Green Gram and Summer Sesame:

The cultivation of summer greengram and summer sesame was done for two seasons, the variety of Pusa Vaishakhi was used for summer greengram whereas for summer sesame, PDKV NT-11 was used for both seasons. Plate 12 and 13 shows the cultivation of summer greengram and summer sesame inside and around the lysimeters.

Plate No. 12. Cultivation of Summer Greengram inside and around the lysimeter

Plate No. 13. Cultivation of Summer sesame inside and around the lysimeter

Cultivation of Kharif Cotton and Pigeon pea:

The cultivation of kharif cotton and pigeon pea was done for two seasons, the variety of PDKV- JKAL-116 was used for cotton whereas for pigeon pea, PDKV–Ashlesha was used for both seasons. Plate 14 and 15 shows the cultivation of kharif cotton and pigeon pea inside and around the lysimeters.

Plate No. 14. Cultivation of Kharif Cotton inside and around the lysimeter

Plate No. 15. Cultivation of Kharif Pigeon pea inside and around the lysimeter

1. CROP COEFFICIENTS (Kc) FOR SUMMER GREENGRAM:

The weekly crop coefficient values were computed as the ratio of weekly crop evapotranspiration and weekly reference evapotranspiration. Weekly crop evapotranspiration was measured from lysimeters by growing crop in lysimeters. For summer greengram, two lysimeters were used and the crop coefficient values were measured for both lysimeters. The crop coefficient values obtained from both lysimeters were averaged to avoid errors in the measurement. The weekly crop coefficient values obtained from both lysimeters of summer greengram for summer season of 2022 and 2023 were averaged to get more precise Kc values which are represented in table 9.

Table 9. Average weekly crop coefficient (Kc) values for summer greengram

Crop Week	t/T	Weekly Kc Values			Stagewise Days	Stagewise Kc Values		
		2022	2023	Average		2022	2023	Average
1	0.09	0.59	0.53	0.56	Initial (15 Days)	0.57	0.60	0.59
2	0.18	0.64	0.65	0.65				
3	0.27	0.74	0.79	0.77	Deve. (25 Days)	0.96	0.98	0.97
4	0.36	0.86	0.93	0.90				
5	0.45	1.00	1.06	1.03	Mid (25 Days)	1.17	1.16	1.16
6	0.55	1.11	1.16	1.13				
7	0.64	1.19	1.21	1.20				
8	0.73	1.22	1.20	1.21				
9	0.82	1.16	1.13	1.15	End (12 Days)	0.81	0.78	0.80
10	0.91	1.02	0.96	0.99				
11	1.00	0.75	0.70	0.72				

The comprehensive average weekly Kc values for summer greengram for the growing period of 11 weeks were found 0.56, 0.65, 0.77, 0.90, 1.03, 1.13, 1.20, 1.21, 1.15, 0.99 and 0.72 respectively. Whereas, comprehensive average stage wise Kc values for initial (15 Days), development (25 Days), mid (25 Days) and end stage (15 Days) were 0.59, 0.97, 1.16 and 0.80 respectively. The highest values of crop coefficients were found during the mid-season stage which may be due to the higher canopy during mid stage. Figure 2 shows the comparison between weekly crop coefficient values obtained using lysimeter for summer greengram for season 2022 and 2023.

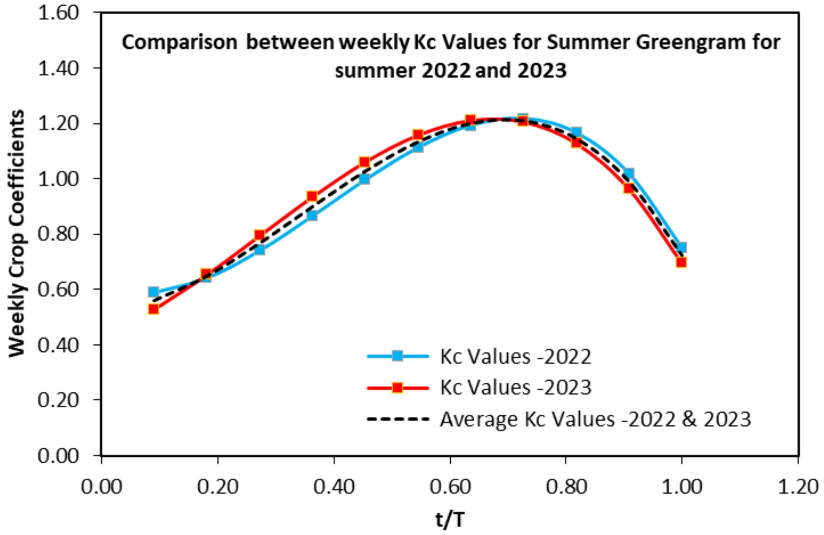

Figure 2. Comparison between weekly Kc values for summer greengram for summer season of 2022 and 2023

