# A

# Report on

# Crop Coefficient, District and Taluka wise Water and Irrigation Requirement of Western Maharashtra by Different Irrigation Practices for Sesame, Gram and Fodder Bajra based on FAO 56 Method from standard FAO Crop Coefficients

# in

# "Determination of Crop Coefficients for Major Crops by Lysimetric Studies"

# at

# Mahatma Phule Krishi Vidyapeeth, Rahuri

**Title of the project:** "Determination of Crop Coefficients for Major Crops by Lysimetric Studies"

**Location:** CAAST- CSAWM Climate smart research block, Mahatma Phule Krishi Vidyapeeth, Rahuri

**Duration:** Three years (2020-2023)

**Total Outlay:** Rs. 31.43 Lakhs (Rs. Thirty one lakh fourty three thousand only)

**Investigators:**

| | | |
|---|---|---|
| **Principal Investigator** | : | Dr. A. A. Atre, Professor of SWCE and CAAST-CSAWM Member and Dr. ASCAE&T, MPKV, Rahuri |
| **Co-Principal Investigator** | : | Dr. M. G. Shinde, Professor of SWCE and Co-PI CAAST-CSAWM, MPKV, Rahuri |
| | | Dr. S. A. Kadam, Associate Professor of IDE, CAAST-CSAWM, MPKV, Rahuri |
| **Coordinator for the project for three universities** (MPKV, Rahuri; Dr. PDKV, Akola and VNMKV, Parbhani) | : | Dr. S. D. Gorantiwar, Head, Dept. of Agril. Engg. and PI CAAST- CSAWM, MPKV, Rahuri |

**Activities Completed:**

1. **Data Collection: Meteorological Data, Crop Data**

   i) The meteorological parameters required for the estimation of reference crop evapotranspiration for Rahuri region were collected for previous 47 years (1975-2021) such as

      - Temperature (Minimum and Maximum)
      - Relative Humidity (Minimum and Maximum)
      - Wind Speed at 2 m height from ground surface
      - Bright Sunshine Hours
      - Rainfall

   ii) Crop data of Sesame (JLT 408) Gram (Phule Vikram) and Fodder Bajra was recorded daily and made required corrections.

   iii) The height of crop at four growth stages were recorded.

2. **Estimation Reference Crop Evapotranspiration ET$_r$ by Penman-Monteith Method**

   The following formula is used for estimation of ET$_r$:

$$ET_r = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad\quad .....(i)$$

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$_s$ - e$_a$ : Saturation vapour pressure deficit [kPa],

   $\Delta$ : Slope vapour pressure curve [kPa/ °C],

   $\gamma$ : Psychrometric constant [kPa/°C].

## 3. Methodology for modification of Crop Coefficients for local conditions

For modification of $K_c$ 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 1 shows the flow chart of methodology used for modification of $K_c$ at initial, mid and end stages during crop growth period.
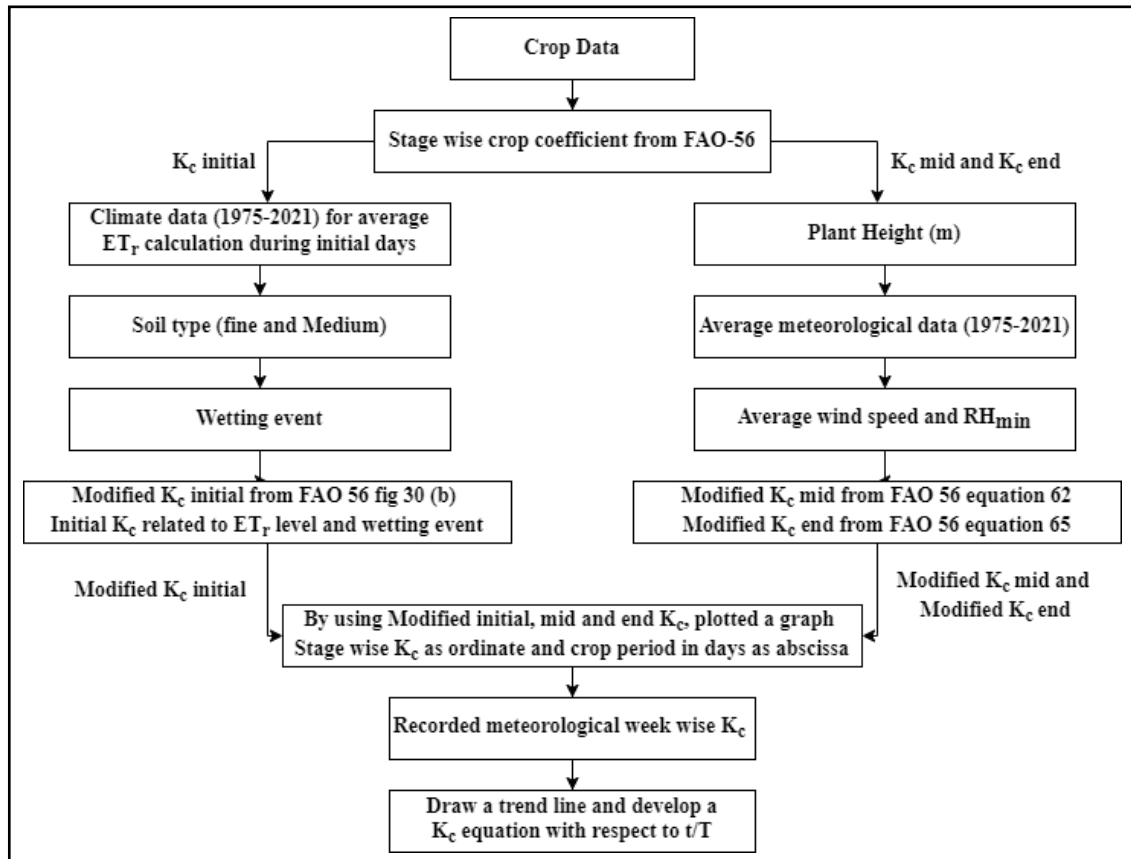


