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Determination of crop coefficients for wheat (*Triticum aestivum* L.) Under different land configuration and irrigation systems

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Abstract
An experiment was conducted at Research cum demonstration Farm, RTTC, Junagadh Agricultural University during year 2017-18 to determine crop coefficients of wheat (GW-366) under different land configurations (broad bed furrow L1 and flat land L2) and irrigation systems (drip irrigation S1 and surface irrigation S2) with two irrigation levels (1.0 ETc I1 and 0.8 ETc I2). Soil moisture sensors were installed to monitor daily fluctuations of soil moisture which were utilized to calculate actual crop evapotranspiration. Results revealed that adjusted FAO Kc predicts higher value than sensor based Kc values at both irrigation levels. Sensor based Kc-ini, Kc-dev, Kc-mid and Kc-end under flat land configuration with drip irrigation scheduled at 0.8 ETc were lower by 22.25%, 17.44%, 19.61% and 25.17% over adjusted FAO Kc-ini, Kc-dev, Kc-mid and Kc-end respectively and 51.35%, 30.42%, 16.81% and 28.80% over flat land configuration with surface irrigation at 1.0 ETc respectively. Broad bed furrow (BBF) land configuration with drip irrigation observed lower sensor based Kc-ini, Kc-dev, Kc-mid and Kc-end by 53.81%, 34.15%, 15.91% and 28.39% and 51.47%, 34.14%, 17.36% and 21.93% than flat land configuration with surface irrigation at 1.0 ETc and 0.8 ETc respectively. P-M ETc over estimated irrigation water by 106.18mm (38.28%) and 194.25mm (36.67%), 249.29mm (59.61%) and 89.43mm (30.40%), 49.23mm (19.11%) and 93.05mm (19.14%), and 153.54mm (40.36%) and 44.78mm (17.09%) than sensor based irrigation under L1S1, L2S2, L1S2 and L2S1 at I1 and I2 respectively. The results provide estimates of ET0, ETc and Kc for use in irrigation scheduling of wheat crop planted in Junagadh region or elsewhere with similar environmental conditions.

Keywords: Crop coefficient, land configuration, irrigation systems, wheat

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most important staple food grains of human race. Availability of irrigation water is the major limiting factor for improving wheat productivity in India. At present, more than 60 per cent of wheat area is under irrigated condition, of which about 50 per cent receive only one or two irrigations (Chouhan and Yadav, 2012) [4]. The reason for the low irrigation coverage is the predominant use of flood irrigation with low water use efficiency (35-40%). The economic constraint of the traditional irrigation methods, which cause extremely large time fluctuation in the soil-water potential (Bresler and Yaron, 1972) [2], has been partly removed by the development of drip irrigation systems capable of delivering water to the soil in small quantities as often as desired with no additional cost (Rawlins, 1973) [8]. Land configuration plays a major important role in minimizing soil erosion and improving water use efficiency of field crops. Land configuration increases water use efficiency (Chiroma *et al.* 2008) [3] 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. In irrigated areas, a reasonable irrigation scheduling under different land configuration is a key factor to help farmers increase crop yield and save water regarding limited water resources. Determination of crop evapotranspiration (ET_c) is the most fundamental requirement for proper scheduling of irrigation (Jaspinder Kaur *et al.*, 2017) [7]. Experimentally, determination of crop coefficient (K_c) is multiplied by reference crop evapotranspiration (ET_0) to compute ET_c (Chowdhary and Shrivastava, 2010) [5]. Crop coefficient values taken from literature may provide a practical guideline for scheduling irrigation, but considerable error in estimating crop water requirement can occur due to their empirical nature (Jagtap and Jones 1989) [6]. Therefore, it becomes necessary to make corrections in crop coefficient values as per local conditions. Since local development of K_c is a difficult task, most practitioners rely on the published values.

