DOI: 10.54083/ResBio/4.2.2022/69-73

Res. Bio., 2022, 4(2):69-73

Research Biotica

Crossref

e-ISSN: 2582-6743

June, 2022

Article ID: RB123

Research Article

Determination of Growth-Stage-Specific Crop Coefficients (K_c) for Drip Irrigated Wheat (*Triticum aestivum* L.) under Different Land Configurations

D.D. Vadalia[1*], G.V. Prajapati[1], S.H. Parmar[1] and G.D. Gohil[2]

[1]*Centre of Excellence on Soil and Water Management, Research Testing and Training Centre, Junagadh Agricultural University, Junagadh, Gujarat (362 001), India*

[2]*Dept. of Processing and Food Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh, Gujarat (362 001), India*

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Corresponding Author

D.D. Vadalia

✉: daxv30@gmail.com

Conflict of interests: The author has declared that no conflict of interest exists.

How to cite this article?

Vadalia *et al*., 2022. Determination of Growth-Stage-Specific Crop Coefficients (K_c) for Drip Irrigated Wheat (*Triticum aestivum* L.) under Different Land Configurations. *Research Biotica* 4(2): 69-73.

Abstract

Determination of the actual crop evapotranspiration (ET_c) during the crop growth is important for precise irrigation scheduling, sustainable development and environmentally sound water management. Development of a crop coefficient (K_c) can enhance ET_c estimations in relation to specific crop phenological development. An experiment was conducted on sandy loam soil at Junagadh Agricultural University, Junagadh to determine growth stage specific K_c of wheat (GW-366) using drip irrigation under different land configurations (L_1: broad bed furrow and L_2: flat land) at different irrigation levels (I_1: 1.0 ET_c and I_2: 0.8 ET_c). Soil moisture sensors were utilized to estimate Actual crop evapotranspiration. Results revealed that adjusted FAO K_c predicts higher value than sensor-based K_c values under both land configurations. Broad bed furrow (BBF) land configuration observed lower K_c values compared to flat land configuration at all growth stages of wheat. Sensor based $K_{c\text{-ini}}$, $K_{c\text{-dev}}$, $K_{c\text{-mid}}$ and $K_{c\text{-end}}$ values of BBF observed 0.21 (7.26%), 0.59 (13.78%), 1.00 (7.27%) and 0.29 (9.48%) and 0.20 (8.43%), 0.55 (13.04%), 0.91 (8.18%) and 0.26 (9.48%) lower than flat land configuration. Overestimated adjusted FAO-K_c values caused a loss 106.18 mm and 89.43 mm precious water for wheat under BBF and flat land respectively.

Keywords: Broad bed Furrow, Crop coefficient, Drip irrigation, Land configuration, Wheat

Introduction

Wheat (*Triticum aestivum* L.) being an important staple food grain, productivity of wheat can be stunted with limited availability of irrigation water. In India around 50% irrigated wheat receive only one or two irrigations (Chouhan *et al.*, 2015a). Out of total wheat are around 60% is under irrigated condition. Prominent use of flood irrigation with low water use efficiency is a major limiting factor in irrigation coverage. It is the main sector in India which consume 80% of the existing surface and ground water resources (Bhattacharyya *et al.*, 2015). Development of drip irrigation systems capable of delivering water to the soil in small quantities as often as desired with no additional cost can partly remove the economic constraint of the traditional irrigation methods, which cause extremely large time fluctuation in the soil-water potential. Chouhan *et al.* (2015b) recommended the drip irrigation may improve yield by 16.42% and save water by 25%.

Water use efficiency of field crops can be improved as well as soil erosion can be minimized by altering land configuration. Land configuration increases water use efficiency (Chiroma *et al.*, 2008) and also increases availability of nutrients to crops. Broad Bed Furrow (BBF) land configuration is simpler, more efficient, use less water, improves crop yields and saves wheat seeds compared to flatbed method. Karrou *et al.* (2012) concluded that Raised Beds remains more a promising technique for wheat crop. The smaller root length density (RLD) in deep layers of the

Article History

RECEIVED on 27th April 2022 RECEIVED in revised form 14th June 2022 ACCEPTED in final form 16th June 2022

soil restricted the soil water uptake by the crop (Fang *et al.*, 2018). In irrigated areas with limited water resources, crop yield can be improved by a reasonable irrigation scheduling under different land configurations. Majeed *et al.* (2015) stated that bed planting of wheat not only saves water but improves fertilizer use efficiency and grain yield.