**Figure 1: Methodology flowchart for modification of $K_c$**

The soil type of Rahuri region where the experiment are taken is having fine and medium texture, therefore the irrigation interval was considered as 10 days. These values are considered for modification of initial value of crop coefficient, $K_{cini}$.

## 4. FAO 56 Crop Coefficients

The standard values for $K_c$ given by FAO are taken and modified using the methodology presented in Figure 1.

## 5. Estimation of $K_c$ for Local Conditions based on Modification in FAO standard $K_c$ table

Daily $ET_r$ is estimated for all the years and averaged for each day for period of 47 years from 1975 - 2021. Averaged $ET_r$ is used for finding local $K_c$ at initial growth stage ($K_{cini}$) from the reference graphs (figure 2) provided by FAO.

- **$K_c$ initial ($K_{cini}$):** $K_{cini}$ is taken from $K_c$ vs $ET_r$ graph provided in FAO-56 paper using averaged $ET_r$ value for previous years, soil type/texture and wetting event for initial growth period.

- **$K_c$ mid:** The following equation is used for estimation of $K_c$ mid:

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

- **Kc end:** The following equation is used for estimation of $K_c$ end:

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

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 2m height, m/s

$RH_{min}$= Mean value for daily minimum relative humidity during the end season growth stage,
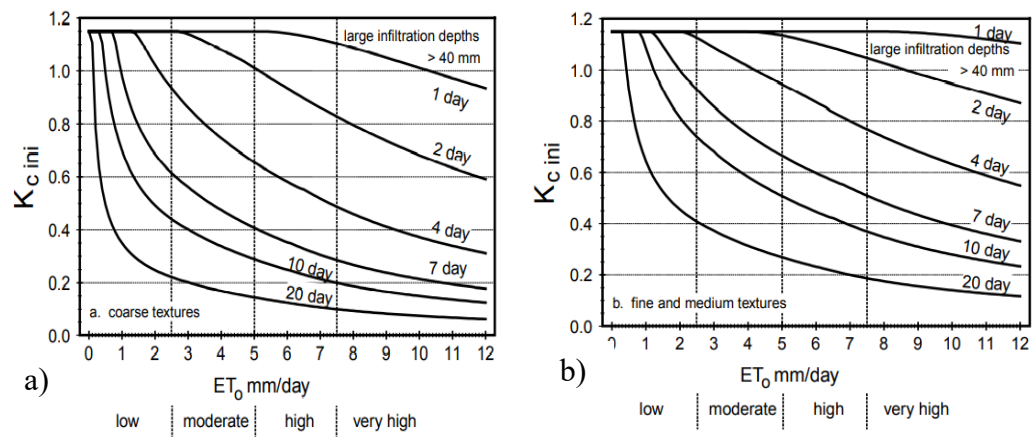
h = Mean plant height during end-season (m)



**Figure 2: Average $K_{cini}$ as related to the level of ETo and the interval between irrigation greater than or equal to 40 mm per wetting event, during the initial growth stage for a) coarse textured soil; b) medium and fine textured soils.**

The crop height, minimum relative humidity and wind speed at 2 meter height required for estimation of $K_c$ for mid and end season stages, was recorded for respective field/region and the weekly $K_c$ values were developed. The curve of weekly $K_c$ Vs t/T was plotted and a polynomial equation was fitted with maximum accuracy. Using this polynomial equation the daily $K_c$ values for the crop were calculated.