Till date, no such efforts were made in estimation of K_c values for wheat under different land configuration, irrigation system and irrigation levels. Realizing the necessity, the study was undertaken to determine crop coefficients for different growth stage of wheat crop under different land configuration and irrigation systems using soil moisture sensors installed at different depths.

2. Materials and Methods

The field experiment was conducted at the Research cum Demonstration farm of Centre of Excellence on Soil and Water Management, Research Testing and Training Centre, Junagadh Agricultural University, during rabi season of 2017-18 to evaluate the conjunctive impact of two land configurations; broad bed furrow (L1) and flat land (L2), two irrigation systems; drip irrigation (S1) and surface irrigation (S2) and two irrigation levels; 1.0 ETc (I1) and 0.8 ETc (I2) on productivity of wheat (GW-366). Each of eight treatments was replicated thrice. Large plot design was adopted and data were analysed using factorial randomized block design. Plot size were kept as 6.2 m × 15 m. Soil is sandy loam (1-1.5m depth) with volumetric water content at field capacity and permanent wilting point determined at 39 and 15 per cent, 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) with provision of irrigation channels was made with tropiculture. Sowing of wheat seed was done on 3rd week of November by tractor mounted seed cum fertilizer drill Seed rate was maintained as 100 kg/ha with 22.5 cm row to row spacing. Recommended dose of fertilizer N: P: K (120: 60: 60) was given to wheat crop. First 60 kg nitrogen and whole quantity of phosphorus and potash were applied as basal dose. Another 60 kg nitrogen were applied 21 days after sowing. The crop was kept free from weeds for proper growth and development of plants. Spraying of pendimethalin 30% EC (Stomp) after common surface irrigation to whole treatments to keep the weeds under check.

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 ETc and 0.8 ETc. The sensors were calibrated for local condition and moisture content calculated based on calibrated soil moisture characteristic curve.

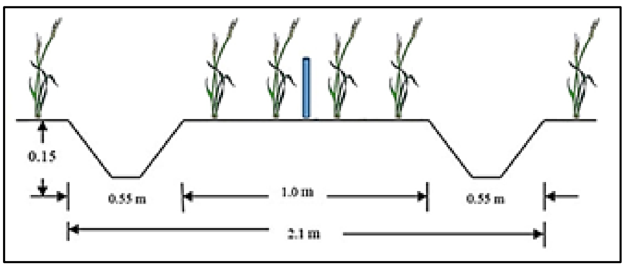

Fig 1: Dimensions of broad bed furrow

3. Tables, Figures and Equations

3.1 Determination of FAO K_c curves: Crop coefficient (Kc) is determined for

a) As per the FAO-56 approach

b) Based on moisture sensor observations

a) Kc as per FAO-56

Crop coefficient for the initial stage (Kc ini) calculated using procedure suggested by FAO-56 (Allen *et al*. 1998). FAO also suggested adjustment for partial wetting by irrigation, in which, the fraction of the surface wetted, fw only 0.4 for trickle irrigation, for furrow irrigation 0.6 and for border 1.0 (Table 1, FAO-56)

$$K_{c\ ini} = f_w \times K_{c\ ini\ (tab\ fig)} \qquad (1)$$

Where,
fw = fraction of surfaced wetted by irrigation or rain (0-1);
$K_{c\ ini\ (tab\ fig)}$ = value for $K_{c\ ini}$ from Table 2 (FAO 56).

The average infiltration depth, expressed in millimetres over the entire field surface, should be divided by f_w to represent the true infiltrated depth of water for the part of the surface that is wetted (Fig. 1, 3, FAO 56):

$$I_w = \frac{I}{f_w} \qquad (2)$$

Where,
I_w = irrigation depth for the part of the surface that is wetted (mm),
f_w = fraction of surface wetted by irrigation,
I = the irrigation depth for the field (mm)

$$K_{c\ mid} = K_{c\ mid\ (tab)} + [0.04\ (u_2 - 2) - 0.004\ (RH_{min} - 45)]\ \left(\frac{h}{3}\right)^{0.3} \qquad (3)$$

$$K_{c\ end} = K_{c\ end\ (tab)} + [0.04\ (u_2 - 2) - 0.004\ (RH_{min} - 45)]\ \left(\frac{h}{3}\right)^{0.3} \qquad (4)$$

