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Development of Crop Coefficients for Precise Estimation of Evapotranspiration for Mustard in Mid Hill Zone- India

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Abstract:

Precise estimation of evapotranspiration obtained by multiplying crop coefficient to reference evapotranspiration using readily available climatic data. Penman-Monteith equation is adopted world wide as the most reliable and accurate method for computing reference evapotranspiration. The Food and Agriculture Organization (FAO) presented crop coefficient for estimation of evapotranspiration of different crops based on Penman-Monteith equation. The crop coefficient curves can be developed by plotting the ratios of crop evapotranspiration and reference evapotranspiration with respect to time. The crop coefficient curves were developed for mustard (*Brassica juncea*) by FAO-56 curve method and modified FAO-56 curve method. The FAO-56 curve method underestimates mustard evapotranspiration by 16.80 per cent. Therefore, FAO-56 curve method does not appear to predict mustard evapotranspiration accurately. The modified FAO-56 curve method underestimates mustard evapotranspiration only by 8.33 per cent. Therefore, performance of modified FAO-56 curve method was found better than FAO-56 curve method for estimation of mustard evapotranspiration.

Keyword: Crop evapotanspiration, crop coefficient, reference evpotranspiration, and FAO curve .

1.0 Introduction:

Sustainable food production will depend on the judicious use of water resources, to meet future food demands and growing competition for clean water, a more effective use of water in both irrigated and rainfed agriculture will be essential. Water use for crop production is depending on the interaction of climatic parameters that determine crop evapotranspiration and water supply from rain. The compilation, processing and analysis of meteorological information for crop water use and crop production will therefore constitute a key element in developing strategies to optimize the use of water for crop production and to introduce effective water management practices. United Nations of Food and Agricultural Organization (FAO) proposed a methodology for computing crop evapotranspiration (ET) and crop coefficient (Kc) (Doorenbos and Pruitt 1977). These coefficients depend on several factors including crop type, stage of crop growth, canopy height and density (Allen et al. 1998). To schedule irrigation properly, an accurate and standard method to estimate ET to predict crop water requirements was stated by several authors (Chiew et al. 1995; Allen 1996). A great number of models was developed to estimate ETo for use in environments that lack direct ET measurements (Pereira and Pruitt 2004, Gavilán et al. 2006). An international scientific community has accepted the FAO-56 Penman-Monteith model as the most precise one for its good results when compared with other models in various regions of the entire world (Chiew et al. 1995, Garcia et al. 2004, Gavilán et al. 2006). Estimation of reference ET_o by globally accepted FAO-56 P-M (Allen et al. 1998) requires the weather parameters like maximum and minimum temperature, solar radiation, sunshine hours, wind speed, relative humidity. The local calibration and validation of other models is more important in mid hill regions because most of these models were calibrated and validated in temperate environment (Dehghani Sanji et al. 2003).

Evapotranspiration (ET) being the major component of hydrological cycle will affect crop water requirement and future planning and management of water resources mustard is an important crop of India. Precise estimates of evapotranspiration are essential for maximum production of mustard in the country The efficient irrigation water management is very important to conserve water and optimize crop yield. Evapotranspiration, which includes transpiration by plants and evaporation from adjacent soil surfaces, continues to be foremost importance in irrigated agriculture. The different methods used for ET estimation were Penman (1963), Kimberly Penman(1972) and (1982), FAO Penman(Doorenbos & Pruitt(1977). According to Brutseart (1982) the potential evapotranspiration is a maximum intensity ofevapotranspiration from a large surface covered completely and homogeneously with actively growing plants under conditions of unlimited availability of soil water. The actual evapotranspiration is the amount of water transpired from plants and evaporated from soil surface under actual meteorological conditions and under non-optimal soil, biological, management and environmental conditions. According to Allen et al. (1998) the evapotranspiration from crops grown under management and environmental conditions that differ from the standard conditions defined for the potential evapotranspiration can be called the crop evapotranspiration under nonstandard conditions. The evapotranspiration from a reference surface is called the reference evapotranspiration and is denoted as ETo. Reference evapotranspiration (ETo) is an important agrometeorological parameter for climatological and hydrological studies, as well as for irrigation planning and management. There are several methods to estimate ETo. The FAO Penman-Monteith (FAO P-M) method has been considered as a universal standard to estimate ETo (Allen et al., 1989, 1994, 1998). About 90% of water used in agriculture is lost by crops as evapotranspiration (ET). Crop coefficient can be improved for estimating the effects of evaporation from wet soil on Kc on a daily basis (Wright, 1982).