Firstly, the week wise $K_c$ values were developed. The curve for t/T and weekly $K_c$ was plotted and a polynomial equation was derived of the curve with maximum

accuracy. Using this polynomial equation the daily $K_c$ values for the crop were calculated.

**i)    Modified crop coefficient and water requirement of Sesame**

The weekly crop coefficients for sesame crop under Rahuri region is presented in below Table 1and modified $K_c$ values for initial, mid and end of growth stages are presented in Table 2. The crop coefficient ($K_c$) curve and polynomial equation of sesame crop are presented in Figure 3. From table 1; it is revealed that the crop coefficients for sesame were estimated to the range of 0.27 to 1.07.

**Table 1: Weekly $K_c$ values of Sesame considering crop period from 27[th]Standard Meteorological Week (SMW) to 40th Meteorological Week (MW) having crop period of 95 days (2[nd]July to 4[th]Oct)**

| SMW | Week since sowing | Days | X= t/T | Avg.$U_2$ km/h | Rh min, % | Crop height, m | Modified $K_c$ |
|-----|-------------------|------|--------|----------------|-----------|----------------|----------------|
| 27 | 1 | 7 | 0.07 | 11.3 | 59 | 0.04 | 0.55 |
| 28 | 2 | 14 | 0.15 | 10.7 | 60 | 0.13 | 0.58 |
| 29 | 3 | 21 | 0.22 | 11.4 | 62 | 0.22 | 0.64 |
| 30 | 4 | 28 | 0.29 | 10.6 | 64 | 0.32 | 0.71 |
| 31 | 5 | 35 | 0.37 | 10.6 | 63 | 0.41 | 0.8 |
| 32 | 6 | 42 | 0.44 | 10.7 | 64 | 0.51 | 0.89 |
| 33 | 7 | 49 | 0.52 | 10 | 62 | 0.6 | 0.97 |
| 34 | 8 | 56 | 0.59 | 8.3 | 61 | 0.7 | 1.03 |
| 35 | 9 | 63 | 0.66 | 7.8 | 62 | 0.8 | 1.07 |
| 36 | 10 | 70 | 0.74 | 7.3 | 60 | 0.9 | 1.06 |
| 37 | 11 | 77 | 0.81 | 6 | 57 | 0.99 | 0.98 |
| 38 | 12 | 84 | 0.88 | 5.4 | 59 | 1.08 | 0.83 |
| 39 | 13 | 91 | 0.96 | 4.3 | 57 | 1.1 | 0.57 |
| 40 | 14 | 95 | 1 | 3.9 | 52 | 1.1 | 0.27 |

**Table 2: Modified $K_c$ values for initial, mid, end season of Sesame crop for Rahuri region**

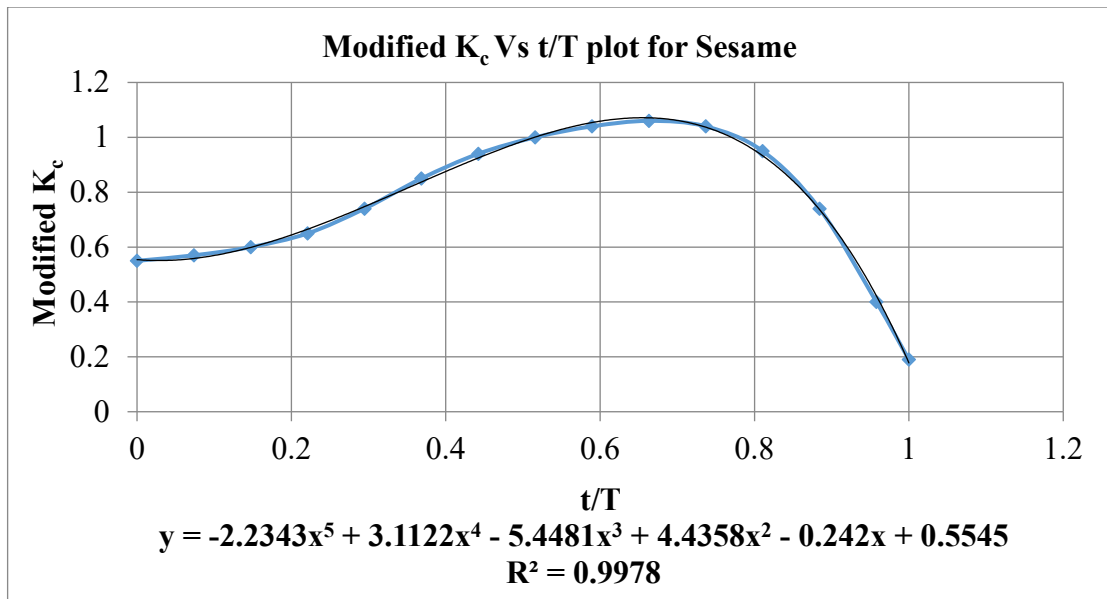| Crop: Sesame | | | | | |
|-----|-----|-----|-----|-----|-----|
| SMW | Sowing Date | FAO $K_c$ Values | | Mod $K_c$ | Crop Period | |
| MW27-MW40 | 02nd July, 2021 | $Kc_{ini}$ | 0.35 | 0.28 | Initial | 20 |
| | | $Kc_{mid}$ | 1.1 | 1.06 | Development | 25 |
| | | $Kc_{end}$ | 0.25 | 0.19 | Mid | 35 |
| | | | | | Late | 15 |
| | | | | | Total/Crop Period | 95 |

