Research Article

STAGE SPECIFIC ACTUAL CROP EVAPOTRANSPIRATION OF BT. COTTON UNDER DIFFERENT MULCH CONDITIONS

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ABSTRACT

Acquaintance of the exact water loss through actual evapotranspiration is necessary for sustainable development and environmentally sound water management to avoid the underestimation or overestimation of crop water consumption. An accurate estimation of crop evapotranspiration is important for better irrigation scheduling and water management. An attempt has been made to estimate actual evapotranspiration (ET_a) at different growth stage of Bt. cotton under silver black plastic mulch, biodegradable plastic mulch, wheat straw mulch and no mulch condition using soil moisture sensor and it was compared with crop evapotranspiration (ET_c) estimated using Penman- Monteith and Pan Evaporation method. Results revealed that Pan evaporation and Penmen Monteith approach over estimated cumulative ET_c under by 46.11%, 45.84%, 39.33%, 56.10% and 22.89%, 22.50%, 13.19%, 39.42% than sensor based ET_c under silver black plastic mulch, biodegradable plastic mulch, wheat straw mulch and control respectively at initial stage of Bt. cotton which was followed by development stage, mid stage and end stage of Bt. cotton. Sensor based approach estimated lower cumulative ET_c at all growth stage than Penmen Monteith method and Pan ET_c approach.

INTRODUCTION

Accurate estimation of evapotranspiration is required for efficient irrigation management. Evapotranspiration is a complex process because it depends on several weather factors, such as temperature, radiation, humidity, wind speed and type and growth stage of the crop. Numerous equations, classified as temperature-based, radiation-based, pan evaporation-based and combination-type, have been developed for estimating reference evapotranspiration (ET_o) (Chowdhary and Shrivastava, 2010; Dinpashoh, 2006). Field water balance is commonly used to measure total water use or actual crop evapotranspiration (ET_a) when lysimeter facilities are not available (Parihar and Sandhu, 1987; Bandyopadhyay and Mallick, 2003; Kar *et al*., 2007). Direct measurement methods of ET_c are expensive and involve hard work and the results apply only to the exact or similar conditions in which they are measured. The Food and Agriculture Organization (FAO) recommends the use of the FAO Penman-Monteith (FAO-PM) equation for estimating reference evapotranspiration (ETo) (Allen *et al.*, 1998, 2006). This method is the most widely used in the world, and has been proven to accurately estimate ET_0 in different climates (Allen *et al.*, 1998; De Bruin and Stricker, 2000; Hussein and Al-Ghobari, 2000; Walter *et al*., 2000). However, it requires several measurements of climatic variables such as air temperature, relative humidity, solar radiation and wind speed. Unfortunately, there are a limited number of sites over the world where complete meteorological stations are installed for routine measurements of these climatic variables. There are many equations available to estimate ET_o, but simpler equations give inconsistent values (George *et al.*, 2002; Temesgen *et al.*, 2005; Trajkovic, 2005; Xu and Singh, 2002) due to their different weather data requirements or because they were developed for specific climatic regions. Pan Evapotranspiration method also used for estimation of evapotranspiration but it clearly reflect the shortcomings of predicting crop evapotranspiration from open water evaporation. The method is susceptible to the microclimatic conditions under which the pans are operating and the rigour of station maintenance. Hence, present study was carried out to estimate actual evapotranspiration for Bt. cotton under silver black plastic mulch, biodegradable plastic mulch, wheat straw mulch and no mulch condition using soil moisture sensor and was compared with crop evapotranspiration estimated using other approaches.