Where, $K_{c\ mid\ (tab)}$ = value of $K_{c\ mid}$ taken from Table 2, u_2 = mean value of daily wind speed at 2 m height over grass during the mid-season growth stage (m/s), for
$1\ m/s \le u_2 \le 6\ m/s$, RH_{min}= mean value of daily minimum relative humidity. h = mean plant height during the mid-season.

b) K_c based on moisture sensor observations

Actual evapotranspiration ETa (ETc) was calculated using soil moisture sensors with data loggers installed at different depth in different treatment for getting soil moisture periodically. It was calculated using following equation

$$ET_a = 1000 \times (M_1 - M_2) \times Z_r \times BD \qquad (5)$$

Where,
ET_a = Actual evapotranspiration (mm),
M_1 = Moisture content after irrigation ($m^3\ m^{-3}$),
M_2 = Moisture content before irrigation ($m^3\ m^{-3}$), Z_r = Rooting depth (m),
BD = Bulk density (g/cc)

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

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (6)$$

Where
ET_0 = 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 = actualvapour pressure (kPa),
$e_s - e_a$ = saturation vapour pressure deficit (kPa),
Δ = slope vapour pressure curve (kPa/°C),
γ = psychrometric constant [kPa/°C].

The sensor-based Kc values were developed as

$$K_c = {ET_a}/{ET_0} \quad (7)$$

Sensor based K_c curve was compared with K_c curves developed as per FAO 56 for wheat under different land configuration and irrigation system with different irrigation levels. (1.0 ET_c and 0.8 ET_c)
Irrigation was given based on the equation (5) considering the application efficiency of drip irrigation 90 per cent at 1.0 ET_c and 0.8 ET_c.

Table 1: Irrigation water requirement estimated by different approaches

Land Configuration		L_1		L_2	
Irrigation System		S_1	S_2	S_1	S_2
I_1	Sensor based ETa	277.39	418.22	294.14	529.71
	P-M ETc	383.57	667.51	383.57	723.96
I_2	Sensor based ETa	257.62	380.47	262.07	486.12
	P-M ETc	306.85	534.01	306.85	579.17

4. 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 $kmhr^{-1}$ to 12.8 $kmhr^{-1}$, 0.8 hr to 10.6 hr, 0.6 mm to 10.7 mm, respectively.

Table 2: 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)
L_1S_1	Adj. FAO K_c		0.28	0.76	1.23	0.38
	Sensor based K_c	I_1	0.21	0.59	1.00	0.29
		I_2	0.20	0.55	0.91	0.26
L_2S_1	Adj. FAO K_c		0.28	0.76	1.23	0.38
	Sensor based K_c	I_1	0.22	0.69	1.08	0.32
		I_2	0.22	0.63	0.99	0.29
L_1S_2	Adj. FAO K_c		0.42	0.83	1.23	0.38
	Sensor based K_c	I_1	0.37	0.77	1.17	0.36
		I_2	0.33	0.71	1.07	0.33
L_2S_2	Adj. FAO K_c		0.70	0.97	1.23	0.38
	Sensor based K_c	I_1	0.45	0.90	1.19	0.40
		I_2	0.41	0.83	1.10	0.33

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.

4.1 Determination of K_c curves

4.1.1 K_c as per FAO-56: The crop coefficient for the initial growth ($K_{c\ ini}$) stage derived from equation 1 was found as 0.28 for drip irrigated, 0.42 for furrow irrigated and 0.7 for flood irrigated wheat, $K_{c\ mid}$ and $K_{c\ end}$ values were adjusted as per eq. 2 and 3 were 1.23 and 0.38 respectively. Corrected K_c values as per FAO 56 for different irrigation methods drip irrigation, furrow irrigation and flood irrigation are depicted in Fig. 1.

