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Research Paper

Development of growth-stage specific crop coefficient for drip irrigated wheat crop grown in climatic conditions of Jalandhar, Punjab

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ABSTRACT

The crop coefficient (Kc) values given in FAO-56 report need to corrected for local conditions due to differences in climate, soil types, and water management practices. Therefore, present study was undertaken to develop growth-stage-specific Kc values of wheat grown under drip irrigated conditions for two years (2022-23 and 2023-24) at Jalandhar, Punjab. The developed K_c values are 0.36, 0.77, 1.05, 0.69, and 0.25 during initial, development, mid, late, and end growth stages, respectively. These average Kc values can be effectively utilized to schedule irrigation for drip-irrigated wheat crops in the Jalandhar region of Punjab. Irrigating wheat crop under drip irrigation with developed K_c values not only enhances grain yield by 36% but also improves IWUE by three times and saves 61% use of irrigation water as compared to conventional irrigation practices (flood irrigation).

Keywords: Crop evapotranspiration (ET_C), Crop coefficient (K_c), Drip irrigation, Irrigation water use efficiency (IWUE), Pan Evaporation (E_{pan}), Reference Evapotranspiration (ET_o) and Wheat.

Wheat is a major crop of Punjab, necessitating rigorous research to enhance wheat production through improved irrigation water savings and water use efficiency. Improving consumption of water during wheat cultivation involves reconciling the crop's water needs with the quantity of water stipulated to it. Drip irrigation can boost crop yield and water productivity while conserving more water than conventional irrigation (Sharma *et al.,* 2021; Sharma *et al.,* 2023; Changade *et al.,* 2023; Kumar and Haroon, 2021). Government subsidies enable Indian farmers to adopt this technique, but it requires region-specific crop water demand considerations (Kumar and Haroon, 2021). Crop evapotranspiration (ETc), indicating crop water demand, is influenced by climatic conditions, crop characteristics, and irrigation practices (Satpute *et al.,* 2021). The FAO-56 approach estimates ETc using reference evapotranspiration (ET_0) and crop coefficient (K_c). Determining region-specific ETc through ET_0 and Kc is crucial for optimizing yield and water savings (Saxena *et al.,* 2020). Crop coefficient (K_c) indicates crop specific use of water and is needed for exact calculation of irrigation water requirement of various crops grown under different agro-climatic regions. The K_c is affected by different local factors like; existing climatic conditions, characteristics of soil, irrigation methods and crop management techniques (Rana *et al.,* 2014). The conventional method for estimating K_c typically involves using lysimeters, which is time-consuming and labor-intensive (Bhantana and Lazarovitch 2010; Mehta and Pandey, 2016; Abedinpour, 2015). Doorenbos and Pruitt (1977) suggested Kc values for various crops, but these are less effective for irrigation scheduling under local climatic conditions in India. They should be used as approximations where local K_c data for drip-irrigated crops are unavailable. Allen *et al.,* (1998) reported that Kc values must be empirically developed for each crop through local field experiments. Research indicates that drip or sprinkler irrigated crops exhibit distinct water use patterns, often necessitating

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different Kc values compared to crops under conventional irrigation (Ayars *et al.,* 2006; Ko *et al.,* 2009). Differences in root distribution, moisture availability, canopy characteristics, and stress conditions between drip and conventional irrigation necessitate adjusting the crop coefficient for drip-irrigated wheat to accurately reflect these conditions (Mehta and Pandey, 2016). Accurate Kc values are essential for optimal water management in precise drip irrigation systems. Further research is needed to develop reliable K_c values for drip-irrigated wheat, aiding farmers in optimizing water use efficiency and maximizing yield. Therefore, this investigation aims to develop growth-stage-specific Kc values for irrigation scheduling of drip-irrigated wheat in the selected study area.

MATERIALSANDMETHODS

The study was carried out under the climatic condition of Lovely Professional University Jalndhar, Punjab (latitude 31.25° N and longitude 75.70° E along with altitude of 280 m above mean sea level). Wheat (*Tritium aestivum*), cultivar (Cv.) Unnat PBW-550 was grown under drip irrigation technique during *rabi* season (Nov to April) of two consecutive years (2022-2023 and 2023-2024).Seeds were directly sown with row spacing of 15 cm on 20th November during both selected years (2022-23 and 2023-24) in total 24 &4 plots having drip &flood irrigation methods, respectively. Harvesting of wheat was done on April 10th and 14th during the growing seasons of 2022-23 and 2023-24, respectively. In drip irrigated plots, irrigation water was supplied on the basis of 50% depletion in field capacity of soil which was continuously monitored with the help of soil moisture sensor placed at 15 to 30 cm depth. Water meters were installed at the starting of each plot to measure volume of irrigation water supplied during each irrigation event. The total depth of irrigation water supplied during each growth stages was estimated corresponding to area of plot. Further, corresponding to actual depth of irrigation water supplied during each irrigation event, the crop evapotranspiration (ET_C) was estimated by water balance formula which is given as follows (Michael and Ojha, 2013);