Equation No. 1 given below is polynomial equation obtained for comprehensive average weekly K_c values for summer greengram against 't/T' to derive daily K_c values.

$$Kc_t = -3.8882\left(\frac{t}{T}\right)^3 + 3.9756\left(\frac{t}{T}\right)^2 + 0.1172\left(\frac{t}{T}\right) + 0.5182 \quad \text{........(1)}$$

Comparison between Lysimetric and FAO Modified Kc values for Summer Greengram:

Average lysimetric Kc values for the year 2022 and 2023 were found as 0.59, 0.97, 1.16 and 0.80 for initial, development, midseason and late season stages of summer greengram respectively. Whereas the FAO modified Kc values were obtained as 0.56, 0.96, 1.12 and 0.83 for initial, development, mid-season and late season stage. Table 10 shows the comparison between comprehensive average lysimetric kc values and FAO modified Kc values for summer greengram.

Table 10. Comparison between average lysimetric and FAO modified Kc values for summer greengram

Growth Stages	Average Lysimetric Kc (2022 &2023)	FAO Kc	FAO modified Kc
Initial season stage	0.59	0.4	0.56
Development Stage	0.97	-	0.96
Mid-season stage	1.16	1.05	1.12
Late season stage	0.80	0.6	0.83

Figure 3 shows the comparison between comprehensive average weekly Kc values obtained from lysimeters and FAO modified K_c values for summer greengram.

The polynomial equation (2) obtained for FAO modified Kc values for summer greengram is as follow;

$$Kc_t = -4.8077\left(\frac{t}{T}\right)^5 + 15.953\left(\frac{t}{T}\right)^4 - 21.272\left(\frac{t}{T}\right)^3 + 10.868\left(\frac{t}{T}\right)^2 - 0.5872\left(\frac{t}{T}\right) + 0.516$$

……...(2)

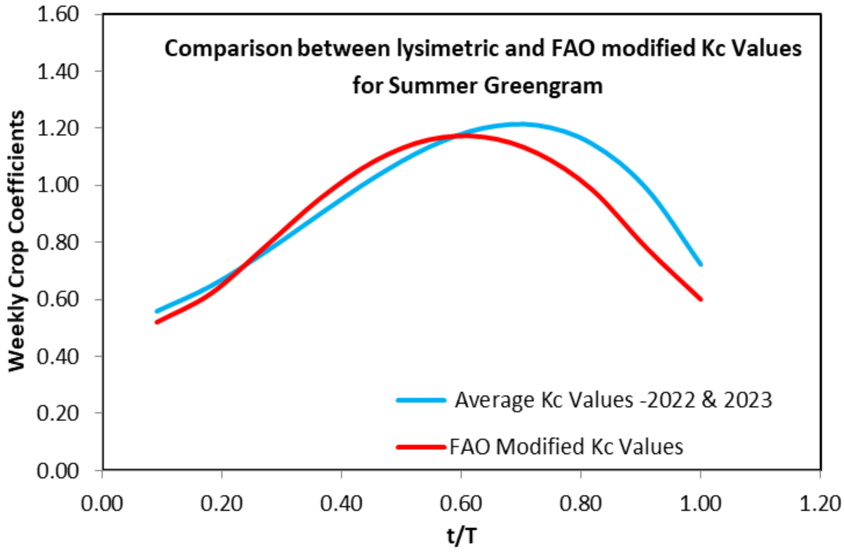

Figure 3. Comparison between average lysimetric (2022 and 2023) and FAO modified Kc values for summer greengram

2. CROP COEFFICIENTS (Kc) FOR SUMMER SESAME:

The weekly crop coefficient values were computed as the ratio of weekly crop evapotranspiration and weekly reference evapotranspiration. For summer sesame, one lysimeter was used. The weekly crop coefficient values obtained from lysimeter of summer sesame for summer season of 2022 and 2023 were averaged to get more precise Kc values which are represented in table 11.