In May 1990, the Food and Agricultural Organization (FAO) organized a consultation of experts and researchers in collaboration with the International Commission on Irrigation and Drainage and with the World Meteorological Organization, to review the FAO methodologies on crop water requirements and to advise on the revision and update of procedures. The panel of experts recommended the adoption of the Penman-Monteith combination method as a new standard for reference evapotranspiration (ETo).The FAO Penman-Monteith method was developed by defining the reference crop as hypothetical crop with an assumed height of 0.12 m, with a surface resistance of 70 sm-1 and an albedo of 0.23, closely resembling the evaporation from an extensive surface of green grass of uniform height, actively growing and adequately watered (Allen et al., 1998). The method overcomes the shortcomings of the FAO-24 Penman method (Doorenbos and Pruitt, 1977) and provides values that are more consistent with actual crop water use data worldwide. The FAO-56 (Irrigation and Drainage) on 'Crop Evapotranspiration, guidelines for computing crop water requirements', by Allen et al., (1998) in which crop coefficients are presented for estimation of evapotranspiration of different crops based on Penman-Monteith equation. The crop coefficient curves can be developed by plotting the ratios of crop evapotranspiration (ETc) and reference evapotranspiration with respect to time. The crop coefficient curves developed by the FAO method are designated as FAO-56 curve method. There is a need to evaluate FAO-56 crop coefficients under different climatic conditions. The FAO P-M method considers many meteorological parameters related to the evapotranspiration process (net radiation, air temperature, vapor pressure deficit, wind speed) and has presented very good results when compared to data from lysimeters populated with short grass [9] found a good agreement between the calculated FAO PM reference evapotranspiration and measured evapotranspiration in lysimeters.FAO suggested general trend of crop coefficient in different growth stages of the crops (Figure 1).

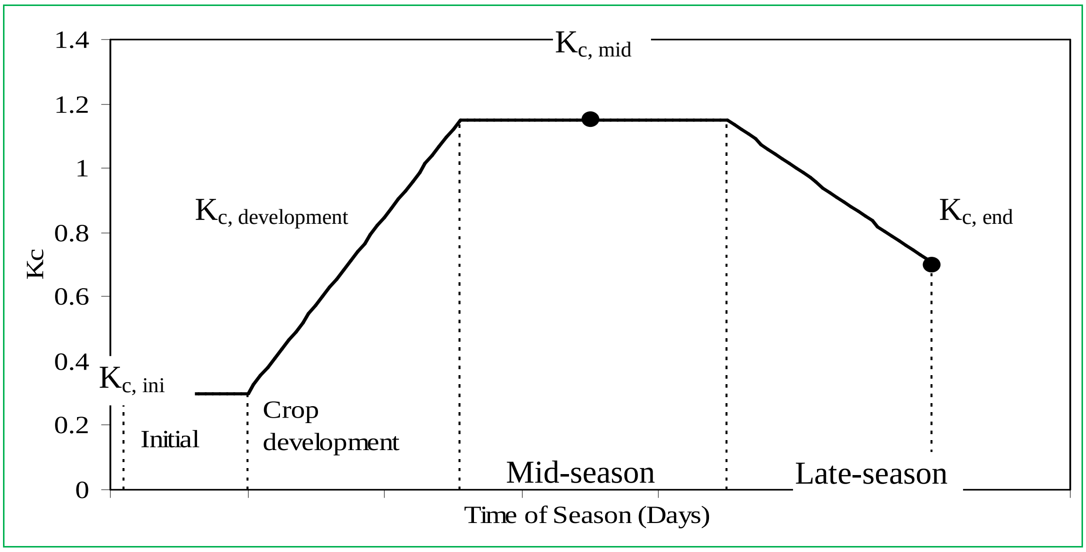

Figure 1: FAO suggested general crop coefficient curve (Allen *et al.*, 1998)