$$ETc= \frac{\text{Irrigation Depth}+\Delta S-R}{(1-p)\times\eta}$$

Where, ETc=Crop evapotranspiration (mm day^{-1}), Irrigation Depth: It is the depth of irrigation water applied (mm), ΔS: change in soil moisture content (before irrigation - after irrigation) in decimals, R: Effective rainfall (mm), : Soil moisture depletion fraction (in decimals), : Soil water extraction coefficient (in decimals)

The irrigation was given to wheat crop at 50% depletion in field capacity (24%) of soil so change in soil moisture content (ΔS) was consider as (0.12-0.24) = 0.12 during each irrigation event. In order to estimate ET_c by above equation, p and η values were assumed as 0.5 (commonly used value for soil moisture depletion fraction) and 1 (for simplicity, assuming full extraction), respectively (Michael and Ojha, 2013). The reference evapotranspiration (ET_0) was computed by FAO-Penman Monteith formula (Allen *et al.,* 1998) by using the existing weather data during both field experiments. The daily weather data such as maximum & minimum temperature as well as relative humidity, wind speed and sunshine hour were acquired for Jalandhar station from the Department of Agrometeorology, Punjab Agricultural University Ludhiana.

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

Where, ET_o = reference/potential evapotranspiration (mm day^{-1}), R_n= net radiation over surface of crop (MJ m^{-2} day), T= air temperature at approximately 2 m height (°C), G= heat flux density of soil (MJ m^{-2}day), u_2= speed of wind at 2 m height (m s^{-1}), e_s - e_a = vapour pressure deficit (kPa),Y= psychrometric constant, (kPa°C^{-1}), Δ= vapour pressure curve slope (kPa°C^{-1}).

Finally, in existing climatic conditions of selected study area, the stage wise average crop coefficient (Kc) value for drip irrigated wheat crop was developed by dividing estimated crop evapotranspiration (as per soil water balance method) to its corresponding actual reference evapotranspiration.

$$K_c = ETc/ETo$$

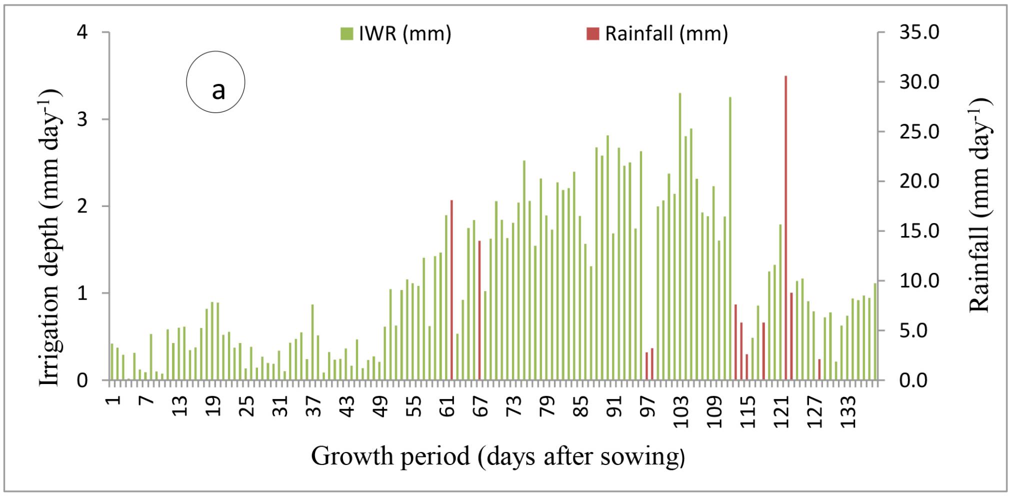
Where, K_c: Crop coefficient, ETc: Average crop evapotranspiration (mm day^{-1}), ETo: Average reference evapotranspiration (mm day^{-1}).