The comprehensive average weekly Kc values for summer sesame for the growing period of 17 weeks were found 0.43, 0.55, 0.68, 0.81, 0.93, 1.05, 1.15, 1.23, 1.28, 1.30, 1.29, 1.23, 1.12, 0.97, 0.77, 0.57 and 0.47 respectively. Whereas, comprehensive average stage wise Kc values for initial (20 Days), development (30 Days), mid (42 Days) and end stage (15 Days) were 0.55, 1.00, 1.22 and 0.68 respectively. The highest values of crop coefficients were found during the mid-season stage which may be due to the higher canopy during mid stage. Figure 4 shows the comparison between weekly crop coefficient values obtained using lysimeter for summer sesame for season 2022 and 2023.

Table 11. Average weekly crop coefficient (Kc) values for summer sesame

Crop Week	Weekly Kc Values						Stagewise Days	Stagewise Kc Values		
	t/T	2022	t/T	2023	t/T	Average		2022	2023	Average
1	0.06	0.43	0.07	0.44	0.06	0.43	Initial (20 Days)	0.55	0.54	0.55
2	0.12	0.54	0.13	0.56	0.12	0.55				
3	0.19	0.67	0.20	0.69	0.19	0.68				
4	0.25	0.80	0.26	0.82	0.25	0.81	Deve. (30 Days)	0.99	1.02	1.00
5	0.31	0.93	0.33	0.94	0.31	0.93				
6	0.37	1.05	0.39	1.06	0.37	1.05				
7	0.43	1.15	0.46	1.15	0.43	1.15				
8	0.50	1.23	0.52	1.23	0.50	1.23	Mid (42 Days)	1.21	1.23	1.22
9	0.56	1.29	0.59	1.28	0.56	1.28				
10	0.62	1.31	0.65	1.29	0.62	1.30				
11	0.68	1.31	0.72	1.26	0.68	1.29				
12	0.75	1.27	0.79	1.19	0.75	1.23				
13	0.81	1.19	0.85	1.06	0.81	1.12				
14	0.87	1.07	0.92	0.87	0.87	0.97	End (15 Days)	0.69	0.67	0.68
15	0.93	0.91	0.98	0.62	0.93	0.77				
16	0.97	0.71	1.00	0.43	0.97	0.57				
17	1.00	0.47			1.00	0.47				

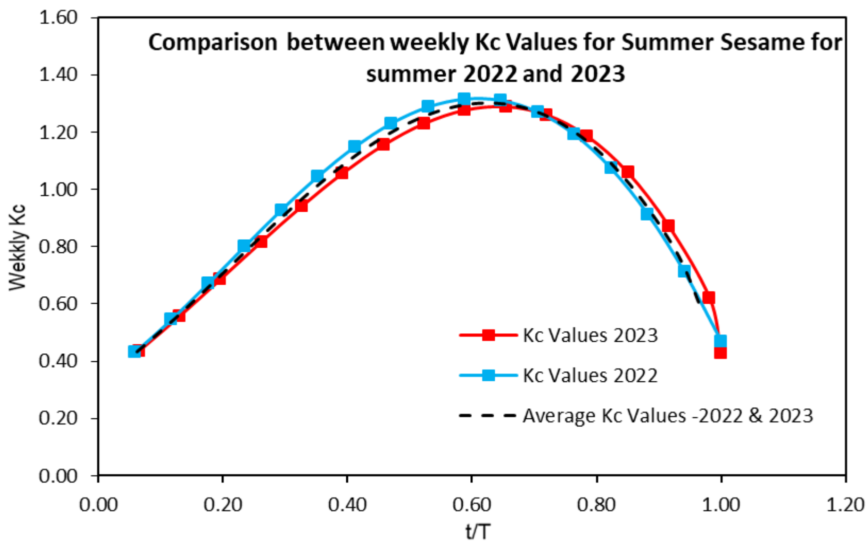

Figure 4. Comparison between weekly Kc values for summer sesame for summer season of 2022 and 2023

Equation No. 3 given below is polynomial equation obtained for comprehensive average weekly K_c values for summer sesame against ‘t/T’ to derive daily K_c values.

$$Kc_t = -3.7933\left(\frac{t}{T}\right)^3 + 2.2841\left(\frac{t}{T}\right)^2 + 1.6237\left(\frac{t}{T}\right) + 0.3229 \quad ......(3)$$

Comparison between Lysimetric and FAO Modified Kc values for Summer Sesame:

Average Lysimetric Kc values for the year 2022 and 2023 were found as 0.55, 1.00, 1.22 and 0.68 for initial, development, midseason and late season stages of summer sesame respectively. Whereas the FAO modified Kc values were obtained as 0.61, 0.90, 1.21 and 0.74 for initial, development, mid-season and late season stage. Table 12 shows the comparison between comprehensive average lysimetric kc values and FAO modified Kc values for summer sesame.