MATERIALS AND METHODS

An experiment was undertaken at Junagadh Agricultural University, Junagadh has bearing of 21°30' N, 70°27' E and 77.5 above mean sea level. The climate of the area is categorized under subtropical and semi-arid with an average annual rainfall of 900 mm and average pan evaporation of

6.41 mm/day. About 95% of the total rainfall is received during monsoon months only. The experiment conducted for consecutively two years during *Kharif* season of 2013-14 and 2014-15, to estimate actual evapotranspiration of drip irrigated Bt. cotton (Hy-6 BG-II) under silver black plastic mulch (M_1), biodegradable plastic mulch (M_2), wheat straw mulch (M_3) and no mulch (C) condition. Irrigation scheduling was done based on actual evapotranspiration measured with the help of soil moisture sensors installed at 10cm and 50cm from top of the soil near the root zone of cotton crop. The sensors were calibrated for local condition and moisture content calculated based on calibrated soil moisture characteristic curve. Crop evapotranspiration was also estimated using Penman Monteith and Pan Evaporation methods.

Assessment of Actual Evapotranspiration (ET_a)

Actual evapotranspiration ET_a (ET_c) was calculated using soil moisture sensors with data loggers installed at different depth for getting soil moisture periodically. In the absence of water supply, the water content in the root zone decreases as a result of water uptake by the crop. It was calculated using following equation,

$$ET_a = 1000 \times (M_1 - M_2) \times Z_r \times BD \qquad \text{………….(1)}$$

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 = Root depth (m) (calculated using model developed by Fereres *et al.*, 1981), BD = Bulk density (g/cc).

Assessment of Reference Evapotranspiration (ET_0) using P-M Approach

The reference evapotranspiration was calculated using the Penman-Monteith equation (Allen *et al.*, 1998; Allen *et al.*, 2006). The FAO P-M method for calculating reference (potential) evapotranspiration ET can be expressed as:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \qquad \text{………….(2)}$$

Where, ET_0= reference evapotranspiration (mm day^{-1}), Rn= net radiation at the crop surface (MJ $m^{-2}day^{-1}$), G = soil heat flux density (MJ $m^{-2}day^{-1}$), Ta = 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), A = slope vapour pressure curve (kPa $°C^{-1}$), and *a* = Psychrometric constant (kPa $°C^{-1}$).

Assessment of ET_0 using Pan Evaporation Approach

One of the most common techniques for estimating ET_0 is using evaporation pan data, with adjustments made for the pan environment (Singh, 1989). However, reliable estimation of reference evapo-transpiration (ET_0) using pan evaporation (E_{pan}) data depends on the accurate determination of pan coefficients (K_{pan}), which is defined as the ratio of ET_0 to E_{pan} and is found to vary from 0.35 to 0.80. K_p is basically a correction factor which depends upon the prevailing upwind fetch distance, average daily wind speed, and relative humidity associated with the installation conditions of the evaporation pan (Doorenbos and Pruitt, 1977). Most of the K_{pan} estimation models have been developed based on the FAO-24 table using linear, nonlinear and indicator regression techniques or combinations thereof. In the present study, the Snyder model (1992) is adopted to estimate the pan coefficient. Snyder (1992) proposed a simpler equation to calculate daily K_{pan} values as a function of U_2, RH, and F. The final expression of the model can be expressed as:

$$K_{pan} = 0.482 + [0.24\ln(F)] - (0.000376\, U_2) + (0.0045\, RH) \qquad \text{………….(3)}$$

The relationship between ET_0 and E_{pan} can be expressed as (Snyder, 1992):

$$ET_o = K_p \times E_{pan} \qquad \text{………….(4)}$$

Where, ET_o = reference evapotranspiration (mm/day), K_p = pan coefficient, E_{pan}= pan evaporation (mm/day).

ET_c was calculated by multiplying ET_0 with adjusted K_c for plastic mulch suggested by FAO 56.