The objective of this present paper is to evaluate FAO-56 crop coefficients for mustard and to highlight the development of modified FAO-56 crop coefficients for precise estimates of wheat evapotranspiration under climatic conditions of mid hill zone of India.

2.0 Material and Methods:

The study was conducted at the Dr. Y.S Parmar University of Horticulture and Forestry, Nauni, Solan (HP), India. Field crop experiments have been conducted nearby the experimental field of the university farm from Nov, 2009 to Febauray, 2010. University of Horticulture and Forestry is located at location, at 30°50' N latitude and 77°11'30" E longitude and 1260 m above mean sea level and represents the mid-hill zone of Himachal Pradesh. The annual precipitation is 1000-1300 mm, with most rainfall occurring from June-September. The south-west monsoon generally breaks in mid June and the north-east during November-December. The average annual sunshine duration is 2750 hrs. The mustard crop grown on November 1, 2009 and harvested on February 26, 2011, the rainfall pattern during crop season is shown in Figure 2.

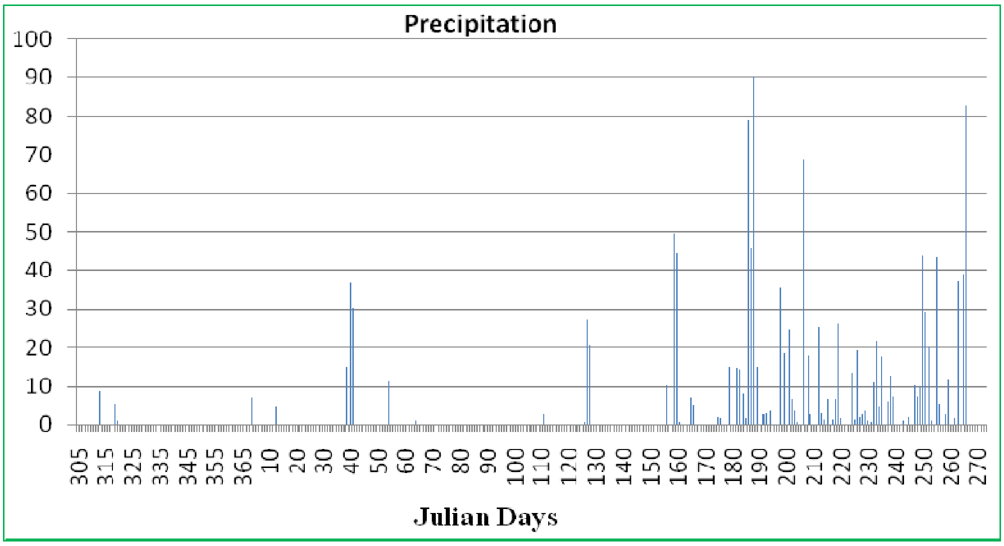

Fig. 2: Precipitation at Solan for year 2009-10

Table 1: Detail of crop duration, growth stages and irrigation days pertaining to the crop grown in the field

Crop	Date of sowing	Date of Harvesting	Duration. (Days)	Growth stages				Irrigation (Day after sowing)	Spacing
				I	II	III	IV		
Mustard (Brassica juncea)	1.11.2009	26.02.2010	107	17	30	35	25	11, 21, 34 68 and 88	40x10