Table 12. Comparison between lysimetric and FAO modified Kc values for summer sesame

Growth Stages	Average Lysimetric Kc (2022 &2023)	FAO Kc	FAO modified Kc
Initial season stage	0.55	0.35	0.61
Development stage	1.00	-	0.90
Midseason stage	1.22	1.10	1.21
Late season stage	0.68	0.25	0.74

Figure 5 shows the comparison between polynomial curves obtained from lysimetric and FAO modified K_c values for summer sesame.

The polynomial equation (4) obtained for FAO modified Kc values for summer sesame is as follow;

$$Kc_t = 2.2581\left(\frac{t}{T}\right)^4 - 8.8507\left(\frac{t}{T}\right)^3 + 6.3618\left(\frac{t}{T}\right)^2 - 0.0535\left(\frac{t}{T}\right) + 0.5663 \quad .....(4)$$

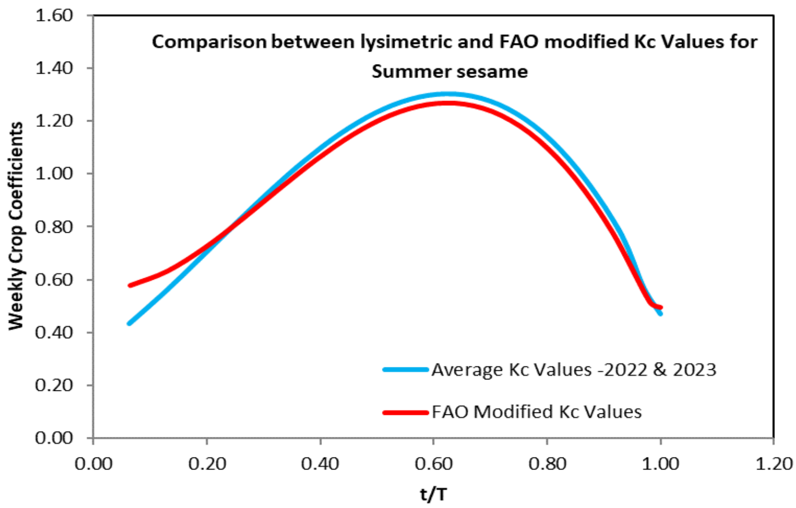

Figure 5. Comparison between lysimetric and FAO modified Kc values for summer sesame

3. CROP COEFFICIENTS (Kc) FOR KHARIF COTTON:

The weekly crop coefficient values were computed as the ratio of weekly crop evapotranspiration and weekly reference evapotranspiration. Weekly crop evapotranspiration was obtained from lysimeters by growing crop in lysimeters. For cotton, two lysimeters were used and the crop coefficient values were measured for both lysimeters. The crop coefficient values obtained from both lysimeters were averaged to avoid errors in the measurement. The weekly crop coefficient values of cotton for Kharif season of 2022 (alternate Kc values) and 2023 were averaged to get more precise Kc values which are represented in table 13.

Table 13. Average weekly crop coefficient (Kc) values for cotton

Crop Week	t/T	Weekly Kc Values			Stagewise Days	Stagewise Kc Values		
		Kc - 2022	Kc - 2023	Average Kc		2022	2023	Average
1	0.00	0.47	0.56	0.52	22 days - Initial Stage	0.51	0.6	0.55
2	0.04	0.50	0.59	0.55				
3	0.09	0.55	0.64	0.60				
4	0.13	0.61	0.71	0.66	38 days- Development stage	0.79	0.89	0.84
5	0.18	0.68	0.78	0.73				
6	0.22	0.76	0.86	0.81				
7	0.26	0.84	0.94	0.89				
8	0.31	0.92	1.01	0.97				
9	0.35	0.98	1.07	1.03	59 days- Mid season stage	1.08	1.18	1.13
10	0.39	1.04	1.13	1.09				
11	0.44	1.08	1.17	1.13				
12	0.48	1.11	1.2	1.16				
13	0.53	1.12	1.22	1.17				
14	0.57	1.12	1.22	1.17				
15	0.61	1.10	1.21	1.16				
16	0.66	1.07	1.18	1.13				
17	0.70	1.06	1.14	1.10				
18	0.74	1.02	1.08	1.05	48 days - Late stage	0.85	0.87	0.86
19	0.79	0.97	1.02	1.00				
20	0.83	0.90	0.94	0.92				
21	0.88	0.84	0.86	0.85				
22	0.92	0.72	0.78	0.75				
23	0.96	0.68	0.71	0.70				
24	1.00	0.68	0.63	0.66				

