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Crop Coefficient for Mulched Cotton Under Variable Irrigation Regimes

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ABSTRACT

Reduced cost of cultivation (30%) and increase in yield (40%) obliged the Saurashatra farmers to adopt Bt. Cotton on mass scale. Saurashtra cotton earns more profit at international market due to good luster, low naps, more wax on fibers surface, very low dye absorption. High evaporative conditions, scarcity of groundwater, and deficient rainfall condition are detrimental to cotton yields. Climatic change is adding another dimension to this complex nexus of soil-water-plant-atmosphere. Adverse environmental conditions coupled with water scarcity intrigued farmers of this region to adopt drip irrigation with mulch in Bt. Cotton for mitigating the impact of climatic aberrations. Determination of actual crop evapotranspiration during crop growing season is highly advantageous for sound irrigation scheduling. So far no study is reported to develop crop coefficient for drip irrigated biodegradable mulch cotton subjected to variable irrigation regimes. An experiment was undertaken 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 irrigation regimes 1.0 IW/ETc and 0.8 IW/ETc. The control treatment was taken as drip with no mulch. Adjusted FAO K_c predict higher value than sensor based K_c values at both irrigation regimes. Sensor based K_{c-mid} values were lower by 12.99% and 30.04% than the adjusted FAO K_{c-mid} value at 1.0 IW/ET_c and 0.8 IW/ET_c respectively. Biodegradable plastic mulch reduced K_{c-ini} value by 72.26% and 66.54% over control at 1.0 IW/ET_c and 0.8 IW/ET_c respectively. Overestimated adjusted FAO K_c values caused a loss of 78.13mm 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, Moisture 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. However, the productivity of cotton crop is still below the potential because of high evaporative conditions, scarcity of groundwater, deficient rainfall, and poor water management practices like poor scheduling of cotton during water scarce conditions, lack knowledge on the frequency of irrigation during low availability of water, low water application efficiencies, water use efficiencies in surface irrigation practices and climatic conditions with poor and erratic rainfall. Therefore in irrigated areas, irrigation scheduling is a main factor for farmers to increase crop yield and save water.

Adverse environmental conditions coupled with water scarcity intrigued farmers of this region to adopt drip irrigation with mulch in Bt. Cotton for mitigating the impact of climatic aberrations. Proper irrigation scheduling is prime requirement for on farm water management[3]. Determination of crop evapotranspiration (ET_c) is fundamental requirement for scheduling. Crop coefficient (Kc) algorithm method is most popular to estimate ET_c[2].

$$ET_C = K_c \times ET_o$$

Doorenbos and Pruitt (1977) recommended accepted equations for computation of ET_o. Recently, the FAO-56[1] suggested Penman-Monteith (P-M) combination equation. Various tabulated values of K_c obtained from field and lysimeter ET_c measurements provided in literature[2,6,7,8,9]. Use of K_c approach is indisputable but its adoption for generalizing K_c curves can lead to errors[5]. As it is difficult to develop locally K_c values, most researcher dependent on published values. No study is reported to develop crop coefficient for drip irrigated biodegradable mulch cotton subjected to variable irrigation regimes in this region. The objective 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. Generalized FAO K_c values adjusted for local climate and management compared with Sensor based K_c.

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 biodegradable plastic mulched (20 micron) cotton (Hy-6, BG-II) with irrigation regimes; 1.0 IW/ETc (I_1) and 0.8 IW/ETc (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 2.5cm 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) 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 x 2.5 kg/cm² with emitter discharge of 2 lph with spacing of 0.4m.

Determination of FAO K_c curves

K_c is determined for three cases. First case is determination of crop coefficient as per the FAO approach. The second case is the determination of K_c for a particular mulch as suggested by FAO 56. The third is determination of K_c for a particular mulch and for a particular irrigation interval as per the sensor based daily observations.

Kc for no mulch as per FAO 56

K_c 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. FAO also suggested adjustment for partial wetting by irrigation, in which, f_w, may be only 0.4. Value for $K_{c\,ini}$ obtained using equation

$$K_{cini} = f_w \times K_{cini\,(Tab\,Fig)} \quad ...(1)$$

Infiltration depth calculated using equation

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

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 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.

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

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

Crop coefficient for plastic mulched cotton as per FAO 56

As 50-80% reduction in soil evaporation, the K_c values decrease by an average of 10-30%.

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.

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

$$ET_\alpha = 1000 \times (M_1 - M_2) \times Z_r \times BD \quad ...(5)$$

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).

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[4].

