An Attempt to Modify the Crop Coefficient Value of Wheat and Chickpea for Humid Subtropical Climate of Varanasi District, Uttar Pradesh

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Authors’ contributions

This work was carried out in collaboration among all authors. Author CKK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author GS managed the analyses of the study. Author AG managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2020/v13i117091

Editor(s):
(1) Dr. Guang Yih Sheu, Chang Jung Christian University, Taiwan.

Reviewer(s):
(1) S. Kizza-Nkambwe, Uganda Christian University, Uganda.
(2) Zimeras Stelios, University of the Aegean, Greece.

Complete Peer review History: http://www.sdiarticle4.com/review-history/57032

Received 15 March 2020
Accepted 20 May 2020
Published 29 May 2020

ABSTRACT

Crop water requirement is one of the essential components that should always be taken into account wherever water management strategies are adopted for effective utilization of water. In India agriculture is considered as the backbone of economy but nothing technical or advance technology has being adopted for its advancement and still major portion of agriculture are dependent on the verge of monsoon. Therefore crop coefficient (Kc) value for wheat and Chickpea as a function of relative humidity, wind speed and crop height has been formalized in this study for efficient use of available water. The empirical formula was applied for estimating Kc(mid) and Kc(end) values for humid subtropical climate of Varanasi. The corrected crop coefficient value of wheat for Kc(mid) was found to be 1.12 and for end season Kc(end) corrected was found to be 0.42. Mean maximum height of wheat crop in mid-season was obtained as 0.80 m and for the end season mean maximum height was found to be 0.99 m. The corrected crop coefficient value of
Chickpea for midseason was found to be 0.98 whereas it was found out to be 0.38 at Kc(end). Mean maximum height of chickpea crop in mid-season was obtained as 0.39 m and for the end season of the crop mean maximum height was found to be 0.52 m. Crop coefficient curve for wheat crop was prepared in which X-axis represents time in days and Y-axis represents crop coefficient value for wheat. A third-order polynomial equation \((y = -3E - 06x^3 + 0.0005x^2 - 0.0039x + 0.3702)\) has been obtained for wheat crop with correlation coefficient of 0.97. Similarly, graphical plot was constructed for chickpea crop and a third-order polynomial equation \((y = -2E - 06x^3 + 0.0002x^2 - 0.0004x + 0.3732)\) has been obtained with correlation coefficient of 0.98. Furthermore, third-order polynomials were fitted well to predict the crop coefficient values as function of growing degree-days (GDD).

**Keywords:** Chickpea; crop coefficient; polynomial equation; crop water requirement; wheat.

### 1. INTRODUCTION

In India, most regions are affected by a problem of drought like situation and water resource scarcity. Under such a situation, suitable management of existing water resources and better solutions for their usage are essential. Crop coefficient (Kc) value of crop for each region is generally affected by different climatic parameters as well as geographical attributes. Because Kc value affects the amount of water lost through crop, estimation of the Kc value play important role in computing crop evapotranspiration (ETc). The ETc plays an important role in water resource management by eliminating losses through estimating exact crop water requirements. The objective of the present study was to evaluate corrected crop coefficient value for humid sub tropical climatic condition of Varanasi. Wheat is main cereal crop in India with total crop area of about 29.8 million hectares and production with all time record high of 94.88 million MT in 2011-12 [1-3]. The productivity of wheat which was 2602 kg/hectare in 2004-05 has increased to 3140 kg/hectare in 2011-12 [4,5]. Chickpea is an important pulse and accounts to 45% of total pulses production in India. An accurate estimate of crop evapotranspiration rates using Kc value is important in agricultural planning, due to its strong influence on irrigation schedule [6,7]. In particular, a high level of accuracy in crop evapotranspiration estimation can result in saving economic and water resources for both planning and management of irrigated areas [8].

### 2. MATERIALS AND METHODOLOGY

#### 2.1 Study Area

Varanasi district of Uttar Pradesh is situated at latitude 25°26' N and longitude 82° 99' E with an altitude of 80.71 m; experiences a humid subtropical climate with large variations between summer and winter temperatures [9]. It receives an average annual rainfall of 1110 mm. The district has a humid subtropical climate (Cwa or Cfb) class [10]. The area is characterized by dry winters with mean temperature that vary between 8°C to 32°C; summers mainly have mean temperature range from 24°C to 48°C. The location map of the study area is shown in Fig. 1.