The comprehensive average weekly Kc values for cotton for the growing period of 24 weeks were found 0.52, 0.55, 0.60, 0.66, 0.73, 0.81, 0.89, 0.97, 1.03, 1.09, 1.13, 1.16, 1.17, 1.17, 1.16, 1.13, 1.10, 1.05, 1.00, 0.92, 0.85, 0.75, 0.70 and 0.66 respectively. Whereas, comprehensive average stage wise Kc values for initial (22 Days), development (38 Days), mid-season (59 Days) and late season stage (48 Days) were 0.55, 0.84, 1.13 and 0.86 respectively. The highest values of crop coefficients were found during the mid-season stage which may be due to the higher canopy during mid stage. Figure 6 shows the comparison between weekly crop coefficient values obtained for cotton during season 2022 and 2023.

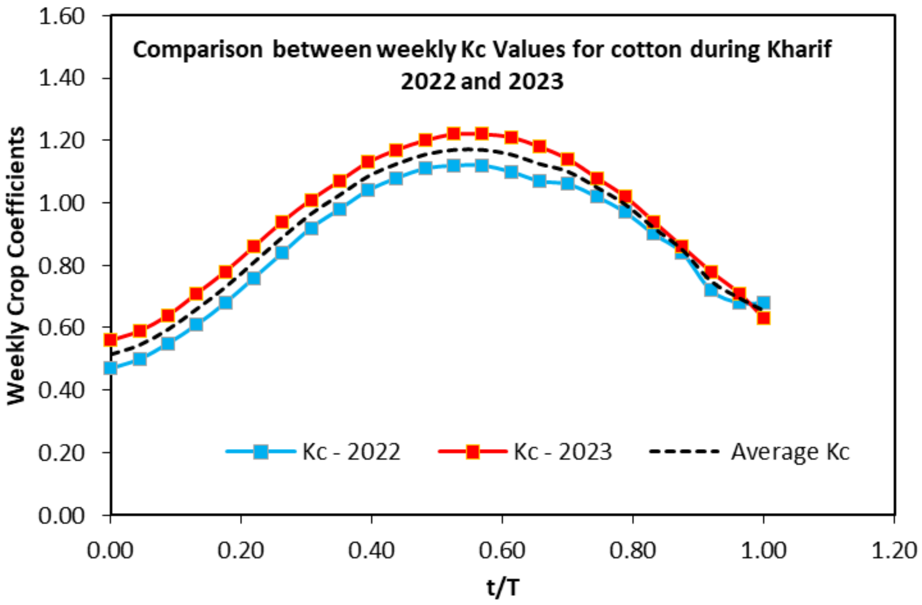

Figure 6. Comparison between weekly Kc values for cotton during Kharif season of 2022 and 2023

Equation No. 5 given below is polynomial equation obtained for comprehensive average weekly K_c values for cotton against 't/T' to derive daily K_c values.

$$Kc_t = 5.7075\left(\frac{t}{T}\right)^4 - 12.522\left(\frac{t}{T}\right)^3 + 6.4562\left(\frac{t}{T}\right)^2 - 0.4923\left(\frac{t}{T}\right) + 0.5125 \quad \text{........ (5)}$$

Comparison between Lysimetric and FAO Modified Kc values for cotton:

Average lysimetric Kc values for the year 2022 and 2023 were found as 0.55, 0.84, 1.13 and 0.86 for initial, development, midseason and late season stages of cotton respectively. Whereas the FAO modified Kc values were obtained as 0.51, 0.79, 1.08 and 0.85 for initial, development, mid-season and late season stage. Table 14 shows the comparison between comprehensive average lysimetric kc values and FAO modified Kc values for cotton.

Table 14. Comparison between average lysimetric and FAO modified Kc values for cotton

Growth Stages	Average Lysimetric Kc (2022 &2023)	FAO Kc	FAO modified Kc
Initial season stage	0.55	0.35	0.51
Development Stage	0.84	-	0.79
Mid-season stage	1.13	1.15	1.08
Late season stage	0.86	0.70	0.85

Figure 7 shows the comparison between comprehensive average weekly Kc values obtained from lysimetric and FAO modified K_c values for cotton.