For proper irrigation scheduling the most fundamental requirement is determination of crop evapotranspiration (ET_c) (Kaur *et al.*, 2017). There is also a need for effective on-farm water management, *i.e.*, proper scheduling of irrigation (Farahani *et al.*, 2008). Hong *et al.* (2006) stated that with increasing ET, the irrigation requirements of winter wheat increase. But due to empirical nature of crop coefficient values taken from literature considerable error can occur in estimation of crop water requirement. Therefore, correction in crop coefficient values as per local climate is necessary. Most practitioners rely on the published values as local development of K_c is a difficult task. Realizing the necessity, efforts were made in estimation of K_c values for different growth stage of wheat crop under different land configuration and irrigation levels.

Materials and Methods

Field Experimental Details

The field experiment was conducted at the Research cum Demonstration farm of Centre of Excellence on Soil and Water Management, RTTC, Junagadh during *rabi* season to determine the K_c values for different growth stage of wheat crop under two land configurations; broad bed furrow (L_1) and flat land (L_2), and two irrigation levels; 1.0 ETc (I_1) and 0.8 ETc (I_2). Plot size were kept as 6.2 m × 15 m. Soil is sandy loam (1.0-1.5 m depth) with volumetric water content at field capacity and permanent wilting point determined at 39% and 15%, respectively. Field was ploughed using tractor operated cultivator and blade harrow. Raised beds (15 cm high and 210 cm wide with 100 cm tops and 55 cm furrows) were prepared with tropiculture. Wheat was shown on 3rd week of November by tractor mounted seed cum fertilizer drill Seed rate was maintained as 100 kg ha^{-1} with 22.5 cm row to row spacing. Fertilizer N:P:K (120:60:60) was applied to wheat crop.

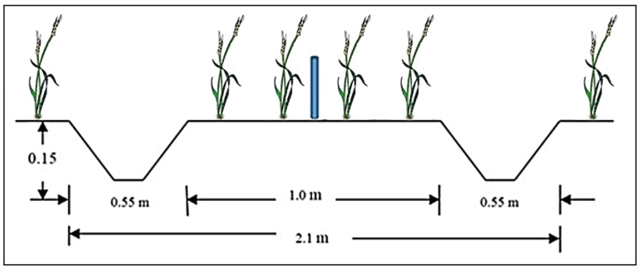

Figure 1: Dimensions of broad bed furrow

Irrigation Scheduling

Drip irrigation system with an emitter of 4 lph discharge and 0.6 m spacing was adopted for present study. Irrigation scheduling was done based on actual evapotranspiration measured with the help of soil moisture sensors installed at 15 cm and 30 cm from top of soil near the root zone of wheat crop in different treatments. Two set of sensors with data loggers were installed in different treatments at irrigation level 1.0 ET_c and 0.8 ET_c.

The reference crop evapotranspiration (ET_0) was estimated using Penman Monteith (PM FAO-56) equation,

$$ET_0 = \frac{0.48\Delta(Rn-g)+\Upsilon\frac{900}{T+278}u_2(e_s-e_a)}{\Delta+\Upsilon(1+0.34u_2)} \qquad \text{......................... (1)}$$

Where, ET_0 = reference evapotranspiration (mm day^{-1}); 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^{-1}); e_s = saturation vapour pressure (kPa); e_a = actual vapour pressure (kPa); e_s-e_a = saturation vapour pressure deficit (kPa); Δ = slope vapour pressure curve (kPa °C^{-1}); γ = psychrometric constant [kPa °C^{-1}].

Actual evapotranspiration (ET_a) was estimated in situ by calculation soil moisture depletion in root zone by detection soil moisture content using soil moisture sensors. The moisture content was also determined using gravimetric method to support the sensor information. The sensors were calibrated for local condition and moisture content calculated based on calibrated soil moisture characteristic curve. These differences between the soil moisture readings were used to determine the actual evapotranspiration. Actual Evapotranspiration (ET_a) was calculated using following equation.

$$ET_a=1000\times(M_1-M_2)\times Z_r\times BD \qquad \text{......................... (2)}$$

Where, = Actual evapotranspiration (mm); = Moisture content after irrigation (m^3 m^{-3}); = Moisture content before irrigation (m^3 m^{-3}); = Rooting depth (m); = Bulk density (g cc^{-1}).