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

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

Crop coefficient based on moisture sensor observations

The 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

$$K_c = ET_\alpha / ET_0 \quad ...(7)$$

The 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 for local conditions as per the procedure suggested by FAO 56 using equation 3 and 4. The corrected values of $K_{c\ ini}$, $K_{c\ mid}$ and $K_{c\ end}$ were 0.1, 1.036 and 0.425 for 2014-15, respectively. Temporal variation of ET_a/ET_o depicts the seasonal trend of sensor based K_c, whereas the

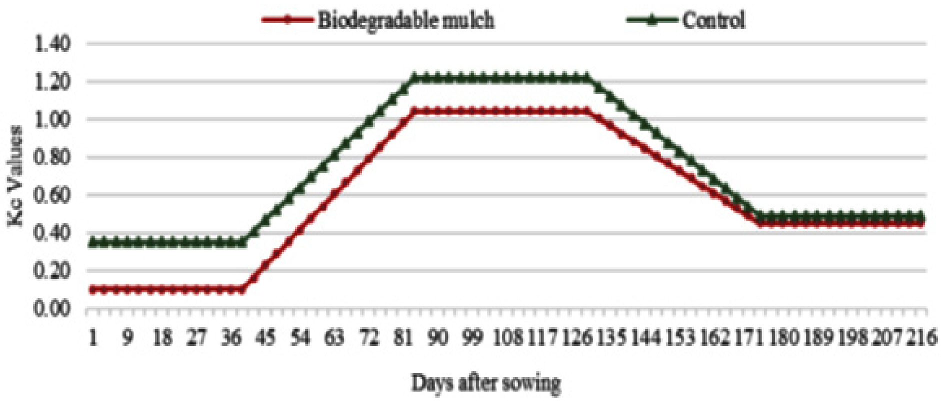

Fig. 1: Adjusted FAO Crop Coeffcient curves for much and no mulch condition

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. Adjusted FAO K_c curves and sensor based K_c curves at

