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Crop Coefficient for Biodegradable and Wheat Mulched Bt. Cotton Under Variable Irrigation Regimes

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Abstract: *Bt. Cotton is one of the important cash crops being adopted by the farmers of Gujarat. Lack of knowledge on irrigation scheduling for mulched cotton and poor design of the drip system are the major constraints for reduced water productivity. Irrigation scheduling based on the fraction of evapotranspiration require a priori information of temporal synchronization of crop coefficient. No study came across by the authors for developing Bt. cotton crop coefficient operated at various drip irrigation regimes under mulched (biodegradable and wheat straw) conditions. An experiment was undertaken in this direction consecutively for two years (2013-14 and 2014-15) to address this issue. Diurnal and temporal variation of soil moisture with depth was monitored using soil moisture sensors at two irrigation regimes (1.0 and 0.8 IW/*ET_c*). Drip with no mulch was accounted towards control treatment. Split plot design was used. The treatments were replicated thrice. Crop coefficient was developed using the local corrected procedure for mulch condition outlined by FAO 54 and compared with the actual crop coefficient determined using diurnal, temporal and profile variated soil moisture values observed through moisture sensors. Adjusted FAO* K_c *predict higher value than sensor based* K_c *values at both irrigation regimes. Biodegradable plastic mulch reduced* $K_{c-ini,}$ K_{c-dev}, K_{c-mid}, K_{c-end} *value by 5.64%, 9.82%, 6.43%, 0.56% and 71.26%, 29.49%, 14.23%, 9.50% and 66.54% over wheat straw mulch and control respectively at 1.0 IW/*$ET_{c.}$ *whereas, it was reduced* $K_{c-ini,}$ K_{c-dev}, K_{c-mid}, *value by 2%, 5.4%, 10.89% and 66.54%, 16.11% 12.21% over wheat straw mulch and control respectively 0.8 IW/*ET_c *respectively. Overestimated adjusted FAO* K_c *values caused a loss of 78.13mm and 66.54mm of precious water at 1.0 IW/*ET_c *and 0.8 IW/*ET_c *respectively. This study admonishes blind adoption of published FAO* K_c *curves, for mulch conditions.*

Keywords: biodegradable mulch, crop coefficient, drip irrigation, irrigation regimes.

INTRODUCTION

Cotton is an important commercial crop in the world. Indian economy continues to receive great support from the most important commercial fibre crop. Paucity of quantity and quality groundwater reserves, high evaporative conditions, deficient rainfall condition, enhanced pest and insect damage due to climate change are some of the detrimental factors for poor cotton yields in the state. Combined influence of carbon and water cycle is adding another dimension to the improved productivity of this cash crops. To combat the abiotic and biotic stress on the crop, farmers of this region are adopting drip irrigation with mulch in Bt. cotton on mass scale.

Major constraints for reducing the water productivity is lack of knowledge on irrigation scheduling for mulched cotton and poor design of the drip system. Determination of crop evapotranspiration (ET_c) is the most fundamental requirement for proper scheduling of irrigation [1]. Experimentally, determination of crop coefficient

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(K_c) is multiplied by evapotranspiration from reference vegetation (ET_o) to compute ET_c [2], or

$$ET = K_c \times ET_o$$

More recently, the FAO-56 Allen[3] promotes the more superior Penman-Monteith (P-M) combination equation. Tables of K_c values derived from field and lysimeter ET_c measurements are provided in literature [2,4,5,6,7]. The practical simplicity of using the K_c approach is indisputable, but the adoption of generalized K_c curves can lead to errors[8]. Since local development of K_c is a difficult task, most practitioners rely on the published values. No study is reported to develop crop coefficient for drip irrigated wheat straw and biodegradable mulch cotton subjected to variable irrigation regimes in this region. The objective of this study is to develop the K_c curves for drip irrigated mulched cotton using soil moisture sensors installed at different depth for the period 2013-2015. Sensor based K_c compared with generalized FAO K_c values adjusted for local climate and management.