Irrigation was provided at 50% of the available water based on the equation (2) considering the application efficiency as 90% (drip irrigation) at 1.0 ET_c and 0.8 ET_c. Prajapati (2017) also calculated actual crop evapotranspiration considering the root depth of cotton with model developed by Fereres *et al.* (1981).

Determination of K_c Values

Crop coefficient (K_c) is determined as per the FAO-56 approach and based on moisture sensor observations. Crop coefficient for the initial stage ($K_{c\,ini}$) was adjusted by multiplying the Tabulated value for $K_{c\,ini}$ provided in FAO-56 with the fraction of the surface wetted by trickle irrigation (0.4). $K_{c\,mid}$ and $K_{c\,end}$ were adjusted using following equation (4) and (5) as suggested by Allen *et al.* (1998).

$$K_{c\,ini}=f_w\times K_{c\,ini\,(Tab\,fig)} \qquad \text{................ (3)}$$

$$K_{cmid}=K_{cmid\,(tab)}+[0.04\,(u_2-2)-0.004\,(RH_{min}-45)](h/3)^{0.3} \qquad \text{....... (4)}$$

$$K_{cend}=K_{cend\,(tab)}+[0.04\,(u_2-2)-0.004\,(RH_{min}-45)](h/3)^{0.3} \qquad \text{....... (5)}$$

Where, f_w = fraction of surfaced wetted by irrigation or rain (0-1); u_2 = mean value of daily wind speed at 2 m height over grass during the mid-season growth stage (m s^{-1}); for 1 ms^{-1} ≤ u_2 ≤ 6 ms^{-1}; RH_{min} = mean value of daily minimum relative humidity; h = mean plant height during the mid-season.

Crop water use is directly related to ET. The crop's water use can be determined by multiplying the reference ET_0 by a crop coefficient (K_c). The crop coefficient adjusts the calculated reference ET_0 to obtain the crop evapotranspiration ET_a. Different crops will have a different crop coefficient and resulting water use. The sensor-based K_c values were developed as,

$$K_c = \frac{ET_a}{ET_o} \quad \text{.......................} \quad (6)$$

The reference evapotranspiration (ET_0) is determined using penman Monteith approach as explained in FAO 56. The values of actual evapotranspiration (ET_a) are determined from the daily moisture content values determined by the sensor which is explained in the earlier section. Sensor based K_c curve was compared with K_c curves developed as per FAO 56 for wheat under different land configuration with different irrigation levels (1.0 ET_c and 0.8 ET_c).

Results and Discussion

The study area is having typically subtropical and semi-arid climate, characterized by fairly cold and dry winter, hot and dry summer and warm and moderately humid during monsoon. Partial failure of monsoon once in three to four years is common in this region. The last 35 years weather data recorded at the Junagadh Agricultural University observatory located near to the experimental site showed that the variation in the weekly mean of daily maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, wind speed, bright sun shine hours and pan evaporation were from 27.0 °C to 42.7 °C, 10.0 °C to 27.3 °C, 28.1% to 94.6% , 10.4% to 87.3%, 2.1 km hr^{-1} to 12.8 km hr^{-1}, 0.8 hr to 10.6 hr, 0.6 mm to 10.7 mm, respectively.

During the period of experiments (November to March), the minimum and maximum reference evapotranspiration, temperature and relative humidity were observed as 5.95 mm and 1.43 mm, 8.50 °C and 38.40 °C, 11% and 92%, respectively. The weather parameters were more or less harmonious for favorable growth of wheat under irrigated condition during season.

Determination of K_c Curves

K_c as per FAO-56: The crop coefficient for the initial growth ($K_{c\ ini}$) stage derived from equation (3) was found as 0.28 for drip irrigated K_{cmid} and K_{cend} values were adjusted as per eqn. (4) and (5) were 1.23 and 0.38 respectively. Corrected K_c values as per FAO 56 for different irrigation methods drip irrigation is depicted in Figure 2.

K_c based on moisture sensor observations: Temporal variation of ET_a/ET_o depicts the seasonal trend of sensor-based K_c; whereas, the spikes are due to high rates of evapotranspiration. Sensor based K_c curves were compared with the adjusted FAO K_c curves for different land configuration at different irrigation levels. Adjusted FAO K_c remains same for a particular combination of land configuration and irrigation level.