![Location map of study area](image_url)
2.2 Data Used

The meteorological data i.e. relative humidity ($R_{\text{H mean}}$), and wind speed (km/hr) for 29 years (1986-2014) were collected from the observatory of Institute of Agricultural Sciences, BHU, Varanasi and analyzed for the present study. Crop height (m) was measured during the mid-season stage and end-season stage of the crops i.e. wheat and chickpea at agriculture farm situated in BHU Campus, Varanasi, Uttar Pradesh and Fig. 2a, b. depicted the measurement of crop height during mid-season stage and end-season stage for wheat crop.

2.2.1 Wheat

*Triticum aestivum* (L) emend Ficri and Paol developed with the parents HUW 12/SPRW/HUW 12 in the year 1986. The variety was released by CVRC which was developed by the prestigious Banaras Hindu University, Varanasi. It was widely adopted in the area of North east plain zone (NEPZ) covering about 80% of net sown area. Area of wheat under cultivation for Varanasi region is 70642 ha. An excellent variety for the late sowing (25 November to Last week of December) in irrigated conditions, which performs very well in production as compared to the time sown in irrigated conditions. The sowing distance of this variety like plant to plant and row to row distance of the variety was found to be 10 and 20 cm respectively. It takes early (81-90 days) to heading and the variety normally takes early (126-134 days) to mature with the potential yield recorded to be 45 quintals per hectare. The variety is also suitable for general cultivation as well as for zero tillage practice. The physical characteristics of the variety like the growth habit is semi erect along with the green colour of coleoptiles and foliage, peduncle is straight, peduncle length of the plant is medium (31-50 cm), pith is thin (hollow), auricle pigmentation is colourless (green) and auricle pubescence is moderate (few hairs) and the flag leaf attitude is drooping.

2.2.2 Chickpea

Chickpea is important pulse crop grown in large area of Varanasi district of eastern Uttar Pradesh. This crop generally requires one or two irrigation during crop growth stage. The crop matures in 140-150 days and the production yield was found to be 25-35 quintals per hectare. It is suitable for sowing in the month of November to December and harvested during the month of May. The varieties like DCP-92-3, Pusa Kabuli (BG-1003), Surya (WCG-2), Vallabh color chana (WCG 3), Pragati (K-3256) and Gujarat Gram-4 (GCP-105) are popular in North Eastern plain zone, which consider the various states like Uttar Pradesh, Madhya Pradesh and Bihar.

![a. Wheat crop at mid-season stage](image1.png)
![b. Wheat crop at end-season stage](image2.png)

Fig. 2 (a, b). Measurement of crop height of wheat crop at agriculture farm, BHU campus, Varanasi
2.2.3 Crop coefficient (Kc)

The crop coefficient (Kc) value for any particular crop is of utmost important for estimating the crop water requirement. Estimation of crop water requirements (CWR) is one of the chief component adopted for irrigation planning, design and operation to render the impact resulted due to water stress condition [11,12] in which crop coefficient approach (eq. 1) has been used. The adoption of an accurate amount of the water and right timing of application of the water is very essential for scheduling irrigations to meet the water requirement of the crops, which is extremely significant for the optimum crop production in a sustainable manner. In the present study, the corrected value of crop coefficients were determined for two major crops (i.e. wheat and chickpea) for the humid subtropical climate of Varanasi district, Uttar Pradesh using the eq. 2 and 3.

\[ (ET_c = K_c \times ET_o) \]  

(1)

Where,

- \( ET_c \) = crop evapotranspiration/Crop water requirement (mm day\(^{-1}\)),
- \( ET_o \) = reference evapotranspiration (mm day\(^{-1}\)),
- \( K_c \) = crop coefficient.

The crop coefficient values are affected by various parameters like crop characteristics, crop planting or sowing date, rate of crop development, length of growing season, climatic conditions and different stages of crop growth. \( K_c \) values for different crop are different and vary with crop growth stages. The total duration of these crops were divided into four growth stages namely Initial stage, Developmental stage, Mid-season stage and Late-season stage. The initial stage refers to the germination and early growth stage when the soil surface is not or is hardly covered by the crop (ground cover < 10%), development stage of crop starts from the end of initial stage up to the attainment of effective groundcover (groundcover 70-80%) and the mid-season stage runs from effective full groundcover to the start of maturity. \( K_c \) value reaches to maximum at the third stage (mid-season stage) for any kind of crop. The late season stage runs from the start of maturity to harvest or full senescence [13]. The calculation of \( K_c \) value is presumed to end when the crop is harvested, dries out naturally, reaches full senescence, or experiences leaf drop. The generalized crop coefficient curve is depicted in Fig. 3.