MATERIALS AND METHODS

Experiment was conducted at Junagadh Agricultural University (21°30′ N, 70°27′ E and 77.5 above mean sea level) for two consecutive years during Kharif season of 2012-13 and 2013-14 to develop the K_c curves for drip irrigated wheat straw and biodegradable plastic mulched (20 micron) cotton (Hy-6, BG-II) with irrigation regimes; 1.0 IW/ET_c (I_1) and 0.8 IW/ET_c (I_2) along with no mulch. Soil is sandy loam (1-1.5m depth) with volumetric water content at field capacity and wilting point determined at 39 and 15% respectively. Two cotton seeds were sown at 2.5 cm depth directly through the holes made on the mulch film. Thinning as well as gap filling was done after germination of plants. The recommended package of agronomical practices was adopted. Recommended dose of fertilizer (160:0:120 NPK kg/ha) was applied. Fifty per cent N and K fertilizers was given as basal before spreading the mulching sheet. The remaining N and K was given as four equal splits at vegetative, bud formation, flowering and boll development stages was applied through drip irrigation. Irrigation water applied using heavy duty black colored LLDPE lateral line of 16 mm diameter × 2.5 kg/cm^2 with emitter discharge of 2 lph with spacing of 0.4m.

Determination of FAO K_c Curves

Crop coefficient is determined for (a) as per the FAO 56 approach (b) for a particular mulch as suggested by FAO 56 (c) for a particular mulch and for a particular irrigation interval as per the sensor based daily observations.

(a) **K_c for no mulch as per FAO 56 :** Crop coefficient for the initial stage ($K_{c\,ini}$) calculated using procedure suggested by FAO for a trickle irrigation system from the following figure given by FAO 56.

$$K_{c\,ini} = f_w \times k_{c\,ini\,(Tab\,Fig)} \quad (1)$$

Irrigation depth of water for the part of the surface wetted calculated as:

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

The crop coefficient of cotton crop as per FAO is 0.35 (using equation 4), 1.15-1.20 and 0.70-0.50 for $K_{c\,ini}$, $K_{c\,mid}$ and $K_{c\,end}$, respectively from Table 1 of FAO 56 for drip irrigated cotton

Table 1
Adjusted FAO K_c and average sensor based K_c for various treatments

	Biodegradable plastic mulch			*Wheat straw mulch*			*No mulch*		
	Adj. FAO	*Sensor based*		*Adj. FAO*	*Sensor based K_c*		*Adj. FAO*	*Sensor based K_c*	
Cotton crop stage	*K_c*	*I_1*	*I_2*	*K_c*	*I_1*	*I_2*	*K_c*	*I_1*	*I_2*
Initial stage (20-45 days)	0.10	0.091	0.088	0.10	0.097	0.090	0.35	0.319	0.264
Development stage (45-85days)	0.57	0.54	0.52	0.61	0.60	0.55	0.79	0.77	0.62
Mid stage (85-130 days)	1.04	0.91	0.73	1.13	0.97	0.82	1.22	1.06	0.86
End stage (130-180 days)	0.425	0.449	0.40	0.43	0.451	0.38	0.49	0.496	0.41

crop without mulch (control), The above values were corrected for non-standard conditions using FAO 56 procedure.

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

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

(b) **Crop coefficient for mulched cotton as per FAO 56 :** K_c values decrease by an average of 10-30% due to the 50-80% reduction in soil evaporation. The value for $K_{c\,ini}$ under mulch is often as low as 0.10 suggested by FAO 56. So the crop coefficient of cotton crop under mulching were reduced by 15% for $K_{c\,mid}$ and $K_{c\,end}$. Corrections for local conditions were followed as per equation 3 and 4.

