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Crop coefficients of Bt. cotton under variable moisture regimes and mulching

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ABSTRACT

An experiment was undertaken for two years (2013-14 and 2014-15) on sandy loam soils of Junagadh (21°30' N, 70°27' E) to determine crop coefficients of Bt. cotton under three mulch treatments (M_1- silver black plastic mulch, M_2- biodegradable plastic mulch, M_3- wheat straw mulch and C - control) with two irrigation regimes (I_1- 1.0 IW/ET_c, I_2-0.8 IW/ET_c). Actual evapotranspiration was estimated using soil moisture sensors. Results revealed that adjusted FAO K_c predicts higher value than sensor based K_c values at both irrigation regimes. Silver black plastic mulch recorded lower crop coefficient values at all growth stage of Bt. cotton compared to biodegradable plastic mulch, wheat straw mulch and control. Sensor based $K_{c\ ini}$ and $K_{c\text{-}dev}$values of silver black plastic mulch observed 72.2, 29.0 and 66.9 and 14.8 per cent lower than control at 1.0 IW/ET_c and 0.8 IW/ET_c respectively. Overestimated adjusted FAO K_c values caused a loss of 78.1mm and 66.5mm 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 : Silver black plastic mulch, Biodegradable mulch, Crop coefficient, Drip irrigation andIrrigation regimes

Indian economy continues to receive great support from the most important commercial fibre crop. Paucity of quantity and quality of groundwater reserves, high evaporative and deficient rainfall condition, enhanced pest and insect damage due to climate change are some of the detrimental factors for poor cotton yields in Gujarat state. Combined influence of carbon and water cycle is adding another dimension to the improved productivity. To combat the abiotic and biotic stress on the crop, farmers of this region are adopting drip irrigation with organic and inorganic mulches in Bt. cotton on mass scale (Mariani and Ferrante, 2017). Major constraints for reducing the water productivity are lack of knowledge on irrigation scheduling for mulched cotton and poor design of the drip system (Hajare *et al.*, 2008 and Rajendra *et al.,* 2012).Determination of crop evapotranspiration (ET_c) is the most fundamental requirement for proper scheduling of irrigation Jaspinder Kaur *et al.*, 2017). Experimentally, determination of crop coefficient (K_c) is multiplied by reference crop evapotranspiration (ET_o) to compute ET_c (Chowdhary and Shrivastava, 2010).

The FAO-56 promotes Penman-Monteith (P-M) combination equation which requires data of temperature, relative humidity, wind speed, and solar radiation. This data demand is the main constraint on its use in locations where climate data are limited (Rahimikhoob, *et al.,* 2012). Tables of K_c values derived from field and lysimeter ET_c measurements are provided in literature. The practical simplicity of using the K_c approach is indisputable, but the adoption of generalized K_c curves can lead to errors. 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 silver black plastic mulch, biodegradable plastic mulch and wheat straw mulch cotton subjected to variable irrigation regimes in this region. Therefore, the study was undertaken to develop the K_c curves for drip irrigated mulched cotton using soil moisture sensors installed at different depths.

MATERIALS AND METHODS

The field 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 2013-14 and 2014-15.The experiment was laid out in split plot design with main plot treatments of mulches (i.e. Silver black plastic mulch (M_1), biodegradable plastic mulch (20 micron) (M_2) and wheat straw mulched(M_3) cotton (Hy-6, BG-II) and sub-treatments of irrigation regimes;(i.e. 1.0 IW/ETc (I_1) and 0.8 IW/ET_c (I_2) along with no mulch (C). 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.Two cotton seeds were sown at 2.5cm 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^{-1}) 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 different phonological stages (i.e. vegetative, bud formation, flowering and boll development) was applied through drip irrigation. Irrigation water were applied by using heavy duty black colored LLDPE lateral line of 1.6 cm diameter @ 2.5 kgcm^{-2}with emitter/dripper discharge rate of 2 lph alongwith dripper spacing of 40 cm.

Determination of FAO K_c curves

Crop coefficient (K_c) is determined for a) as per the FAO-56 approach b) for a particular mulch as suggested by FAO-56 and 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 ($K_{c\text{-}ini}$) calculated using procedure suggested by FAO for a trickle irrigation system from the following figure given by FAO-56 (Allen *et al.* 1998).