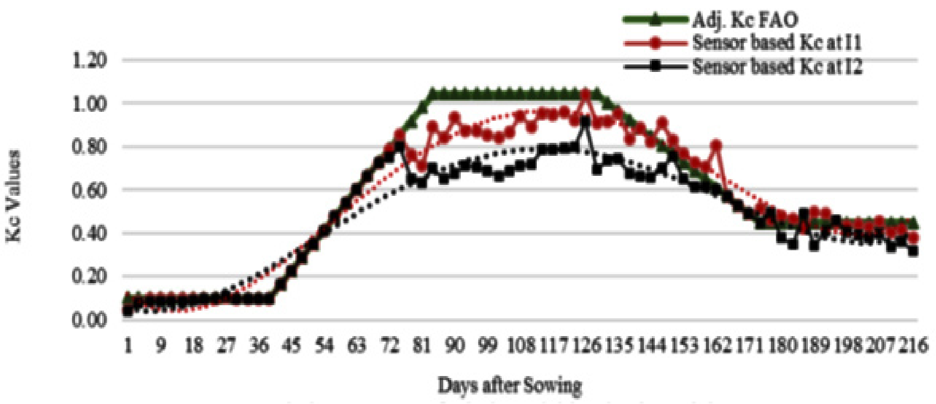

Fig. 2: Pooled Kc Curves of Biodegradable Plastic Mulch

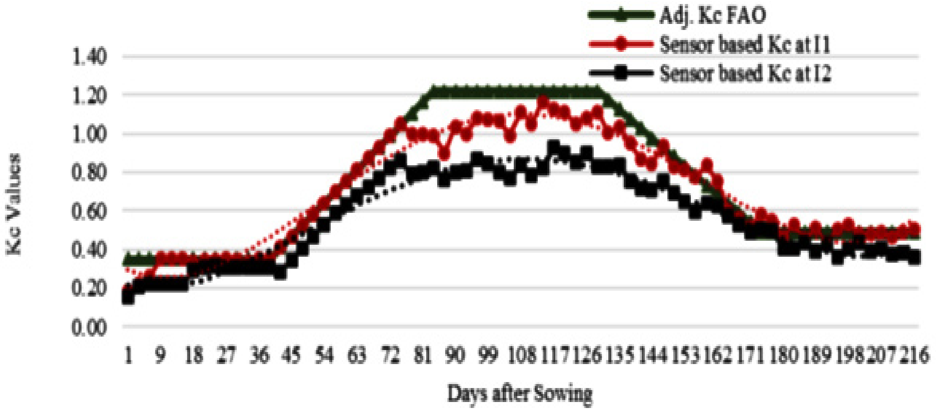

Fig. 3: Pooled Kc Curves of Control

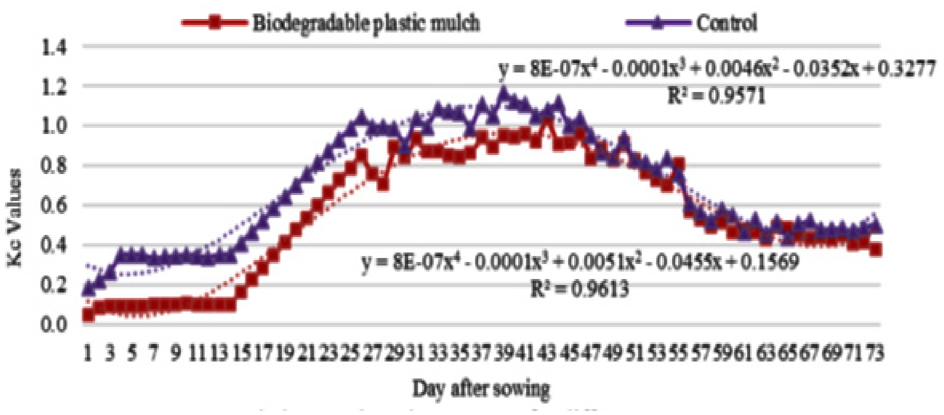

Fig. 4: Pooled sensor based Kc Curves for Different treatment at 11

different irrigation regimes for biodegradable plastic mulch and control are shown in Figure 2 and 3.

The comparison of K_c curves for biodegradable plastic 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%, 30.04% and 11.58% 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. Whereas, it were lower by 24.51%, 21.10%, 29.27% and 16.20% and 5.32%, 8.98%, 13.21% and -1.47% than FAO adjusted for I_2 and I_1 respectively

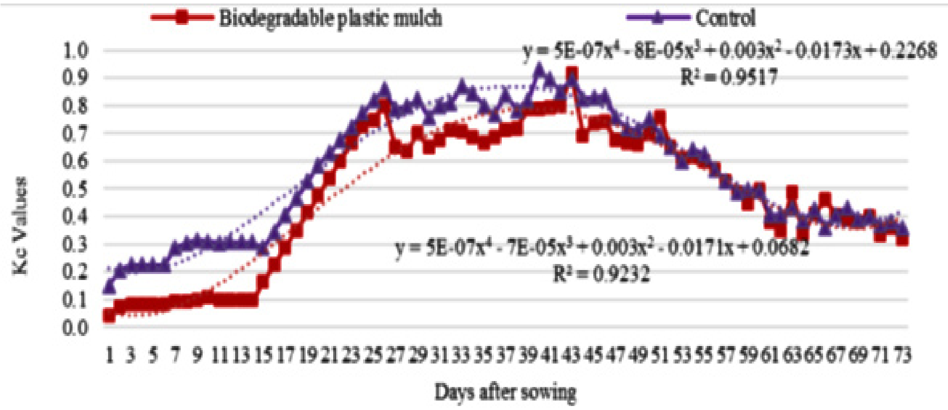

Fig. 5: Pooled sensor based Kc Curves for Different treatment at 12

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

Cotton crop stage	Biodegradable plastic mulch			No mulch		
	Adj. FAO K_c	Sensor based K_c		Adj. FAO K_c	Sensor based K_c	
		I_1	I_2		I_1	I_2
Initial stage (20-45 days)	0.10	0.091	0.088	0.35	0.319	0.264
Development stage						
(45-85days) 0.57	0.54	0.52	0.79	0.77	0.62	
Mid stage (85-130 days)	1.04	0.91	0.73	1.22	1.06	0.86
End stage (130-180 days)	0.425	0.449	0.40	0.49	0.496	0.41

Table 2: Irrigation water requirement estimated by different approaches

Irrigation regimes	Irrigation water (mm)	
Biodegradable plastic mulch		
	Sensor based ETa	**Pan ETc**
I_1	280.31	333.96
I2	231.67	267.17
Control		
I_1	320.45	412.09
I_2	257.11	329.67

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 sensor based K_c for biodegradable plastic mulch over control is observed in Table 1 and Figure 4 and 5. It was lower by 72.26%, 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. 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% & 13.28% than sensor based irrigation at I_1 and I_2 respectively.

CONCLUSIONS

Crop coefficient curves for biodegradable plastic mulched cotton was developed for two irrigation regimes. Two sets of K_c curves were developed, sensor based K_c curves as the ratio of measured ET_a to ET_o and the generalized K_c values published by FAO that were adjusted for local climate 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 at 1.0 IW/ET_c and 0.8 IW/ET_c respectively. Overestimation of seasonal ET_c using adjusted FAO K_c values, cautioning against their blind application without some verification.

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