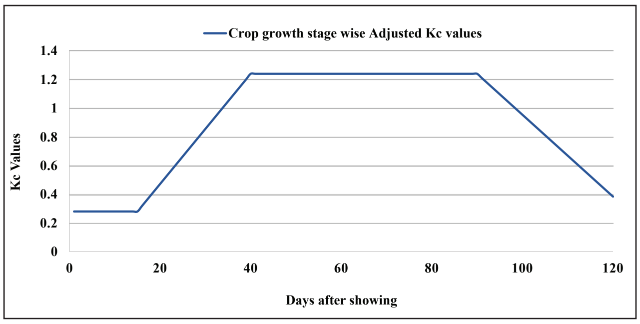

Figure 2: Adjusted FAO K_c curve

Adjusted FAO K_c curves and sensor-based K_c curves at different irrigation levels for flat land configuration are shown in Figure 3. The comparison of adjusted K_c curves for drip irrigation system as per FAO 56 and sensor-based K_c curves at 0.8 and 1.0 ET_c differed considerably. Sensor based $K_{c\text{-ini}}$, $K_{c\text{-dev}}$, $K_{c\text{-mid}}$ and $K_{c\text{-end}}$ were lower by 22.25%, 17.44%, 19.61% and 25.17% and 20.40%, 11.71%, 12.89% and 16.86 % than FAO adjusted values for 0.8 and 1.0 ET_c respectively.

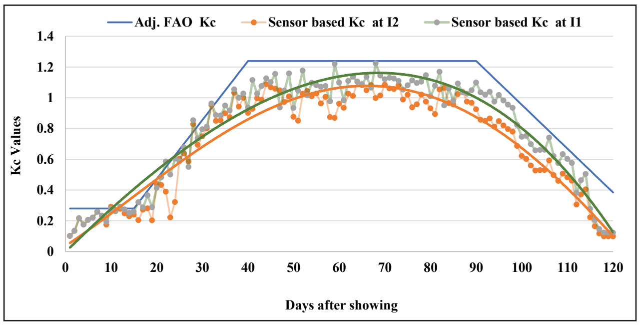

Figure 3: K_c curves for flat land

Adjusted FAO K_c curves and sensor-based K_c curves at different irrigation levels for broad bed furrow land configuration are shown in Figure 4. The comparison of adjusted K_c curves for drip irrigation system as per FAO 56 and sensor-based K_c curves at 0.8 and 1.0 ET_c differed considerably. Vadalia and Prajapati (2022) also observed adjusted FAO K_c predicts higher value than sensor-based K_c. Sensor based $K_{c\text{-ini}}$, $K_{c\text{-dev}}$, $K_{c\text{-mid}}$ and $K_{c\text{-end}}$ were lower by 28.80%, 28.21%, 26.62% and 32.27% and 26.19%, 21.27%, 19.22% and 24.74% than FAO adjusted values for 0.8 and 1.0 ET_c respectively. Prajapati *et al.* (2016) also found adjusted FAO K_c predict higher value than sensor-based K_c values at different irrigation regimes.

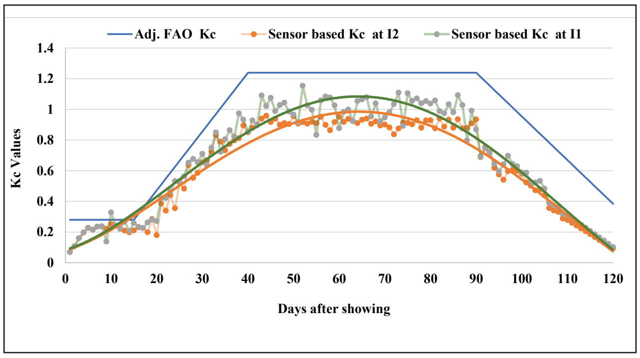

Figure 4: K_c curves for broad bed furrow

Comparison of K_c among All Treatments

Adjusted FAO K_c curve and sensor-based K_c curves at different irrigation regimes for different treatments are shown in Figure 2.