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

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 1), 1.15-1.20 and 0.70-0.50 for $K_{c\text{-}ini}$, $K_{c\text{-}mid}$ and $K_{c\text{-}end}$, respectively from Table 12 of FAO 56 for drip irrigated cotton 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) K_c for mulched cotton as per FAO-56

K_c values decrease by an average of 10-30 per cent due to the 50-80 per cent reduction in soil evaporation. The value for $K_{c\text{-}ini}$ 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 per cent for $K_{c\text{-}mid}$ and $K_{c\text{-}end}$. Corrections for local conditions were followed as per equation 3 and 4.

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

c) Crop coefficient based on moisture sensor observations

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}), Zr = 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 is reference evapotranspiration (mm day^{-1}), *Rn* is net radiation at the crop surface (MJ m^{-2} day^{-1}), *G* is soil heat flux density (MJ m^{-2} day^{-1}), *T* is mean daily air temperature at 2 m height (°C), u_2 is wind speed at 2 m height (m s^{-1}), *es* is saturation vapour pressure (kPa), *ea* is actual vapour pressure (kPa), (*es* - *ea*) is saturation vapour pressure deficit (kPa), Δ is slope vapour pressure curve (kPa °C^{-1}), and ϒ is Psychrometric constant (kPa °C^{-1}).

The sensor based K_c values were developed as

$$K_c = ET_a / ET_o \quad (7)$$

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).

Irrigation was given based on the equation (5) considering the application efficiency of drip irrigation 90 per cent at 1.0 IW/ET_c and 0.8 IW/ET_c.

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

Cotton crop stage	M_1			M_2			M_3			C			CD (0.05)		
	Adj. FAO K_c	Sensor based K_c		Adj. FAO K_c	Sensor based K_c		Adj. FAO K_c	Sensor based K_c		Adj. FAO K_c	Sensor based K_c				
		I_1	I_2		I_1	I_2		I_1	I_2		I_1	I_2	M	I	M x I
Initial stage (20-45 days)	0.10	0.08	0.09	0.10	0.09	0.08	0.10	0.09	0.09	0.35	0.32	0.26	0.081	0.015	0.0074
Development stage (45-85days)	0.57	0.54	0.53	0.57	0.54	0.52	0.61	0.60	0.55	0.79	0.77	0.62	0.061	0.043	0.0213
Mid stage (85-130 days)	1.04	0.89	0.75	1.04	0.91	0.73	1.13	0.97	0.82	1.22	1.06	0.86	0.054	0.090	0.042
End stage (130-180 days)	0.43	0.44	0.37	0.43	0.45	0.40	0.43	0.45	0.38	0.49	0.45	0.41	0.016	0.037	0.017

Table 2: Irrigation water requirement estimated by different approaches

Treatments	Irrigation water (mm)	
	Sensor based ET_a	Pan ET_c
M_1		
I_1	270.9	335.6
I_2	227.6	268.5
M_2		
I_1	280.3	334.0
I_2	231.7	267.2
M_3		
I_1	292.2	357.2
I_2	238.6	285.8
C		
I_1	320.4	412.1
I_2	257.1	329.7
CD(0.05)		
M	13.8	10.4
I	28.1	55.7
MxI	12.9	27.9

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, relative humidity, wind speed, bright sun shine hours and pan evaporation were from 29.5 to 39.4 °C, 10 to 26.7 °C, 51 to 88 per cent, 2.1 to 10.1 $kmhr^{-1}$, 4.2 to 13.4 hours and 3.6 to 10.7 mm, respectively. The average annual rainfall and evaporation is 852.4mm and 2482mm, respectively. During the period of experiments (June to January), the minimum and maximum pan evaporation, temperature and relative humidity were observed as 0.0 mm and 10.90mm, 7.4 °C and 39.50°C and 17.50 per cent and 99.0 per cent, respectively. The weather parameters were more or less congenial for favourable growth of cotton under irrigated condition during both years.