**Figure 3: Modified K$_c$ plots for each crop week for whole crop growth period of Sesame**
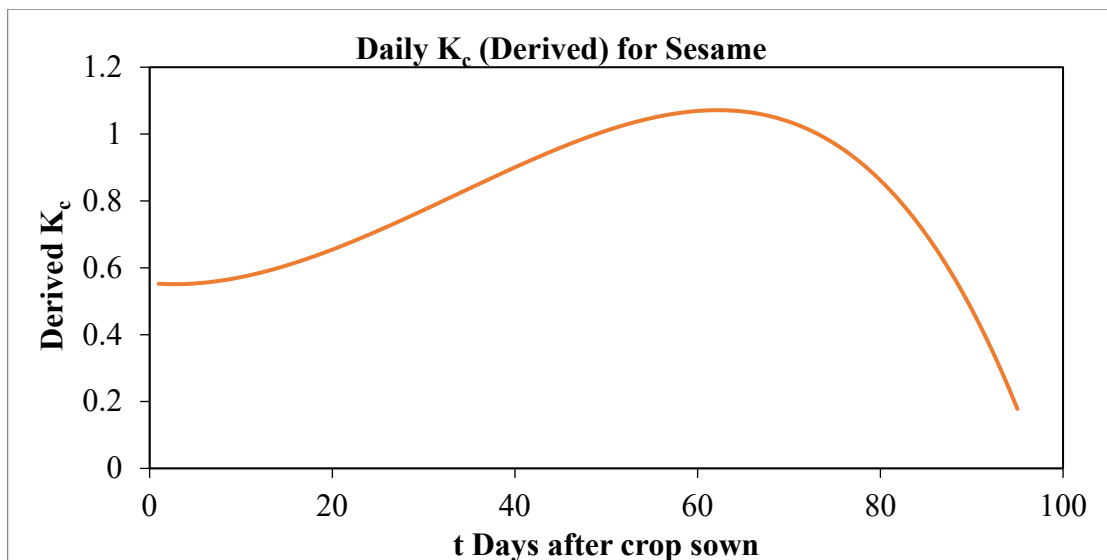


**Figure 4: Plot of days after sowing Vs. K$_c$ derived from polynomial equation for crop growth period of Sesame on daily basis**

The polynomial equation given in figure 3 is used for estimation of daily crop coefficients (figure 4) for Sesame crop. This polynomial relation between t/T and modified K$_c$ has coefficient determination ($R^2$) of 0.997 representing nearly perfect correlation between them. Values of daily K$_c$ of Sesame derived from equation (iv) are given in appendix A (Table A-1).

$$y = -2.2343x^5 + 3.1122x^4 - 5.4481x^3 + 4.4358x^2 - 0.242x + 0.5545 \qquad ……\text{(iv)}$$

Where, x is (t/T) and y is K$_{ct}$ and

$K_{ct}$ = The crop coefficient of Sesame on t$^{th}$ day

t     =     Day after sowing

T     =     Total crop growth period in days

Total seasonal water requirement of Sesame in Rahuri region is found to be 293.51 mm. The average weekly water requirement and irrigation water requirement by surface, sprinkler and drip irrigation methods for different efficiencies ignoring effective rainfall of Sesame is presented in appendix B.

## ii) Modified crop coefficient and water requirement of Gram

The weekly crop coefficients for gram crop for Rahuri region are presented in Table 3 and modified $K_c$ values for initial, mid and end of growth stages are presented in Table 4. The crop coefficient ($K_c$) curve and polynomial equation of gram crop are presented in Figure 5. From table 3, it is revealed that the crop coefficients for gram were estimated to the range of 0.43 to 1.00.