The \( K_{c\text{ini}} \) value for the crops i.e., wheat and chickpea given in FAO-56, which was used as such and no correction was applied due to unavailability of data like time interval between wetting events of soil and magnitude of wetting

![Fig. 3. Variation in Kc value for crops as influenced by weather factors and crop development [14]](image-url)
events. While the value of $K_{c(mid)}$ (mid-season stage) and $K_{c(end)}$ (late-season stage) for each of the crop was calculated by linear interpolation equation. The values for $K_{c(mid)}$ and $K_{c(end)}$ were corrected by using the following given equations [15] and the flowchart of methodology used for the determination of corrected crop coefficient value of wheat and chickpea crops is presented in Fig. 4.

$$K_{c(mid)} = K_{c(mid)(tab)} + \left[0.04(u_2 - 2) - 0.004RH_{min} - 45h^{30.3}\right]$$

(2)

where,

$K_{c(mid)(tab)}$ represents the value for $K_{c(mid)}$ (Table 1), $u_2$ represents mean value for daily wind speed at 2 m height over grass during mid season growth stage (ms$^{-1}$), for $1\text{ m s}^{-1} = u_2 = 6\text{ m s}^{-1}$ and $RH_{min}$ represents the mean value of daily minimum relative humidity during mid season growth stage (%), for $20\% = RH_{min} = 80\%$, and $h$ represents the mean plant height during mid season growth stage (m), for $0.1 \text{ m} < h < 10 \text{ m}$.

$$K_{c(end)} = K_{c(end)(tab)} + \left[0.04(u_2 - 2) - 0.004RH_{min} - 45h^{30.3}\right]$$

(3)

where,

$K_{c(end)(tab)}$ is value for $K_{c(end)}$ (Table 1), $u_2$ is the mean value for daily wind speed at 2 m height over grass during end season growth stage (ms$^{-1}$), for $1\text{ m s}^{-1} = u_2 = 6\text{ m s}^{-1}$ and $RH_{min}$ is the mean value of daily minimum relative humidity during end season growth stage (%), for $20\% = RH_{min} = 80\%$, and $h$ is the mean plant height during end season growth stage (m), for $0.1 \text{ m} < h < 10 \text{ m}$.

### Table 1. FAO crop coefficient ($K_c$) value and mean maximum plant height for non stressed well-managed crops in sub-humid climate ($RH_{min} - 45\%$, $u_2 - 2\text{ ms}^{-1}$) for Wheat [14,16] and Chickpea

| S.No. | Crops    | $K_{c(ini)}$ | $K_{c(mid)}$ | $K_{c(end)}$ | Mean maximum crop height (m) |
|-------|----------|-------------|-------------|-------------|-------------------------------|
| 1.    | Wheat    | 0.40        | 1.15        | 0.41        | 0.80                          |
| 2.    | Chickpea | 0.40        | 1.00        | 0.35        | 0.40                          |

![Fig. 4. Processing steps used for the determination of corrected crop coefficient value of wheat and chickpea crops](image-url)
3. RESULTS AND DISCUSSION

Kc values at different crop growth stages are affected by local climatic condition and therefore Kc value is area oriented. Therefore it is necessary to take it into consideration and criterion for estimating irrigation requirement and for irrigation scheduling. An attempt has been executed for correcting Kc values of Wheat and Chickpea. In both the crop coefficient value for initial stage was taken from FAO without correction as such because of unavailability of data like time interval between wetting soil and magnitude of wetting events.

3.1 Crop Coefficient (Kc) Values for Wheat

The Kc\textsubscript{(ini)} value was taken as the benchmark from the literature (FAO-56) and correction has been made for Kc\textsubscript{(mid)} and Kc\textsubscript{(end)} values for wheat using the above empirical equations (eq. 2 and 3). Table 2 represented the corrected value of Kc\textsubscript{(mid)} and Kc\textsubscript{(end)} for Wheat. The corrected crop coefficient value for mid-season was found to be 1.12, which is very close to the value suggested by FAO. Similarly, for the end season of wheat Kc corrected is found out to be 0.42, which is nearly on par with Kc given by FAO i.e. 0.41. In the field mean maximum height of wheat crop in mid-season was obtained as 0.80 m and for the end season it was found to be 0.99 m.