Determination of K_c curves

K_c for no mulch : $K_{c\,ini}$ for drip irrigated cotton without mulch

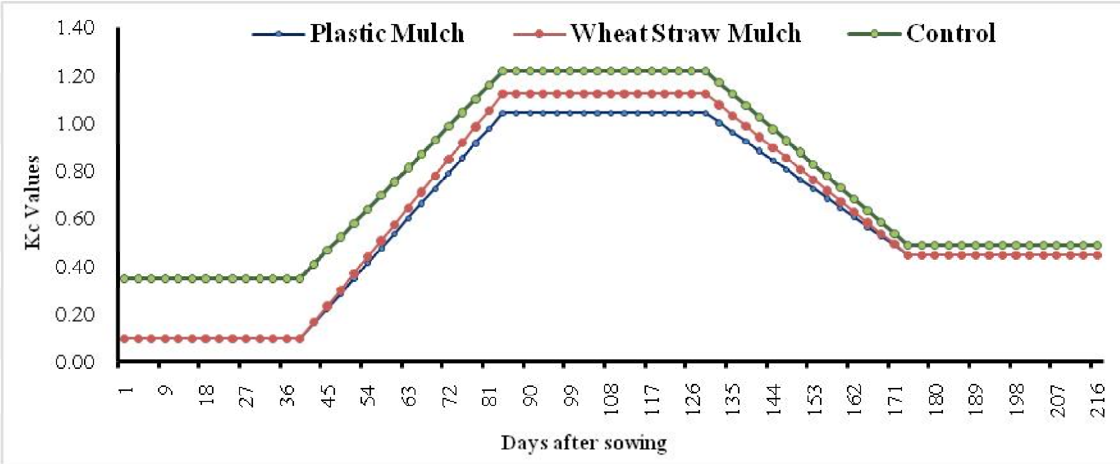

Fig. 1: Adjusted FAO Crop coefficient curves for mulch and no mulch conditions

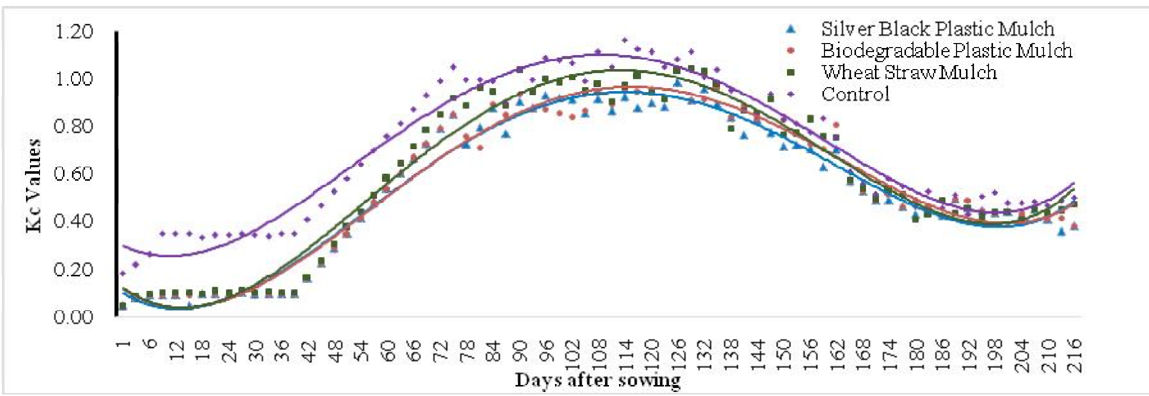

Fig. 2: Pooled sensor based K_c curves for different treatment at 1.0 IW/ET_c

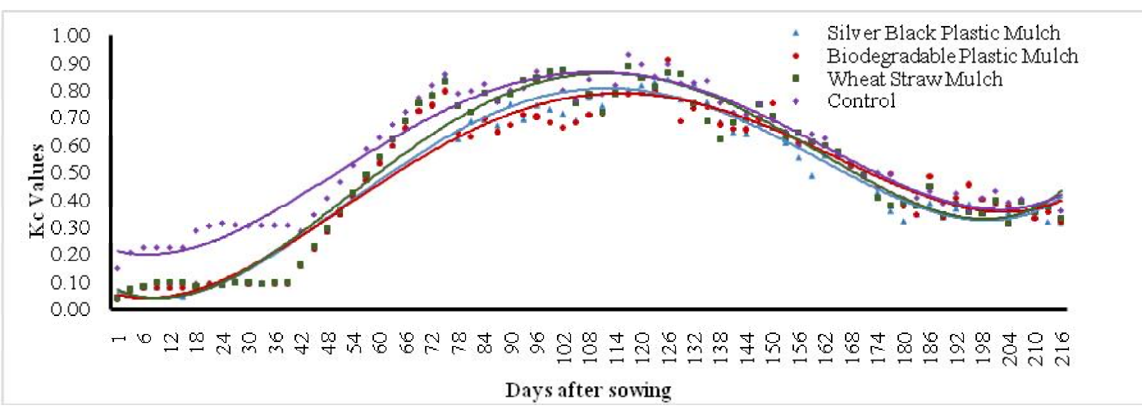

Fig. 3: Pooled sensor based K_c curves for different treatment at 0.8 IW/ET_c

for 2013-14 and 2014-15 was 0.35 as per equation 1. FAO 56 suggested $K_{c\,mid}$ and K_{cend} values for drip irrigated cotton crop without mulch (Control) as 1.20 and 0.50, respectively. The corrected $K_{c\,mid}$ and K_{cend} 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.

K_c for mulched cotton : FAO-56 suggested $K_{c\text{-}ini}$, $K_{c\text{-}mid}$ and $K_{c\text{-}end}$ values for cotton crop under plastic mulch (M_1 and M_2) 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 M_3 were estimated to be 0.1, 1.25 and 0.45 for $K_{c\text{-}ini}$, $K_{c\text{-}mid}$ and $K_{c\text{-}end,}$ respectively and corrected values were 0.1, 1.13 and 0.43 for $K_{c\text{-}ini}$, $K_{c\text{-}mid}$ and $K_{c\text{-}end,}$ respectively.

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 mulches and irrigation regimes. Adjusted FAO K_c remain same for a particular mulch at all irrigation regimes (Fig. 1).

The comparison of K_c curves for M_1, M_2, M_3 and C 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 at mid stage deviated maximum compared to FAO adjusted K_c. Sensor based $K_{c\text{-mid}}$ at M_1, M_2, M_3 and C observed 27.6 per cent, 30.0 per cent, 27.4 per cent and 31.8 per cent lower than adjusted FAO K_c at I_1. Adjusted FAO K_c overestimated ET_c at all growth stages during two consecutive years.A sensor based K_c curves not only