**Table 3: Weekly $K_c$ values of Gram considering crop period from 44th Meteorological Week (MW) to 7[th]Standard Meteorological Week (SMW) having Crop Period of 110 days (29[th]Oct to 15[th]Feb).**

| SMW | Week since sowing | Days | X= t/T | Avg.$U_2$ km/h | Rh min % | Crop height, m | Modified $K_c$ |
|---|---|---|---|---|---|---|---|
| 44 | 1 | 7 | 0.06 | 3.5 | 39 | 0.02 | 0.60 |
| 45 | 2 | 14 | 0.13 | 3.4 | 39 | 0.08 | 0.62 |
| 46 | 3 | 21 | 0.19 | 3.3 | 42 | 0.13 | 0.65 |
| 47 | 4 | 28 | 0.25 | 3.1 | 39 | 0.17 | 0.70 |
| 48 | 5 | 35 | 0.32 | 2.9 | 38 | 0.2 | 0.76 |
| 49 | 6 | 42 | 0.38 | 2.9 | 38 | 0.23 | 0.82 |
| 50 | 7 | 49 | 0.45 | 2.9 | 36 | 0.26 | 0.88 |
| 51 | 8 | 56 | 0.51 | 2.8 | 35 | 0.29 | 0.93 |
| 52 | 9 | 63 | 0.57 | 2.8 | 36 | 0.32 | 0.97 |
| 01 | 10 | 70 | 0.64 | 2.9 | 35 | 0.36 | 1.00 |
| 02 | 11 | 77 | 0.70 | 3.1 | 36 | 0.39 | 0.99 |
| 03 | 12 | 84 | 0.76 | 3.2 | 34 | 0.42 | 0.96 |
| 04 | 13 | 91 | 0.83 | 3.2 | 33 | 0.44 | 0.90 |
| 05 | 14 | 98 | 0.89 | 3.4 | 31 | 0.45 | 0.79 |
| 06 | 15 | 105 | 0.95 | 3.6 | 29 | 0.45 | 0.62 |
| 07 | 16 | 110 | 1 | 3.8 | 28 | 0.45 | 0.44 |

**Table 4: Modified $K_c$ values for initial, mid, end season of Gram crop for Rahuri region**

| Meteorological Week | Sowing Date | FAO $K_c$ Values | | Modified $K_c$ | Crop Period | |
|---|---|---|---|---|---|---|
| | | **Crop:** Gram | | | |
| **Variety:** Phule Vikram | | | | | | |
| MW44-MW7 | 29th October, 2021 | $K_{cini}$ | 0.4 | 0.62 | Initial | 20 |
| | | $K_{cmid}$ | 1 | 1 | Development | 35 |
| | | $K_{cend}$ | 0.35 | 0.36 | Mid | 35 |
| | | | | | Late | 20 |
| | | | | | Total/Crop Period | 110 |



**Modified Weekly $K_c$ vs t/T plot (Gram)**

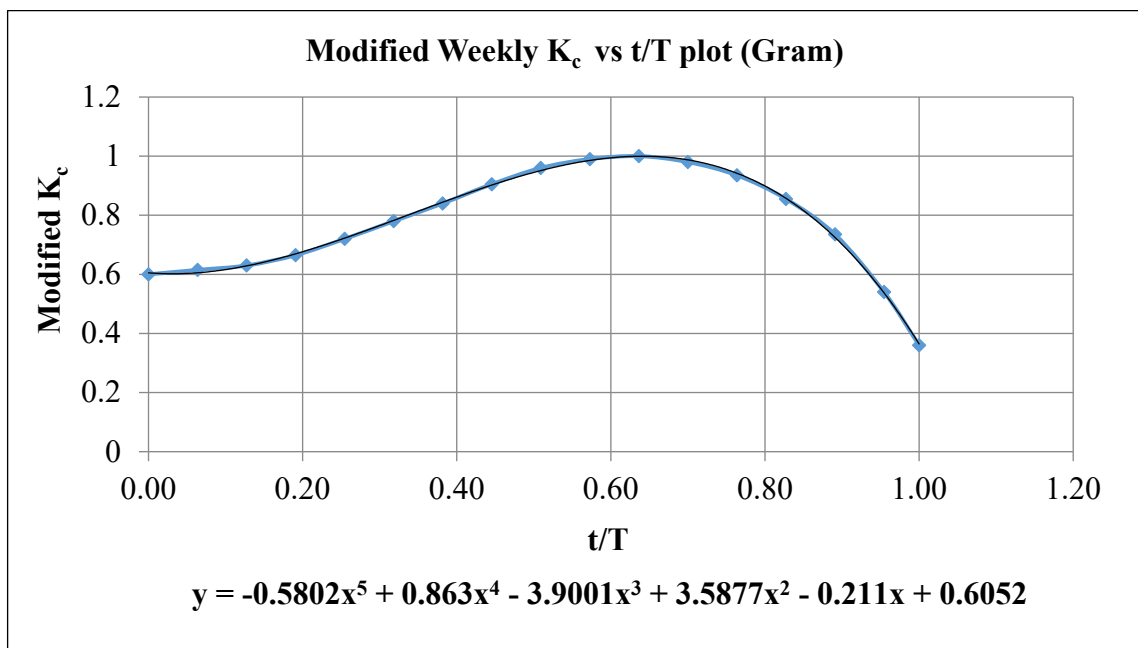$y = -0.5802x^5 + 0.863x^4 - 3.9001x^3 + 3.5877x^2 - 0.211x + 0.6052$