RESULTS AND DISCUSSION

Irrigation water requirement and crop evapotranspiration

The daily irrigation water supplied for drip-irrigated wheat ranged from 0.018 to 3.3 mm day^{-1} and 0.03 to 2.8 mm day^{-1} for the growing seasons of 2022-23 and 2023-24, respectively (Fig. 1a & b). This variability in irrigation water demand throughout the growing period is attributed to temporal fluctuations in the climatic conditions of the study area. It underscores the importance of adopting precise irrigation scheduling, which considers local factors such as prevailing climatic conditions, soil characteristics, and crop management techniques. Notably, the daily irrigation water requirement during the 2023-24 field experiment was slightly lower compared to 2022-23. This reduction is attributed to increased rainfall availability in 2023-24 as compared to 2022-23.

Result in Table 1 indicate that, the daily average crop evapotranspiration (ETc) estimated as per soil water balance method at different growth stages ranges from 1.08 to 4.58 and 0.78 to 3.90 mm day^{-1} for 2022-23 and 2023-24, respectively. Whereas, the daily average actual evapotranspiration (ETo) estimated as per FAO-Penman Monteith formula at different growth stages ranges from 2.1 to 8.7 and 0.1.6 to 6.5 mm day^{-1}, respectively for 2022-23 and 2023-24. As per mean data of both years, the daily average ETc was estimated highest as 4.11 mm day^{-1} at mid growth stage and lowest as 0.93 mm day^{-1} at initial growth stage. The average daily actual reference evapotranspiration (ET0) was estimated maximum and minimum as 7.6 mm day^{-1} and 1.87 mm day^{-1} during end and development growth stage of drip irrigated wheat crop. The fluctuating irrigation depth at different growth stages of drip-irrigated wheat crop is primarily influenced by the evolving physiological demands of the plant throughout its growth cycle. Early growth stages (such as germination & seedling establishment) of drip irrigated wheat crop, demands relatively less water as



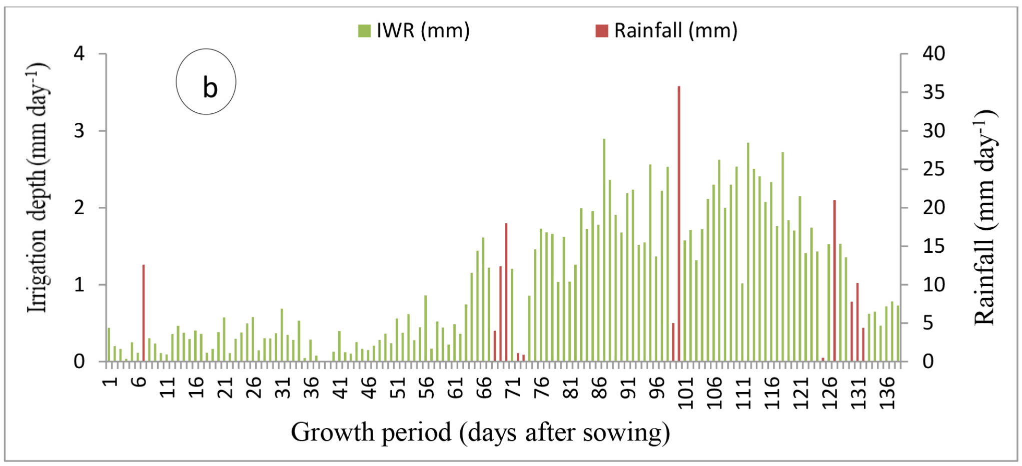


Fig. 1: Daily irrigation water requirement and rainfall during whole growing period in year (a) 2022-23 and (b) 2023-24.

Table 1: Average crop evapotranspiration, reference evapotranspiration and developed crop coefficient values at different growth stages of crop.

Growth stages	Average ETc (mm day^{-1})*			Average ET_0 (mm day^{-1})			Crop coefficient Kc		
	2022-23	2023-24	Mean	2022-23	2023-24	Mean	2022-23	2023-24	Mean
Initial	1.08	0.78	0.93	2.88	**2.27**	2.57	0.38	0.34	0.36
Development	1.71	1.16	1.43	2.14	1.60	1.87	0.80	0.72	0.77
Mid	4.58	3.64	4.11	4.29	3.52	3.91	1.07	1.03	1.05
Late	2.77	3.90	3.34	4.21	5.48	4.84	0.66	0.71	0.69
End	2.20	1.58	1.89	8.79	6.58	7.68	0.25	0.24	0.25

*it was estimated as per soil water balance approach by using daily IWR and Rainfall data

compared to later growth stages (like flowering and grain filling). Mid growth stage of wheat which require increased moisture to support vigorous growth and reproductive processes. As the root system develops and expands, the plant's ability to withdraw water from deeper soil layers improves, necessitating higher irrigation volumes to meet escalating water demands, especially during those critical reproductive stages where water stress can severely impact yield and quality. Consequently, crop & region-specific irrigation management practices tailored to the specific needs of water during each growth stage are essential to optimize irrigation water use efficiency as well as to ensure sustainable wheat production in water scare regions.