Reduce the amount of soil water evaporation by about 5% for each 15% of soil surface that is effectively covered by an organic mulch as suggested by FAO 56. So, the crop coefficient of cotton crop under mulching were reduced by 10% for $K_{c\,mid}$ and $K_{c\,end}$. Corrections for local conditions as per given equation 3 and 4.

(c) **Actual Evapotranspiration of Cotton :** Actual evapotranspiration ET_a (ET_c) 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

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

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).

Irrigation was given based on the equation (1) considering the application efficiency of drip irrigation 90% at 0.8 IW/ET_c and 1.0 IW/ET_c. The rooting depth of Bt. Cotton was calculated using model developed by Fereres[9].

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

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (7)$$

Crop coefficient based on moisture sensor observations

Actual cotton crop evapotranspiration (ET_a) estimated using sensors under different treatments (equation 5) and reference evapotranspiration (ET_o) estimated by FAO Penmen Monteith (equation 7), the sensor based K_c values were developed as

$$K_c = ET_a / ET_o \quad (8)$$

Sensor based K_c curve was compared with K_c curves developed as per FAO 56 for no mulch and with mulch conditions for different irrigation regimes (1.0 IW/ET_c and 0.8 IW/ET_c).

RESULTS AND DISCUSSION

$K_{c\,ini}$ for drip irrigated cotton without mulch for 2013-14 and 2014-15 was 0.35 as per equation 1. FAO 56 suggested $K_{c\,mid}$ and $K_{c\,end}$ values for drip irrigated cotton crop without mulch (control) as 1.20 and 0.50, respectively. The corrected $K_{c\,mid}$ and $K_{c\,end}$ for local conditions for 2013-14 and 2014-15 were 1.22 and 0.48 and 1.23 and 0.48 as per equation 3 and 4 respectively. FAO 56 suggested $K_{c\,ini}$, $K_{c\,mid}$ and $K_{c\,end}$ values for cotton crop under biodegradable plastic mulch was 0.1, 1.063 and 0.45, respectively. These values were corrected 0.1, 1.036 and 0.425 for local conditions as per the procedure suggested by FAO 56 using equation 3 and 4. K_c values of cotton for wheat straw mulch were estimated to be 0.1, 1.25 and 0.45 for $K_{c\,ini}$, $K_{c\,mid}$ and $K_{c\,end}$, respectively. The corrected values were 0.1, 1.125 and 0.43 for $K_{c\,ini}$, $K_{c\,mid}$ and $K_{c\,end}$, respectively.

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 mulches and irrigation regimes. Adjusted FAO K_c remain same for a