**Figure 5: Modified $K_c$ plots for each crop week for whole crop growth period of Gram**

The polynomial equation given in figure 5 is used for estimation of daily crop coefficients (figure 6) for Gram crop. This polynomial relation between t/T and modified $K_c$ has coefficient determination ($R^2$) of 0.999 representing nearly perfect correlation between them. Values of daily $K_c$ of Gram derived from equation (v) are given in appendix A (Table A-2).

$$y = -0.580x^5 + 0.863x^4 - 3.900x^3 + 3.587x^2 - 0.211x + 0.605 \qquad ……(v)$$

Where, x is (t/T) and y is $K_{ct}$ and

$K_{ct}$ = The crop coefficient of Gram on $t^{th}$ day

t = Day after sowing

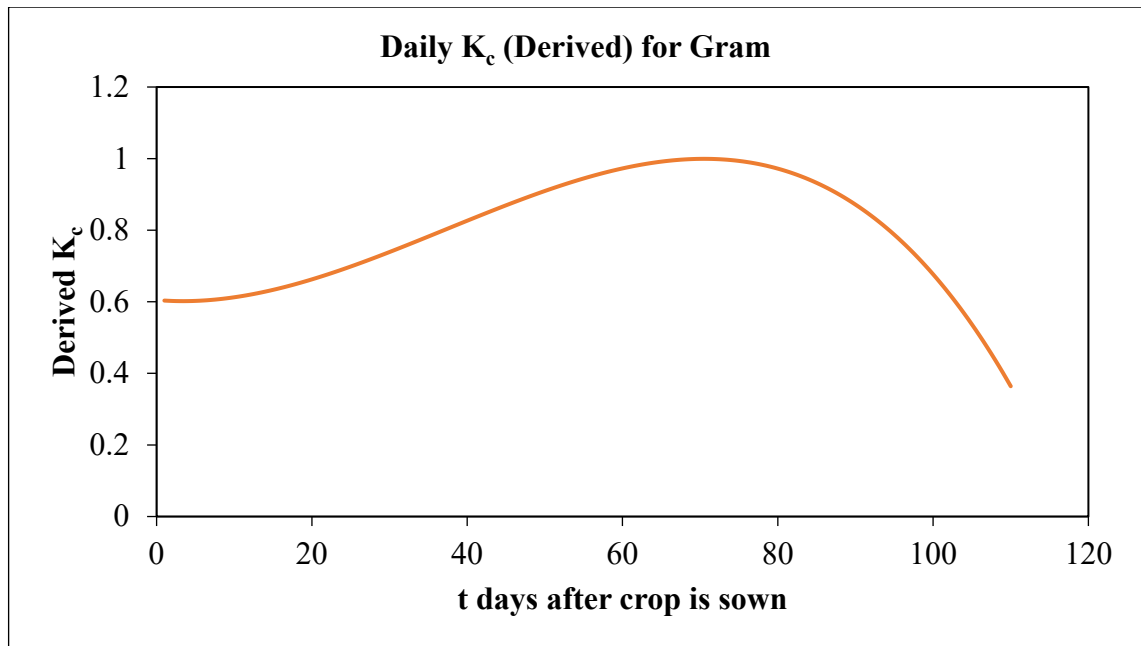T = Total crop growth period in days

**Figure 6: Plot of days after sowing Vs. $K_c$ derived from polynomial equation for crop growth period of Gram on daily basis**

The water requirement is calculated using:

$$ET_c = K_c \times ET_r$$

Total seasonal water requirement of Gram in Rahuri region is found to be 285.83 mm. The average weekly water requirement and irrigation water requirement by surface, sprinkler and drip irrigation methods for different efficiencies ignoring effective rainfall of gram is presented in Appendix C.