Crop Coefficient (K_c) for Plastic Mulched Cotton

K_c values decrease by an average of 10-30% due to the 50-80% reduction in soil evaporation. The value for K_{cini}under mulch is often as low as 0.10 suggested by FAO 56, Chapter 10- ET_c under various management practices. So, the crop coefficient of cotton crop under mulching were reduced by 15% for $K_{c\ mid}$ and K_{cend}. Corrections for local conditions were made using following equations.

$$K_{C\ mid} = K_{C\ mid\ (Tab)} + [0.04(u_2 - 2) - 0.004\,(RH_{min} - 45]\left(\frac{h}{3}\right)^{0.3} \qquad \text{………….(5)}$$

$$K_{C\ end} = K_{C\ end\ (Tab)} + [0.04(u_2 - 2) - 0.004\,(RH_{min} - 45]\left(\frac{h}{3}\right)^{0.3} \qquad \text{………….(6)}$$

Adjusted FAO K_c was multiplied with evapotranspiration estimated by P-M equation and Pan Evaporation method to compute ET_c.

Crop Coefficient for Wheat Straw Mulch

FAO 56 suggested to reduce K_c by about 5% for each 10% of soil surface that is effectively covered by an organic mulch. Generally, the differences between non mulch and organic mulch are 5-10%. K_c values of cotton for wheat straw mulching (M_3) were estimated to be 0.1, 1.25 and 0.45 for K_{cini}, $K_{c\ mid}$ and K_{cend}, respectively. Corrections for local conditions were made using equations (5) and (6).

Crop Coefficient for No Mulch

$K_c$for the initial stage (K_{cini}) 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_{cini}obtained using equation,

$$K_{c\ ini} = f_w \times K_{c\ ini\ (Tab\ Fig)} \quad \text{............(7)}$$

Infiltration depth calculated using equation,

$$I_w = \frac{I}{f_w} \quad \text{............(8)}$$

Crop evapotranspiration (ET_c) was calculated by multiplying Kc developed for no mulch and with mulch condition with ET_0 estimated using P-M method and Pan Evapotranspiration method.

RESULTS AND DISCUSSION

Actual evapotranspiration (ET_a) was calculated using equation (1) considering depth of sowing, days to attain physiological maturity and maximum depth of root zone for Bt. cotton was 2.5 cm, 104 days and 75cm (Freddie *et al.*, 2001) respectively. ET_0 was also estimated with P-M and Pan Evaporation method using equation no. (2) and (4).

FAO 56 suggested values for K_{cini}, $K_{c\ mid}$ and K_{cend}were 0.1, 1.063, 0.45 and 0.1, 1.025, 0.45 and 0.35, 1.20, 1.5 for cotton crop under M_1&M_2, M_3 and Crespectively. These values were corrected using equation (5) and (6). The corrected values of K_{cini}, $K_{c\ mid}$ and K_{cend} were 0.1, 1.04 and 0.425 for 2013-14 and 0.1, 1.036 and 0.425 for 2014-15 respectively for plastic mulch and 0.1, 1.125, 0.43 for 2013-14 and 0.1, 125, 0.43 for 2014-15 respectively for wheat straw mulch and the corrected values of $K_{c\ mid}$ and K_{cend} were 1.22, 0.48 and 1.23, 0.48 for 2013-14 and 2014-15 respectively for cotton under no mulch condition.