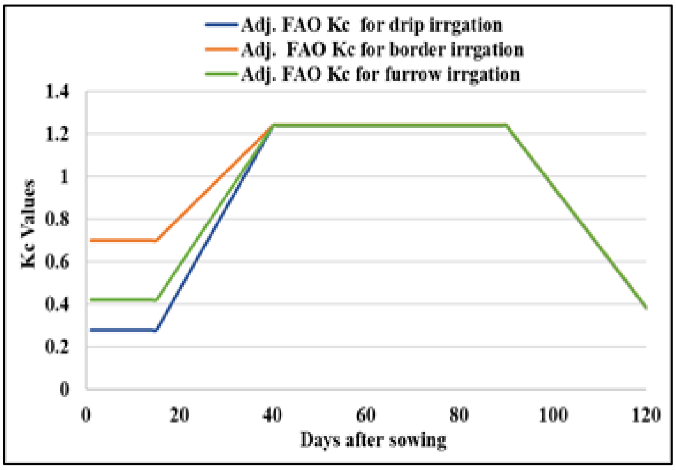

Fig 2: Adjusted FAO K_c curves for different irrigation systems

4.1.2 Kc 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 Kc curves were compared with the adjusted FAO K_c curves for different land configuration and irrigation systems at different irrigation levels. Adjusted FAO K_c remain same for a particular combination of land configuration and irrigation system at both irrigation levels.

Sensor based K_{c-ini}, K_{c-dev}, K_{c-mid} and K_{c-end} were lower by 20.40%, 11.71%, 12.89% and 16.86% and 22.25%, 17.44%, 19.61% and 25.17% than adjusted FAO K_c under flat land configuration with drip irrigation at 1.0 ET_c and 0.8 ET_c respectively.

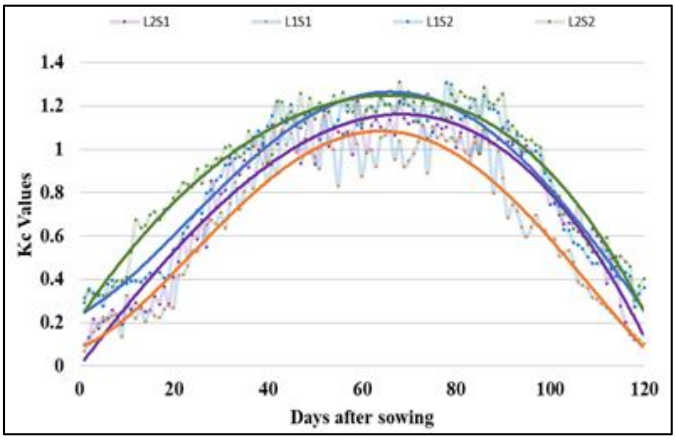

Fig 3: Sensor based K_c curves for different treatment at 1.0 Et_c

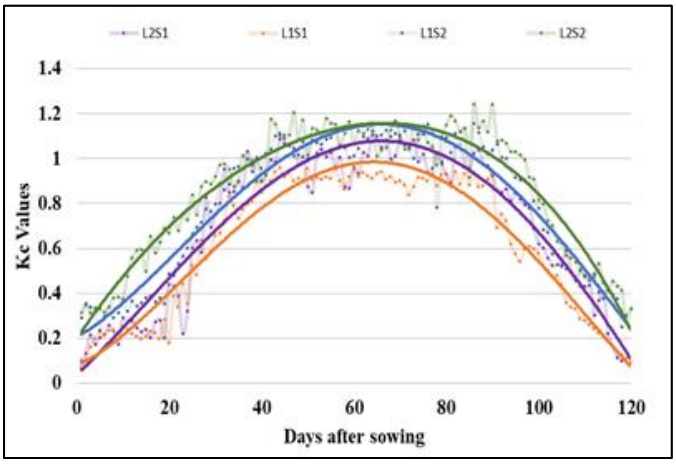

Fig 4: Sensor based K_c curves for different treatment at 0.8 Et_c

Whereas Sensor based K_{c-ini}, K_{c-dev}, K_{c-mid} and K_{c-end} were lower by 26.19%, 21.27%, 19.22% and 24.74% and 28.80%, 28.21%, 26.62% and 32.27% than adjusted FAO K_c under broad bed furrow land configuration with drip irrigation at 1.0 ET_c and 0.8 ET_c respectively.