Daily and growth stage wise crop coefficient (K_c)

The K_c values at initial, development, mid, late & end growth stages were found as 0.38, 0.80, 1.06, 0.66 & 0.25 and 0.34, 0.72, 1.03, 0.71 & 0.24 during growing years 2022-23 and 2023-24, respectively (Table 1). The 2-years mean K_c value at initial, development, mid, late & end growth stages was found as 0.36, 0.77, 1.05, 0.69 & 0.25, respectively to schedule irrigation for drip irrigated wheat crop in selected study area. As per data presented in Fig. 2, Kc value at initial growth stage (1 to 25 DAS) ranges from 0.33 to 0.38 which can consider as constant (0.36) during whole initial stage but in case of development stage (26 to 70 DAS),

Table 2: Performance of wheat crop in drip and flood irrigated plots during field experiments in selected study area

Irrigation method	Parameters	2022-23	2023-24	Pooled	SEM	CV (%)
Drip irrigation	Plant height (cm)	102.0	109.0	105.5	2.1	6.4
	Number of tillers per plant	6.0	7.0	6.5	0.4	11.2
	Ear length (cm)	15.2	16.7	16.0	0.8	9.5
	Number of grains per ear	60.0	64.0	62.0	1.4	7.2
	Test weight (gm)	48.0	55.0	51.5	1.1	8.9
	Grain yield (tha^{-1})	5.5	6.1	5.8	0.31	12.1
	Total irrigation water supplied (cm)	14.6	12.7	13.6	-	-
	Irrigation WUE ($t\ ha^{-1}$-cm)	0.37	0.48	0.42	-	-
	Irrigation water saving over conventional irrigation practice	60	62	61		
Flood Irrigation	Grain yield (tha^{-1})	4.1	4.5	4.25	0.3	12.6
	Total irrigation water supplied (cm)	37.1	34.2	35.6		
	Irrigation WUE ($t\ ha^{-1}$-cm)	0.11	0.13	0.12		

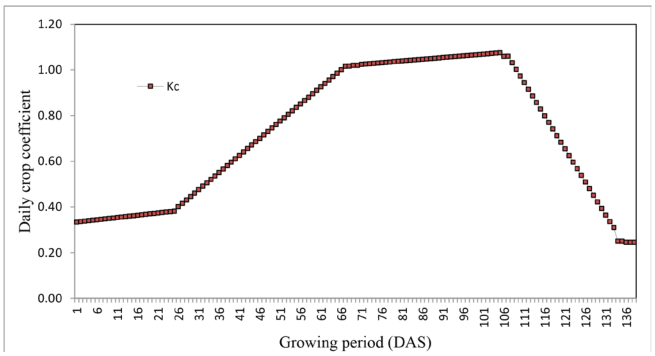


Fig. 2: Developed crop coefficient values (K_c) at different days after sowing for drip irrigated wheat crop (on pooled data basis).

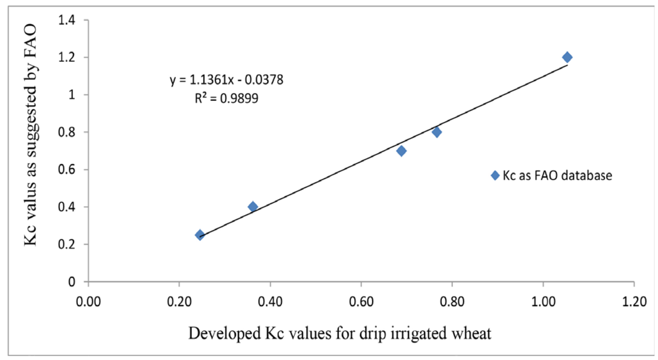


Fig. 3: Correlation analysis between developed Kc and Kc as suggested by FAO.