differed considerably among the two years but were also different than adjusted FAO K_c values (Table 1). Significant difference was observed among different treatments under mulch and irrigation as well as in interaction also. M_1 yielded lower K_c values at all growth stages as compared to M_3 and Control, whereas, $K_{c\text{-ini}}$, $K_{c\text{-dev}}$ and $K_{c\text{-mid}}$ of M_1 was at par with M_2 at both irrigation regimes. Control treatments yielded 72.2 per cent and 66.9 per cent higher K_c at initial stage as compared to M_1 at I_1 and I_2 respectively (Fig. 2 and 3). Farahani *et al.,* (2008) also reported that during the mid-season stage, the adjusted FAO K_c was 24 per cent 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 16.1 per cent and 13.3 per cent than sensor based irrigation at I_1 and I_2 respectively (Prajapati and Subbaiah, 2018).

CONCLUSIONS

Crop coefficient curves for silver black plastic mulch, 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. Silver black plastic mulch has smaller deviation in sensor based K_c at different stages with biodegradable plastic mulch at 0.8 IW/ET_c and 1.0 IW/ET_c. Much more deviation seen for sensors based K_c between Silver black plastic mulch and Control at 1.0 IW/ET_c and 0.8 IW/ET_c. Silver black plastic mulch observed 72.2, 29.0 and 66.9 and 14.8 per cent, lower over control for $K_{c\text{ ini}}$, $K_{c\text{-dev}}$ stage at 1.0 IW/ET_c and 0.8 IW/ET_c respectively. The use of the adjusted FAO K_c values overestimated seasonal crop evapotranspiration thus cautioning against their blind application without some verification. The development of K_c curves for Bt. cotton was pursued because of its simplicity and limited data requirement for irrigation scheduling and water management.

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