Sensor based K_{c-ini}, K_{c-dev}, K_{c-mid} and K_{c-end} were lower by 36.08%, 7.06%, 3.50% and -5.10% and 41.32%, 14.62%, 10.68% and 13.24% than adjusted FAO K_c under flat land configuration with surface irrigation system at 1.0 ET_c and 0.8 ET_c respectively. whereas sensor based K_{c-ini}, K_{c-dev}, K_{c-mid} and K_{c-end} were lower by 13.00%, 7.31%, 4.25% and 5.41% and 21.92%, 14.36%, 13.29% and 13.71% adjusted FAO K_c under broad bed furrow land configuration with surface irrigation system at 1.0 ET_c and 0.8 ET_c respectively.

A considerable deviation in adjusted FAO and sensor based K_c for treatment of L_1S_1 with other treatments is observed. L_1S_1 yielded lower K_{c-ini}, K_{c-dev}, K_{c-mid} and K_{c-end} 7.26%, 13.78%, 7.27% and 9.48% and 8.43%, 13. 04%, 8.18% and 9.48% than L_2S_1values at I_1 and I_2 respectively. L_1S_1 were lower by 43.44%, 22.83%, 14.48% and 20.44% than sensor based K_c of L_1S_2 for K_{c-ini}, K_{c-dev}, K_{c-mid} and K_{c-end} at I_1. Whereas, 39.21%, 23.25%, 15.05% and 21.50% then sensor based K_c values of L_1S_2 K_{c-ini}, K_{c-dev}, K_{c-mid} and K_{c-end} respectively at I_2. L_1S_1 were lower by 53.81%, 34.15%, 15.91% and 28.39% than sensor based K_c of L2S2 for K_{c-ini}, K_{c-dev}, K_{c-mid} and K_{c-end} at I_1. Whereas, 51.47%, 34.14%, 17.36% and 21.93% then sensor based K_c values of L_2S_2 K_{c-ini}, K_{c-dev}, K_{c-mid} and K_{c-end} respectively at I_2. L_1S_1 has smaller deviation in sensor based K_c at different stages with L_2S_1 at I_1 and I_2. Much more deviation seen for sensor based K_c between L_1S_1 and L_2S_2 at I_1 and I_2.

Irrigation water demand was also estimated using P-M ET_c method using adjusted FAO K_c for respective treatments and compared with water requirement estimated using sensor based ET_a values depicted in Table 2. P-M ET_c over estimated irrigation water than sensor based ET_c at all irrigation levels. P-M ET_c over estimated irrigation water by 106.18mm (38.28%) and 194.25mm (36.67%), 249.29mm (59.61%) and 89.43mm (30.40%), 49.23mm (19.11%) and 93.05mm (19.14%), and 153.54mm (40.36%) and 44.78mm (17.09%) than sensor based irrigation under L_1S_1, L_2S_2, L_1S_2 and L_2S_1 at I_1 and I_2 respectively.

5. Conclusions

Crop coefficient curves for different growth stage of wheat crop under different land configuration and irrigation systems was developed at different irrigation levels. Two sets of K_c curves were developed, the 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 with drip irrigation yielded lower K_c values as compared to other treatments but has smaller deviation with flat land with drip irrigation. Bed geometry led reduction in crop canopy coverage and planting density wheat strongly influenced crop ET_c loss and K_c values as well. 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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