### iii) Modified Crop coefficients and water requirement of Fodder Bajra

The weekly crop coefficients for sesame crop under Rahuri region is presented in below Table 5 and modified $K_c$ values for initial, mid and end of growth stages are presented in Table 6. The crop coefficient (Kc) curve and polynomial equation of fodder Bajra crop are presented in Figure 7. From table 5; it is revealed that the crop coefficients for Fodder Bajra were estimated to the range of 0.35 to 1.07.

**Table 5: Weekly $K_c$ values of Fodder Bajra considering crop period from 15th Standard Meteorological Week (SMW) to 26th Meteorological Week (MW) having crop period of 85 day(12th April to 5th July, 2022)**

| SMW | Week since sowing | Days | X= t/T | Avg.U$_2$, km/hr | Rh$_{min}$, % | Crop height, m | Modified $K_c$ |
|-----|------|------|------|------|------|------|------|
| 15 | 1 | 7 | 0.07 | 1.8 | 16 | 0.08 | 0.35 |
| 16 | 2 | 14 | 0.15 | 2.17 | 16.14 | 0.25 | 0.37 |
| 17 | 3 | 21 | 0.22 | 1.93 | 16.14 | 0.43 | 0.47 |
| 18 | 4 | 28 | 0.29 | 3.26 | 18.17 | 0.61 | 0.64 |
| 19 | 5 | 35 | 0.37 | 4 | 21.14 | 0.79 | 0.84 |
| 20 | 6 | 42 | 0.44 | 4.89 | 22.57 | 0.97 | 1 |
| 21 | 7 | 49 | 0.52 | 6.1 | 25 | 1.11 | 1.07 |
| 22 | 8 | 56 | 0.59 | 5.47 | 23.83 | 1.26 | 1.05 |
| 23 | 9 | 63 | 0.66 | 3.77 | 33.43 | 1.41 | 0.93 |
| 24 | 10 | 70 | 0.74 | 3.36 | 38.29 | 1.57 | 0.79 |
| 25 | 11 | 77 | 0.81 | 3.44 | 53.86 | 1.71 | 0.64 |
| 26 | 12 | 84 | 0.88 | 2.47 | 57.71 | 1.86 | 0.49 |

**Table 6: Modified $K_c$ values for initial, mid, end season of Fodder Bajra crop for Rahuri region**

| Crop: Sesame | | | | | |
|------|------|------|------|------|------|
| SMW | Sowing Date | FAO $K_c$ Values | | Modified $K_c$ | Crop Period |
| SMW15-SMW26 | 12th April, 2022 | Kc$_{ini}$ | 0.3 | 0.35 | Initial | 18 |
| | | Kc$_{mid}$ | 1 | 1.06 | Development | 17 |
| | | Kc$_{end}$ | 0.35 | 0.36 | Mid | 20 |
| | | | | | Late | 30 |
| | | | | | Total/Crop Period | 85 |

The polynomial equation given in figure 7 is used for estimation of daily crop coefficients (figure 8) for Sesame crop. This polynomial relation between t/T and modified $K_c$ has coefficient determination ($R^2$) of 0.997 representing nearly perfect correlation between them. Values of daily $K_c$ of Fodder Bajra derived from equation (vi) are given in appendix A (Table A-3).

$$y = -62.247x^6 + 190.93x^5 - 208.75x^4 + 91.3x^3 - 11.842x^2 + 0.6233x + 0.3422 \quad …(vi)$$