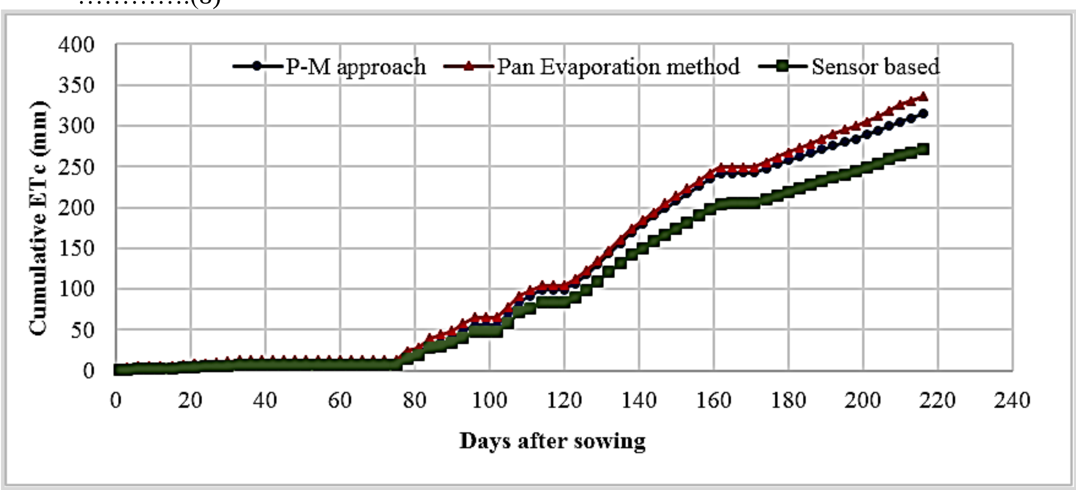

Figure 1: Commulative crop evapotranspiration of Bt. Cotton under silver black plastic mulch

Crop evapotranspiration (ET_c) was calculated by multiplying these adjusted K_c values with estimated ET_0 values calculated using P-M Method and Pan Evaporation method for M_1, M_2, M_3 and C. Quantity of water to be applied was calculated considering 90% application efficiency of drip irrigation. Cumulative ET_c for M_1, M_2, M_3 and C was calculated using different approaches and is depicted in Fig. 1, 2, 3 and 4. It indicated that cumulative ET_c estimated by Pan ET_c approach was higher than P-M ET_c and sensor based method.

Sensor based approach estimated lower cumulative ET_c under M_1, M_2, M_3 and Cat all growth stage of Bt. cotton compared to Pan Evaporation and P-M approach. Pan Evaporation approach estimated 56.10% and 44.41% higher ET_c as compared to sensor based approach under no mulch at initial and development stage respectively. Pan Evaporation and P-M approach estimated higher cumulative ET_c ranging from 17.93% (end stage) to 46.11% (initial stage) and 14.89% (end stage) to 22.89% (initial stage) compared to sensor based ETc respectively at M_1.Pan evaporation method estimated 30.12%, 19.34% higher ET_c compared to P-M approach at initial and development stage at M_1, which is at par with M_2 and M_3, whereas, much deviation not observed during midstage and end stage at M_1, M_2, M_3 and C.

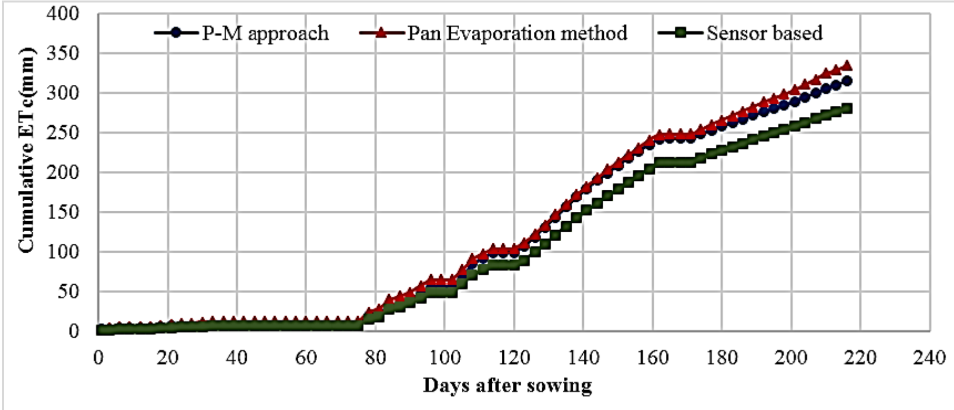

Figure 2: Commulative crop evapotranspiration of Bt. Cotton under biodegradable plastic mulch