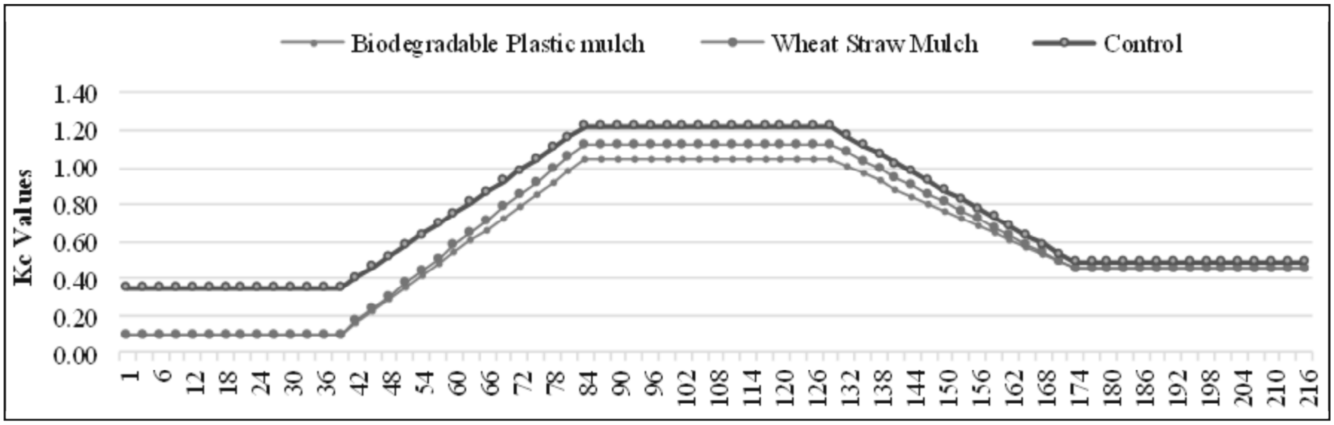

Figure 1: Adjusted FAO Crop coeffcient curves for mulch and no mulch conditions

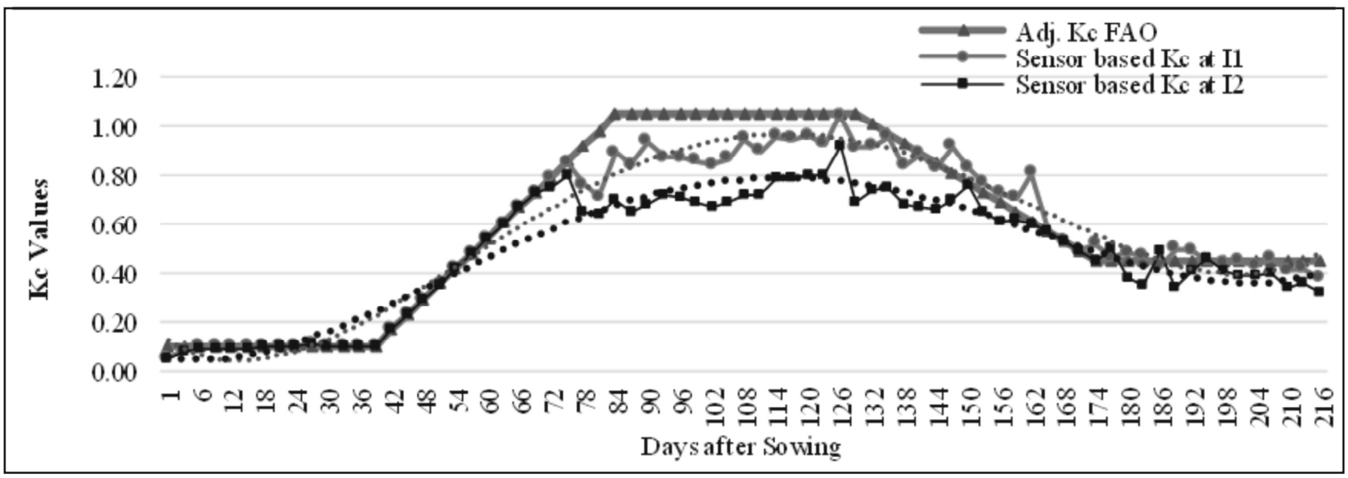

Figure 2: Pooled K_c Curves of Biodegradable Plastic Mulch

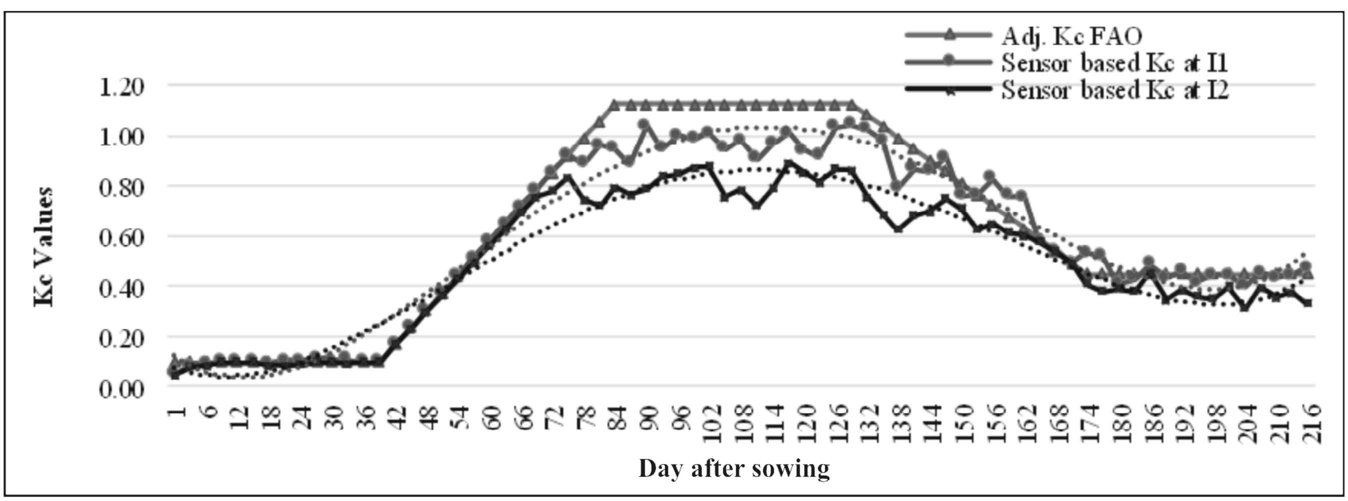

Figure 3: Pooled K_c Curves Wheat Straw Mulch

particular mulch at all irrigation regimes. Adjusted FAO K_c curves and sensor based K_c curves at different irrigation regimes for biodegradable plastic mulch, wheat straw mulch and control are shown in Figure 1, 2, 3 and 4.

The comparison of K_c curves for biodegradable plastic mulch, wheat straw mulch and control as per FAO K_c and sensor based K_c at I_2 and I_1 differed considerably during both years. Sensor based $K_{c\,ini,}$ $K_{c\text{-}dev,}$ $K_{c\text{-}mid}$ and $K_{c\text{-}end}$ were lower by 11.58%, 9.13%,