A considerable deviation in adjusted FAO and sensor-based K_c for treatment of Broad bed furrow with flatland treatments is observed. Broad bed furrow yielded lower $K_{c\text{-}ini}$, $K_{c\text{-}dev}$, $K_{c\text{-}mid}$ and $K_{c\text{-}end}$ 0.21 (7.26%), 0.59 (13.78%), 1.00 (7.27%) and 0.29 (9.48%) and 0.20 (8.43%), 0.55 (13.04%), 0.91 (8.18%) and 0.26 (9.48%) than flatland values at 1.0 ET_c and 0.8 ET_c respectively. Vieira *et al*. (2016) calculated K_c were 0.67, 0.67, 1.01, 1.03 and 0.42 for tillering, stem extension, heading, flowering and ripening, respectively.

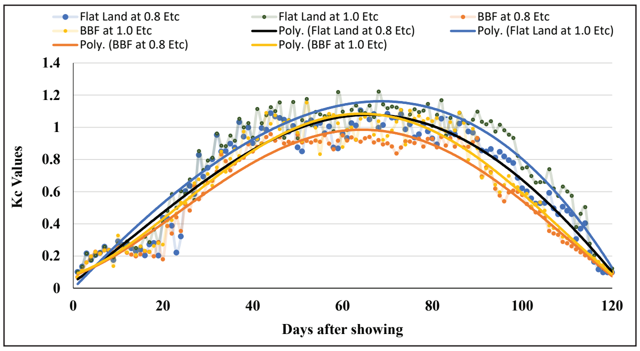

Figure 5: Sensor based Kc curves for different treatments

Irrigation Water Requirement

Irrigation water requirement was also estimated using Penman Monteith (P-M FAO-56) and using adjusted FAO K_c for respective treatments (Table 2).

P-M ET_c over estimated irrigation water by 106.18 mm (38.28%) and 49.23 mm (19.11%), then sensor-based irrigation under broad bed furrow at 1.0 ET_c and 0.8 ET_c respectively. Prajapati and Subbaiah (2018) observed saving of irrigation water by 34% in drip irrigation over then furrow irrigation. While irrigation water was overestimated 89.43 mm (30.40%) and 44.78 mm (17.09%) by P-M ET_c over than sensor-based irrigation under flatland configuration. Prajapati and Subbaiah (2019) also stated that overestimated adjusted FAO K_c values caused a loss of 78.1 mm and 66.5 mm of precious water in cotton at 1.0 IW/ET_c and 0.8 IW/ET_c respectively.

Laaboudi *et al*. (2015) observed crop coefficient values of wheat vary from 0.78 to 1.04 in sub humid region and from 0.50 to 1.35 in hyper arid region. Crop coefficient curves for different growth stage of wheat crop under different land configuration were developed at different irrigation levels.

Table 1: Adjusted FAO Kc and average sensor-based Kc for various treatments

Wheat Crop Stage			Initial Stage (1-15 days)	Development Stage (15-40 days)	Mid Stage (40-90 days)	End Stage (90-120 days)
BBF	Adj. FAO K_c		0.28	0.76	1.23	0.38
	Sensor based K_c	1.0 ET_c	0.21	0.59	1.00	0.29
		0.8 ET_c	0.20	0.55	0.91	0.26
Flat Land	Adj. FAO K_c	0.28	0.76	1.23	0.38	
	Sensor based K_c	1.0 ET_c	0.22	0.69	1.08	0.32
		0.8 ET_c	0.22	0.63	0.99	0.29

Table 2: Irrigation water requirement (mm) estimated by different approaches

Land Configuration	I_1		I_2	
	Sensor based ET_a	P-M ET_c	Sensor based ET_a	P-M ET_c
L_1	277.39	383.57	257.62	306.85
L_2	294.14	383.57	262.07	306.85

Conclusion

Two sets of K_c curves were developed, 6^{th} generalized K_c values published by FAO that were adjusted for local climate, and the sensor-based K_c curves as the ratio of measured ET_a to ET_o. A considerable deviation in adjusted FAO and sensor-based K_c values were observed. BBF yielded lower K_c values as compared to flatland. Bed geometry led reduction in crop canopy coverage and planting density wheat strongly influenced crop ET_c loss and K_c values as well (Choudhury *et al*., 2013). Inadequacy of information on K_c values of bed planted wheat across India and other parts of the world limited the comparison of the presently estimated K_c values of BBF land configuration. Crop coefficient values of wheat on conventional flat lands; however, differ considerably from those suggested by FAO for wheat crop. This unique crop establishment method *i.e.*, BBF system specific K_c estimation under semi-arid climate will certainly help in efficient management of water resources through precise irrigation scheduling for wheat crop planted in Junagadh region or elsewhere with similar environmental conditions.

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