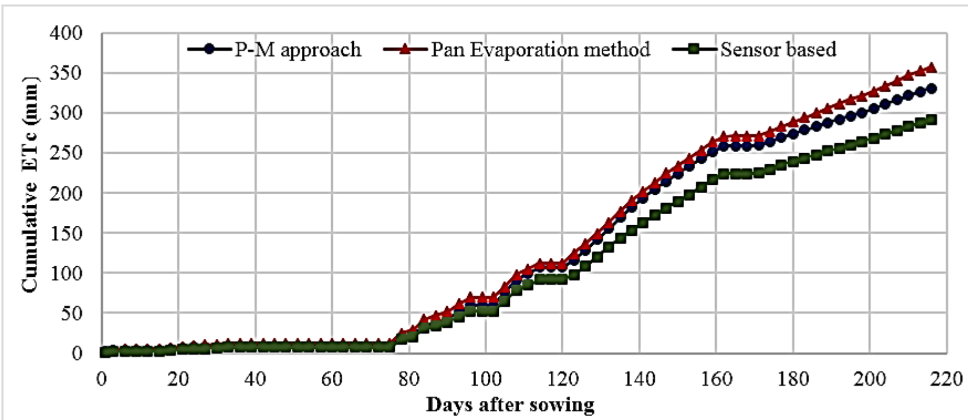

Figure 3: Commulative crop evapotranspiration of Bt. Cotton under wheat starw plastic mulch

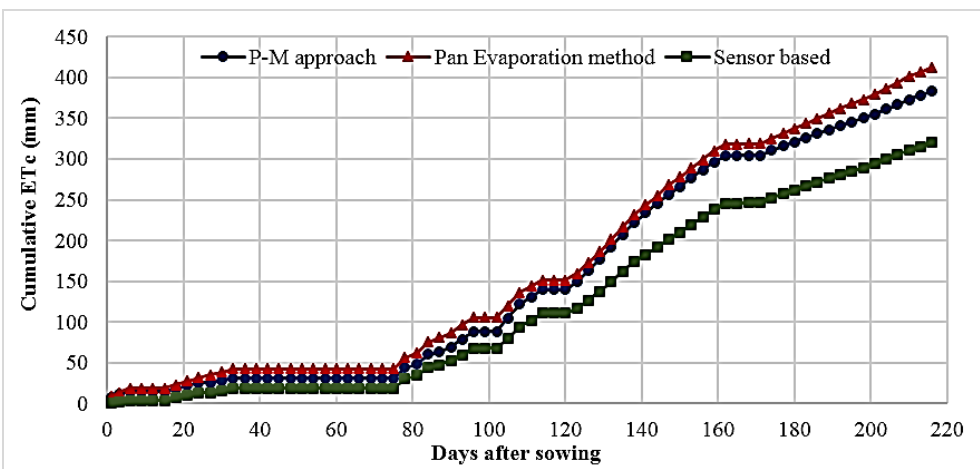

Figure 4: Commulative crop evapotranspiration of Bt. Cotton under no mulch

Results revealed that much deviation was observed after development stage between sensor based vs Pan ET_c and P-M ET_c approach and less deviation was observed between P-M ET_c and Pan ET_c approach till mid stage under M_1 and M_2. Under M_3, much deviation was observed after development stage between sensor based vs Pan ET_c and P-M ET_c approach. P-M ET_c and Pan ET_c approach were at par till mid stage but after mid stage Pan ET_c estimated higher water as compared to P-M ET_c approach. Whereas, under no mulch conditions, much more deviation was observed between Pan ET_c approach and sensor based as well as between Pan ET_c and P-M ET_c approach at all growth stage of cotton crop.

CONCLUSION

Actual evapotranspiration (ET_a) at different growth stage of Bt. cotton under silver black plastic mulch, biodegradable plastic mulch, wheat straw mulch and no mulch condition using soil moisture sensor was estimated and it was compared with crop evapotranspiration (ET_c) estimated using Penman- Monteith and Pan Evaporation approach. Results revealed that lowest irrigation requirements were observed in sensor based values. Pan ET_c overestimated irrigation water than P-M ET_c and sensor based approach. Sensor based approach under silver black plastic mulch saved irrigation water by 34.24% and 29.28%, 24.14% and 18.09% than Pan ET_c and P-M approach over no mulch condition and wheat straw mulch respectively.

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