The polynomial equation (6) obtained for FAO modified Kc values for cotton is as follow;

$$Kc_t = 7.5945\left(\frac{t}{T}\right)^4 - 16.439\left(\frac{t}{T}\right)^3 + 9.2161\left(\frac{t}{T}\right)^2 - 0.1751\left(\frac{t}{T}\right) + 0.4698 \quad \text{.........(6)}$$

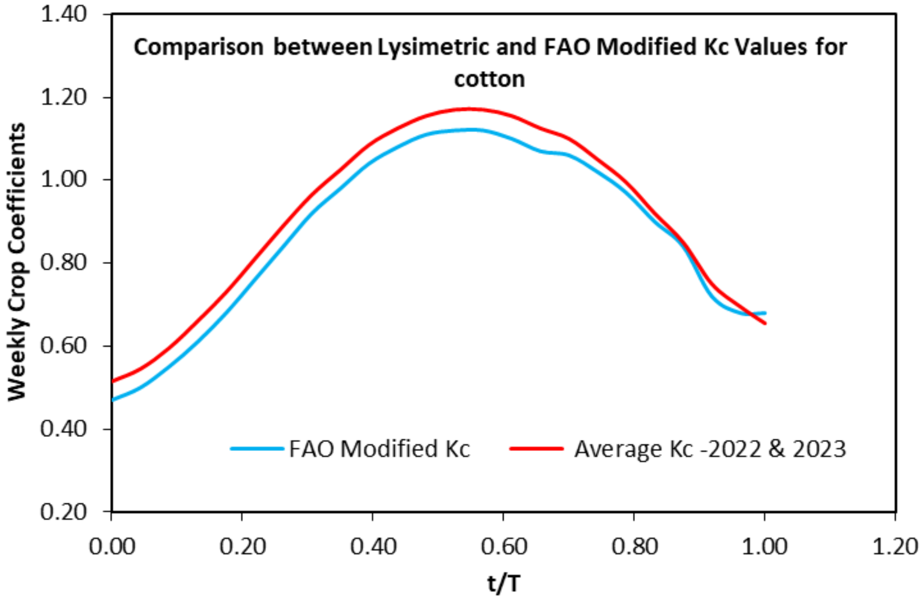

Figure 7. Comparison between average lysimetric (2022 and 2023) and FAO modified Kc values for cotton

4. CROP COEFFICIENTS (Kc) FOR PIGEON PEA:

The weekly crop coefficient values were computed as the ratio of weekly crop evapotranspiration and weekly reference evapotranspiration. For pigeon pea, two lysimeters were used and the crop coefficient values were measured for both lysimeters. The weekly crop coefficient values of pigeon pea for kharif season of 2022 (alternate Kc values) and 2023 were averaged to get more precise Kc values which are represented in table 15.

Table 15. Average weekly crop coefficient (Kc) values for pigeon pea

Crop Week	t/T	Weekly Kc Values			Stagewise Days	Stagewise Kc Values		
		Kc - 2022	Kc - 2023	Average Kc		2022	2023	Average
1	0.04	0.48	0.53	0.51	24 -Initial Stage	0.50	0.55	0.53
2	0.08	0.49	0.54	0.52				
3	0.12	0.51	0.57	0.54				
4	0.16	0.56	0.61	0.59	52 days - developme nt stage	0.78	0.84	0.81
5	0.19	0.61	0.67	0.64				
6	0.23	0.67	0.73	0.70				
7	0.27	0.74	0.80	0.77				
8	0.31	0.81	0.87	0.84				
9	0.35	0.88	0.93	0.91				
10	0.39	0.94	1.00	0.97				
11	0.43	0.99	1.05	1.02	60 days - Mid season stage	1.08	1.12	1.10
12	0.47	1.04	1.09	1.07				
13	0.51	1.07	1.13	1.10				
14	0.54	1.10	1.15	1.13				
15	0.58	1.11	1.16	1.14				
16	0.62	1.11	1.16	1.14				
17	0.66	1.10	1.15	1.13				
18	0.70	1.07	1.12	1.10				
19	0.74	1.03	1.08	1.06				
20	0.78	0.98	1.03	1.01	46 days – Late Season stage	0.76	0.81	0.79
21	0.82	0.91	0.97	0.94				
22	0.86	0.84	0.90	0.87				
23	0.89	0.76	0.83	0.80				
24	0.93	0.66	0.76	0.71				
25	0.97	0.57	0.68	0.63				
26	1.00	0.51	0.61	0.56				