Where, x is (t/T) and y is $K_{ct}$ and

$K_{ct}$ = The crop coefficient of Fodder Bajra on t$^{th}$ day

t = Day after sowing

T = Total crop growth period in days

The total seasonal water requirement of Fodder Bajra under Rahuri region was found to be 415.78 mm. The average weekly water requirement and irrigation water requirement by surface, sprinkler and drip irrigation methods for different efficiencies ignoring effective rainfall of Fodder Bajra is presented in appendix D.
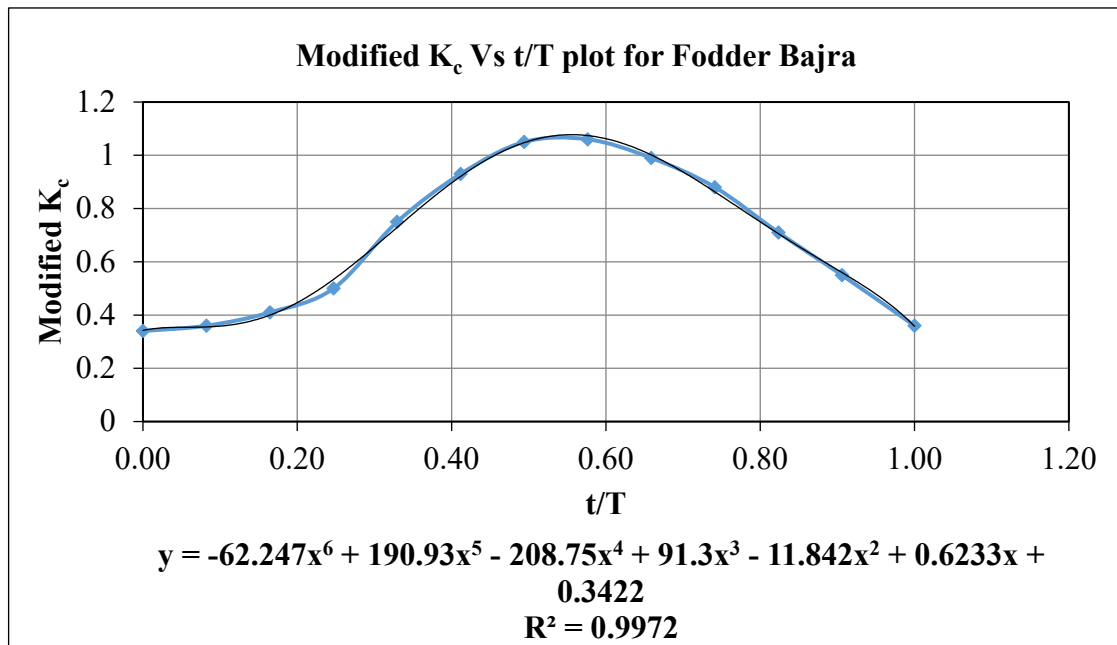
**Modified $K_c$ Vs t/T plot for Fodder Bajra**

$$y = -62.247x^6 + 190.93x^5 - 208.75x^4 + 91.3x^3 - 11.842x^2 + 0.6233x + 0.3422$$
$$R^2 = 0.9972$$

**Figure 7: Modified $K_c$ plots for each crop week for whole crop growth period of Fodder Bajra.**
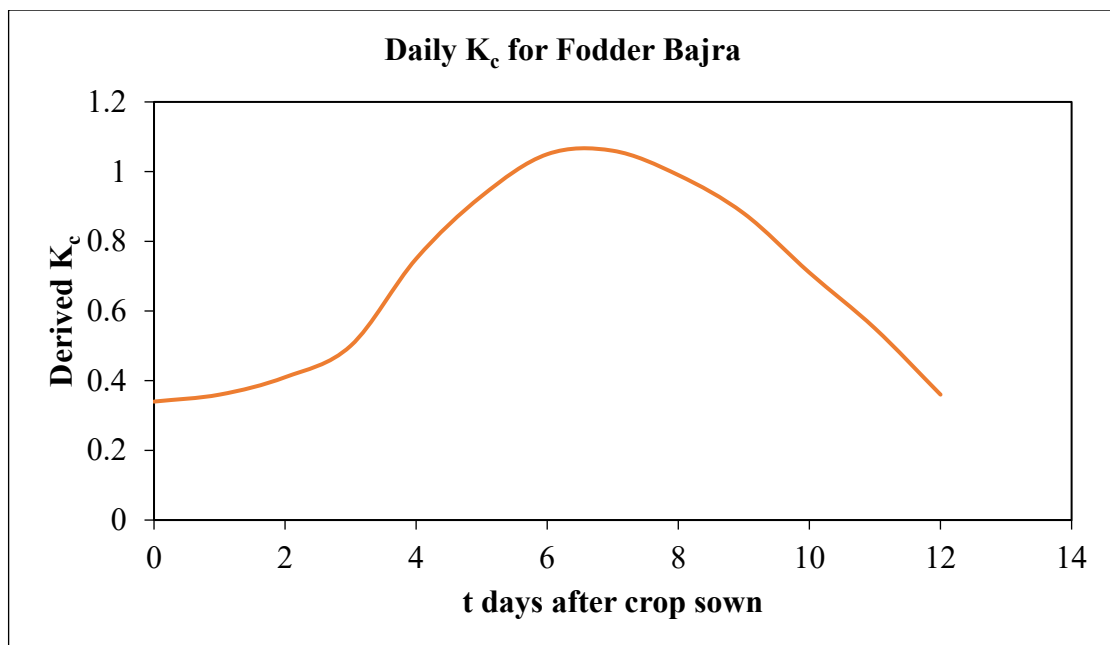
**Daily $K_c$ for Fodder Bajra**

**Figure 8: Plot of days after sowing Vs. $K_c$ derived from polynomial equation for crop growth period of Fodder Bajra on daily basis.**