3.2 Crop Coefficient (Kc) Values for Chickpea

Similar attempt was executed for computation of crop coefficient values of Chickpea or Bengal gram which is a major rabi crop. The value of crop coefficient for initial stage Kc\textsubscript{(ini)} was opted from the literature FAO-56 and no correlation was done to the value. Computation has been accomplished for the values of Kc\textsubscript{(mid)} and Kc\textsubscript{(end)} for Chickpea and it is presented in Table 3. The Table 3 clearly show that the corrected coefficient value for mid-season of chickpea is found to be 0.98; whereas the value of Kc\textsubscript{(mid)} suggested by FAO-56 is 1.00. Similarly, the adjusted value of Kc\textsubscript{(end)} for the end season is 0.38, which lies in close proximity with Kc\textsubscript{(end)} specified by FAO-56. In the field mean maximum height of chickpea crop in mid-season was acquired as 0.39 m whereas for the end season it was found to be 0.52 m.

The graphical representation curve of crop coefficient value (FAO-56 and corrected) for wheat and chickpea crop with respect to time in days (i.e. crop growth period) is been accomplished through the mathematical approach and it is revealed in the Figs. 4 and 5, respectively. In this regards the crop coefficient curve for wheat is prepared with the help of value of crop coefficient for wheat at initial, mid and end season on Y- axis and time (days) on X-axis. It is evidently revealed from the Fig. 5, A third-order polynomial equation (\(y = -3E - 06x^3 + 0.0005x^2 - 0.0039x + 0.3702\)) has been obtained with the correlation coefficient (R\textsuperscript{2}) of 0.97 [17]. Developed third-order polynomial equation for the evaluation of Kc for onion crop. Furthermore, [18] fitted third-order polynomials to predict the crop coefficient (Kc) values from growing degree-days (GDD) for Sesame crop with coefficient of determinations (R\textsuperscript{2}) of 0.72.

Correspondingly, Fig. 6 illustrates about the variation between time of crop growth in days (X-axis) and crop coefficient of chickpea (Y-axis). A third-order polynomial equation (\(y = -2E - 06x^3 + 0.0002x^2 - 0.0004x + 0.3732\)) has been achieved with the coefficient of determination (R\textsuperscript{2}) of 0.98.

### Table 2. Corrected value of crop coefficient (Kc\textsubscript{(mid)} and Kc\textsubscript{(end)}) for wheat

| Crop  | Kc\textsubscript{(ini)} | Kc\textsubscript{(mid)} | Kc\textsubscript{(end)} | Mean maximum crop height (m) |
|-------|------------------------|------------------------|------------------------|-------------------------------|
|       | FAO Corrected          | FAO Corrected          | FAO Corrected          |                               |
| Wheat | 0.4                    | 1.15                   | 1.12                   | 0.45                          |
|       |                        |                        |                        | 0.9                           |

### Table 3. Corrected value of crop coefficient (Kc\textsubscript{(mid)} and Kc\textsubscript{(end)}) for Chickpea

| Crop   | Kc\textsubscript{(ini)} | Kc\textsubscript{(mid)} | Kc\textsubscript{(end)} | Mean maximum crop height (m) |
|--------|------------------------|------------------------|------------------------|-------------------------------|
|        | FAO Corrected          | FAO Corrected          | FAO Corrected          |                               |
| Chickpea | 0.4                    | 0.98                   | 0.35                   | 0.39                          |
|         |                        |                        |                        | 0.52                          |
The computation of crop coefficient value suitable to particular region is of utmost important for the estimation of crop water requirement as well as irrigation water requirement to the researchers and the other agencies. The information will help in making policies associated with crop production in agriculture sector and effective management of
water resources such as operation of canal along with Dam and it's designing.

4. CONCLUSION

Crop water requirements vary during the growing period, mainly due to variation in growth stages of crop, climatic conditions and relationship to both cropping technique and irrigation methods. There is a need to estimate the crop coefficient ($K_c$) for a particular crop with specific location. Use of FAO crop coefficient ($K_c$) values may overestimate or underestimate the crop water requirement for a particular crop at specific location. Accurate estimation of crop coefficient for the crop water requirement not only save the irrigation water but also protect the land from various land degradation causes. Optimal provision of water during the required period of crop growth helps to increase the productivity as well as yield of crop. Therefore, $K_c$ value needs to be corrected to suit the climatic condition which prevails in any particular region.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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