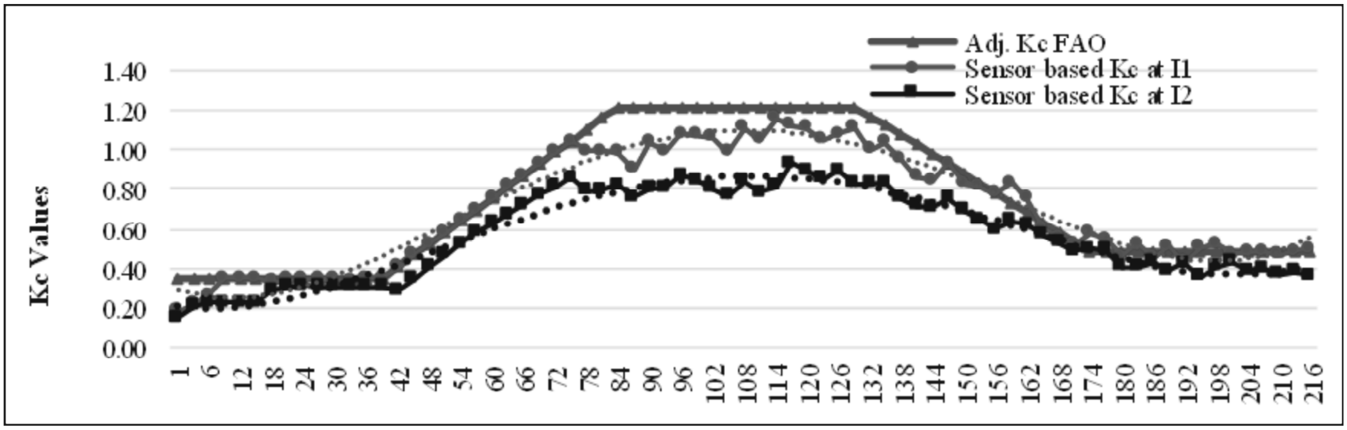

Figure 4: Pooled K_c Curves of Control

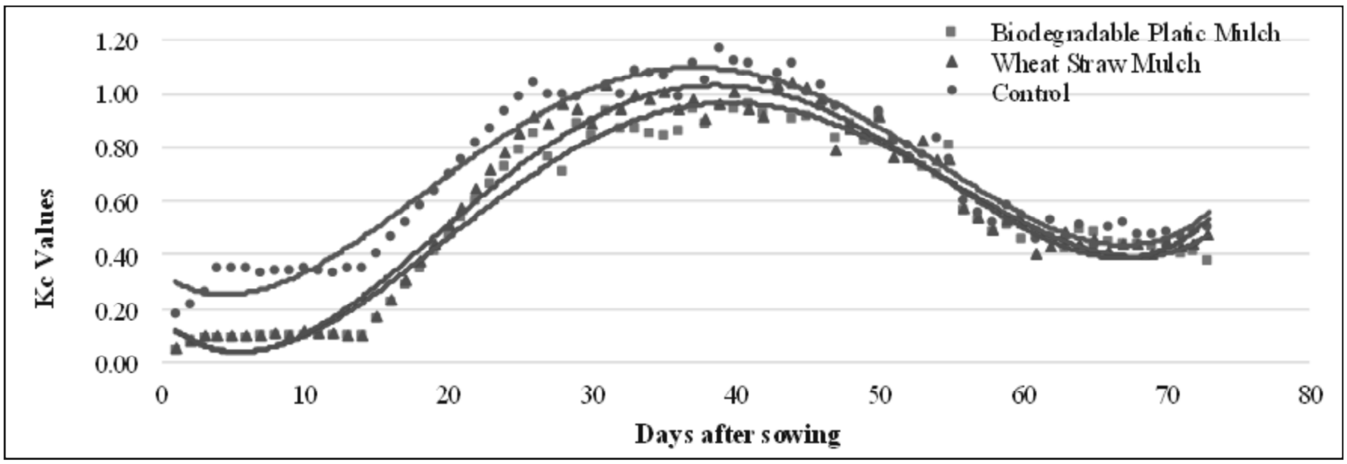

Figure 5: Pooled sensor based K_c Curves for different treatment at I_1

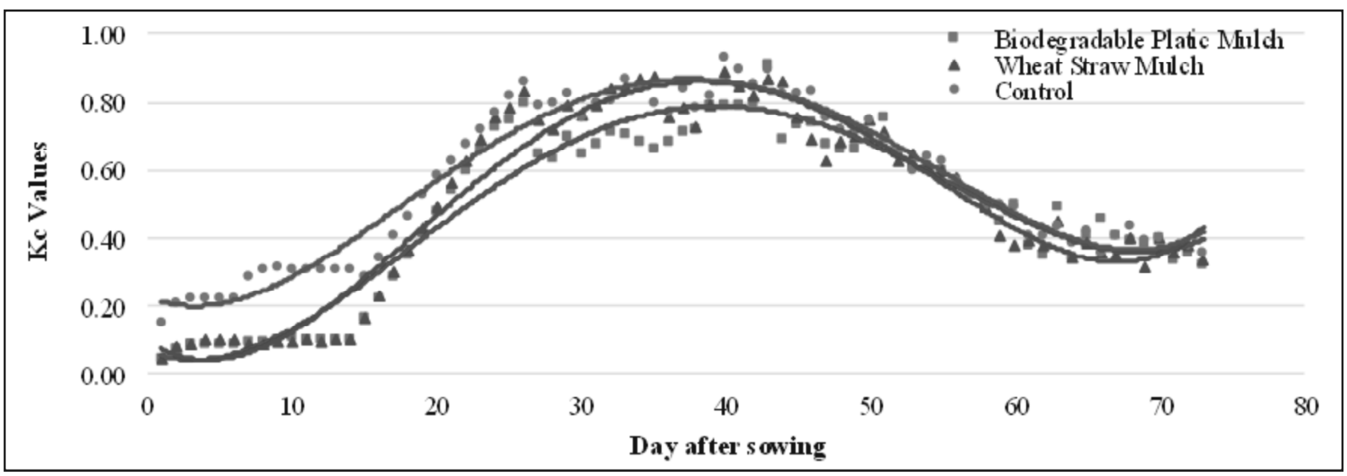

Figure 6: Pooled sensor based K_c Curves for different treatment at I_2

30.04% and 11.65% and 8.42%, 5.63%, 12.99% and 0.25% than FAO adjusted values for I_2 and $I_{1,}$ respectively for biodegradable plastic mulch and it were lower by 9.78%, 9.95%, 27.48% and 16.51 and 2.96%, 1.90%, 14.11% and -0.31% than FAO adjusted values for I_2 and $I_{1,}$ respectively for wheat straw mulch. Whereas, it were lower by 24.51%, 21.60%, 31.82% and 16.20% and 8.98%, 3.12%, 13.21% and –1.47% than FAO adjusted for I_2 and $I_{1,}$ respectively for control. Adjusted FAO K_c overestimated ET_c at all growth stages during two consecutive years. A considerable deviation in pooled adjusted FAO and

Table 2
Irrigation water requirement estimated by different approaches

	Irrigation water (mm)	
Treatments	*Sensor based ET_a*	*Pan ET_c*
Biodegradable plastic mulch		
I_1	280.31	333.96
I_2	231.67	267.17
Wheat straw mulch		
I_1	292.21	357.22
I_2	238.55	285.78
Control		
I_1	320.45	412.09
I_2	257.11	329.67

sensor based K_c for biodegradable plastic mulch over control is observed in Table 1 and Figure 4 and 5. It was lower by 71.26%, 29.49%, 14.23% and 9.50% and 66.54%, 16.11%, 12.21% and 2.94% than sensor based K_c of no mulch $K_{c\text{-}ini}$, $K_{c\text{-}dev}$, $K_{c\text{-}mid}$ and $K_{c\text{-}end}$, respectively at I_1 and I_2. Whereas, it were 5.64%, 9.82%, 6.43% and 0.56% and 2%, 5.4%, 10.89% and –5.82% than sensor based K_c of wheat straw mulch $K_{c\text{-}ini}$, $K_{c\text{-}dev}$, $K_{c\text{-}mid}$ and $K_{c\text{-}end}$, respectively at I_1 and I_2. Farahani *et al.