the trend of Kc values was gradually increased from 0.4 to 1.06 which shows the continuous need of more amount of irrigation water with respect to increase in DAS. It is probably because of that, during development stage plant canopy was continuously increasing so plant requires more water for performing their photosynthesis operation which results gradually increment in ETc value at development stage as compared to initial growth stage of drip irrigated wheat crop. However, Kc for mid growth stage (71 to 105 DAS) was estimated highest which ranges from 1.02 to 1.07 that shows the maximum need of irrigation water for drip irrigated wheat crop in selected study area. Grain filling is an energetically demanding process that requires ample water availability to support cell expansion, starch accumulation, and nutrient transport to developing grains. As a result, the wheat crop's water requirement increases substantially during this stage, contributing to the elevated crop coefficient (Kc) values observed in drip-irrigated wheat crops. Ensuring sufficient irrigation water supply during grain filling is crucial for achieving optimal grain yield, quality, and overall crop productivity. The trend of K_c value during late stage (106 to 133 DAS) was gradually decreased from 1.08 to 0.31 which shows the continuous reduction in need of irrigation water with respect to DAS. Overall, the decreasing trend in Kc values during the late stage of wheat growth reflects the natural progression of the crop's development, characterized by reduced vegetative growth and approaching maturity, all contributing to a diminishing need for irrigation water.

The low Kc value 0.25 at the end stage of wheat crop reflects the minimal metabolic activity, reduced transpiration rates, and physiological maturity, indicating that the crop's water requirements are minimal as it approaches harvest. In contemporary agricultural practices, many farmers tend to use a constant Kc value to schedule irrigation throughout the different growth stages in wheat cultivation as these Kc values are already suggested to respective growth stages by various researchers. However, in regions facing water scarcity in Punjab, prioritizing effective water management is crucial. Therefore, emphasizing the importance of adjusting the Kc value based on the days after sowing (DAS) should take precedence. To facilitate this, the study has presented Fig. 2, showcasing daily crop coefficient values specifically tailored for drip-irrigated wheat crops. These values offer a practical and accessible resource for beginners and irrigation planners, enabling them to accurately schedule irrigation and optimize water use throughout the various growth stages of wheat cultivation.

The study conducted correlation analysis between the Kc values suggested by FAO-56 and the developed Kc values under the specific climatic conditions of the study area. The results revealed a high correlation coefficient (R^2 = 0.98) between the FAO-56 recommended values and the developed values, indicating a strong relationship between them (Fig. 3). This finding provides scientific evidence supporting the adoption of region- and growth stage-specific Kc values for scheduling irrigation in drip-irrigated wheat crops within the Jalandhar region of Punjab. By utilizing these tailored Kc values, farmers and practitioners can optimize irrigation management practices to better meet the water requirements of wheat crops, ultimately enhancing water use efficiency and crop productivity in the region. These values are quite well with those obtained by Arunadevi *et al.,* (2020).

Yield and yield attributes of wheat

The performance of drip irrigated wheat crop during both year field experiments is shown in Table 2. The Kc value was developed according to actual amount of irrigation water supplied to drip irrigated wheat crop and actual ET_0 under existing climatic condition of selected study area during both year's field experiment. Hence, the obtained results will support the suitability of developed K_c value to schedule irrigation for drip irrigated wheat crop in Jalandhar region of Punjab. The plant height, number of tillers plant day^{-1}, ear length, number of grain ear day^{-1} and test weight were recorded as 0.5.5 cm, 6.5, 16 cm, 62.0 and 51.5 gm, respectively which ultimately give 36 % higher grain yield under drip irrigated wheat crop as compared to conventionally irrigated wheat (flood irrigation).

As per data obtained through field experiments it can states that, schedule irrigation as per developed K_c for drip irrigated wheat crop will surely enhance grain yield by 36%, irrigation water use efficiency three times and also gives 61% irrigation water saving over conventionally irrigated wheat crop.

CONCLUSION

In conclusion, the observed fluctuations in daily irrigation water requirement, estimated ET_C, and actual ET_0 underscore the pressing necessity for tailored K_c values corresponding to growth stages and specific regions for drip-irrigated wheat crops. Instead of relying on generic Kc values proposed by various researchers, irrigation managers, farmers, and other water users can utilize stage-specific Kc values such as 0.36, 0.77, 1.05, 0.69, and 0.25 for the initial, development, mid, late, and end growth stages, respectively to schedule irrigation for drip irrigated wheat crop in Jalandhar region of Punjab. In case of water scarcity, these developed K_c values could play a vital role in irrigation scheduling of wheat crop under the goal of sustainable wheat production and food security. Irrigating wheat through drip irrigation technique as per developed K_c values not only enhances grain yield by 36% but also significantly improves IWUE by three times and saves 61% amount of irrigation water compared to conventional irrigation practices (flood irrigation). The developed K_c values can provide a scientific hint/ reference for irrigation planning and water resource management in different regions of India.

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