The comprehensive average weekly Kc values for pigeon pea for the growing period of 26 weeks were found 0.51, 0.52, 0.54, 0.59, 0.64, 0.70, 0.77, 0.84, 0.91, 0.97, 1.02, 1.07, 1.10, 1.13, 1.14, 1.14, 1.13, 1.10, 1.06, 1.01, 0.94, 0.87, 0.80, 0.71, 0.63 and 0.56 respectively. Whereas, comprehensive average stage wise Kc values for initial (24 Days), development (52 Days), mid-season (60 Days) and late season stage (46 Days) were 0.53, 0.81, 1.10 and 0.79 respectively. The highest values of crop coefficients were found during the mid-season stage which may be due to the higher canopy during mid stage. Figure 8 shows the comparison between weekly crop coefficient values obtained for pigeon pea for season 2022 and 2023.

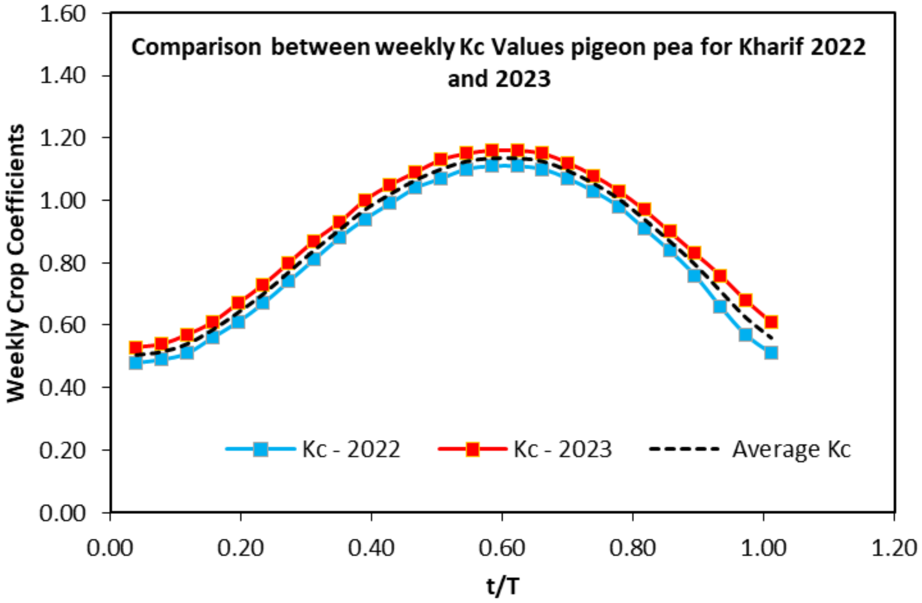

Figure 8. Comparison between weekly Kc values for pigeon pea for kharif season of 2022 and 2023

Equation No. 7 given below is polynomial equation obtained for comprehensive average weekly K_c values for pigeon pea against 't/T' to derive daily K_c values.

$$Kc_t = 6.4884\left(\frac{t}{T}\right)^4 - 16.012\left(\frac{t}{T}\right)^3 + 10.476\left(\frac{t}{T}\right)^2 - 0.9041\left(\frac{t}{T}\right) + 0.5273 \quad \ldots\ldots (7)$$

Comparison between Lysimetric and FAO Modified Kc values for Pigeon pea:

Average Lysimetric Kc values for the year 2022 and 2023 were found as 0.53, 0.81, 1.10 and 0.79 for initial, development, midseason and late season stages of pigeon pea respectively. Whereas the FAO modified Kc values were obtained as 0.50, 0.78, 1.08 and 0.76 for initial, development, mid-season and late season stage. Table 16 shows the comparison between comprehensive average lysimetric kc values and FAO modified Kc values for pigeon pea.

Table 16. Comparison between lysimetric and FAO modified Kc values for pigeon pea

Growth Stages	Average Lysimetric Kc (2022 &2023)	FAO Kc	FAO modified Kc
Initial season stage	0.53	0.40	0.50
Development stage	0.81	-	0.78
Midseason stage	1.10	1.15	1.08
Late season stage	0.79	0.55	0.76

Figure 9 shows the comparison between polynomial curves obtained from lysimetric and FAO modified K_c values for pigeon pea.