* (2008) also reported that during the mid-season stage, the adjusted FAO K_c was 24% higher than the locally developed K_c.

Irrigation water demand was also estimated using Pan ET 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. It indicated that cumulative irrigation water estimated by Pan ET_c approach was higher of 16.06% and 13.28% than sensor based irrigation at I_1 and I_2 respectively.

CONCLUSIONS

Crop coefficient curves for biodegradable plastic and wheat straw mulched cotton was developed for two irrigation regimes. 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 for the two years. Sensor based K_c curves not only differed among the two years, but also from the adjusted FAO K_c values.

Biodegradable plastic mulch reduced $K_{c\text{-}ini}$, $K_{c\text{-}dev}$, $K_{c\text{-}mid}$ and $K_{c\text{-}end}$ values by 72.26%, 29.49%, 14.23% and 9.50% and 66.54%, 16.11%, 12.21% and 2.94% over control and it were 5.64%, 9.82%, 6.43% and 0.56% and 2%, 5.4%, 10.89% and –5.82% than sensor based K_c of wheat straw mulch at 1.0 IW/ET_c and 0.8 IW/ET_c respectively, which appear to be the most susceptible to local variations presumably because of lower canopy cover and higher soil evaporation following wetting. The use of the adjusted FAO K_c values overestimated seasonal crop evapotranspiration thus cautioning against their blind application without some verification.

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