The polynomial equation (8) obtained for FAO modified Kc values for pigeon pea is as follow;

$$Kc_t = 6.3079\left(\frac{t}{T}\right)^4 - 15.341\left(\frac{t}{T}\right)^3 + 9.6189\left(\frac{t}{T}\right)^2 - 0.5745\left(\frac{t}{T}\right) + 0.4895 \quad \text{…... (8)}$$

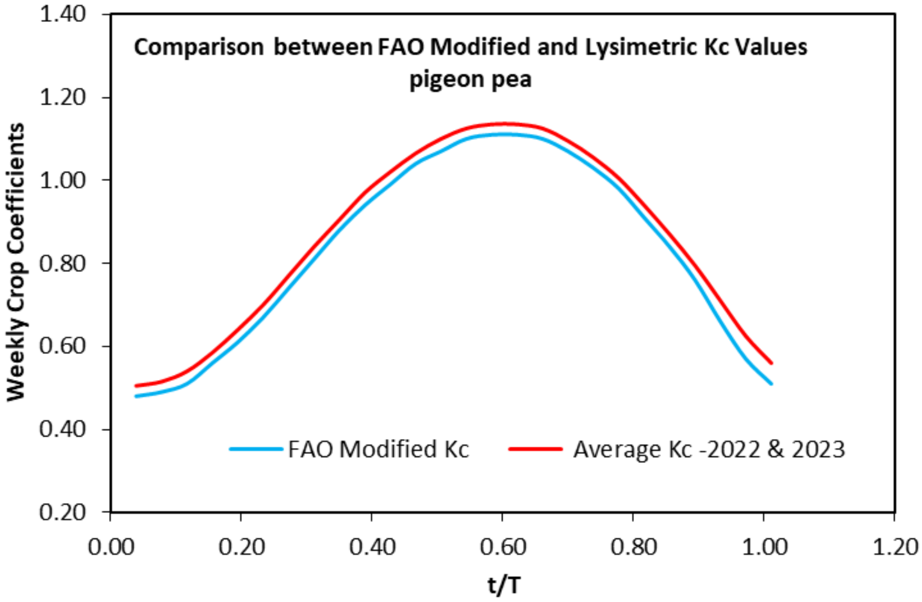

Figure 9. Comparison between lysimetric and FAO modified Kc values for pigeon pea

5. WATER REQUIREMENT OF SUMMER GREENGRAM, SUMMER SESAME, KHARIF COTTON AND KHARIF PIGEON PEA FOR VIDARBHA REGION

Taluka wise weekly crop water requirement was determined using lysimetric Kc values obtained for summer greengram, summer sesame, kharif cotton and kharif pigeon pea by ignoring the effective rainfall for tehsils in Vidarbha region. For that purpose, 30 years average reference evapotranspiration (ETo) were determined for all tahsils of Vidarbha region. Then lysimetric Kc values were multiplied with those determined ETo values to obtain crop water requirement of each specified crop. Also, the irrigation water requirement was determined by considering the crop water requirement at different irrigation efficiencies. It was calculated for surface irrigation at 40%, 50% and 60% irrigation efficiency, for drip irrigation at 90% and 95% irrigation efficiency and for sprinkler irrigation at 80% and 85% irrigation efficiency. The taluka wise water requirement for all four crops is given in appendices for above mentioned irrigation efficiencies.

6. SUBMISSION OF DELIVERABLES

Sr. No	Particulars	Phase	Status of Grant
1.	Inception Report	I.	Received
2.	Set up and Installation of Lysimeter report	II.	Received
3.	Report on Normalized crop Kc, water and irrigation requirement for Cotton, Pigeon pea, based on FAO calculations and technical support	III.	Received
4.	Report on Crop Kc, Water Requirement of Summer Sesame and Summer Greengram	IV.	Received
5.	Report on Crop Kc, Water Requirement of Cotton and Pigeon pea	V.	Received
6.	Report on Crop Kc, Water Requirement of Summer Greengram and Summer Sesame	VI.	Received
7.	Comprehensive Report on Crop Kc, Water Requirement of Summer Greengram and Summer Sesame	VII.	Received
8.	Report on Crop Kc, Water Requirement of Kharif Cotton and pigeon pea	VIII.	Received
9.	Comprehensive Report on Crop Kc, Water Requirement of Kharif Cotton and Pigeon Pea	IX.	Not Received

7. APPENDICES

List of Appendices to be attached

Appendix	Details
A	Water Requirement of Summer Greengram for Vidarbha Region
B	Water Requirement of Summer Sesame for Vidarbha Region
C	Water Requirement of Kharif Cotton for Vidarbha Region
D	Water Requirement of Kharif pigeon pea for Vidarbha Region

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