I: Initial, II: Development, III: Mid-Season, IV Late season

Doorenbos and Pruitt advanced the concept of reference evapotranspiration. The reference crops were considered either alfalfa or alta fescue grass. Reference evapotranspiration is mainly influenced by climatic parameters. The resulting Penman-Monteith equation represents a basic general description of the reference evapotranspiration as follows:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T + 273} U_2 (e_a - e_d)}{\Delta + \gamma(1 + 0.34\, U_2)} \quad (1)$$

where

ET_0 = grass reference evapotranspiration (mm day^{-1})

Rn = net radiation (MJ m^{-2} d^{-1})= R_{ns} - R_{nl}

R_{ns} = net short wave radiation (MJ m^{-2} d^{-1})

R_{nl} = net long wave radiation (MJ m^{-2} d^{-1})
T = mean daily air temperature (°C)
γ = psychrometric constant (kPa°C^{-1})
Δ = slope of the saturation vapour pressure function (kPa °C^{-1})
e_a and e_d = saturation vapour pressure at air temperature and dew point temperature respectively (kPa)
U_2 = average daily wind speed at 2 m height (ms^{-1})

and

$$U_2 = U_z \frac{\ln \frac{(Z_2 - d)}{(Z_{om})}}{\ln \frac{(Z_m - d)}{(Z_{om})}} \qquad (2)$$

where
U_z = mean wind speed measurement at height z (ms^{-1})
Z_m = wind speed measurement at height m (m)
Z_2 = standard height wind speed measurement = 2 m
d = zero plane displacement of wind profile = 0.08 m
Z_{om} = roughness parameter for momentum = 0.015 m

Computation of reference evapotranspiration was done with the help of meteorological data. The relationship between crop evapotranspiration (ET_C) and reference evapotranspiration (ET_0) can be expressed by the following equation (Allen, *et al.,* 1998):

$$ET = K_C \cdot ET_0 \qquad (3)$$

Where K_C is crop coefficient. The effect of both crop transpiration and soil evaporation is integrated into a single crop coefficient. The crop coefficient incorporates crop characteristics and averaged effects of evaporation from the soil. The detail of crop grown is given in Table 1

3.0 Results and Discussions:

The crop coefficient curves were developed for mustard crop by plotting the ratios of crop evapotranspiration and reference evapotranspiration with respect to time. Allen *et al.* proposed the procedure for development of crop coefficient curves. The crop coefficient curves were developed for mustard by FAO-56 curve method and modified FAO-56 curve method. The FAO-56 curve method is based on the estimated value of the crop coefficients while the modified FAO-56 curve method is based on the actual values of crop coefficients. The detailed results of crop - coefficient curves for mustard crop are as under

3.1 FAO-56 Curve Method:

The crop coefficient curve for the mustard crop for three important stages for development of crop coefficient curves. The crop coefficient for initial stage is referred as
$K_{C\ ini}$. Similarly crop coefficient for mid season and end stages are designated as $K_{C\ mid}$ and
$K_{C\ end}$ respectively. Allen *et al.* ,tabulated the values of $K_{C\ ini}$, $K_{C\ mid}$ and $K_{C\ end}$ for different crops under standard growing conditions.

Evapotranspiration during the initial stage is predominately in the form of evaporation. Therefore, the frequency with which the soil surface is wetted during the initial period is taken into account. The value of $K_{C\ ini}$ is affected by the evaporating power of the atmosphere, magnitude of wetting event and time interval between wetting events. The K_{Cini} value for mustard crop was found to be 0.23 and FAO recommended value is 0.3. The value of $K_{C\ mid}$ varies with the climatic conditions and the crop height. More arid climates and conditions of greater wind speed will have higher values of $K_{C\ mid}$. More humid climates and conditions of lower wind speed will have lower values of $K_{C\ mid}$. For specific adjustment in climates where value of minimum relative humidity differs from 37 per cent or where U_2 is larger or smaller than 2.0 m s^{-1}, $K_{C\ mid}$ values are determined from the following equation:

$$\mathbf{K_{C\ mid} = K_{C\ mid(TAB)} + [0.04(U_2\text{-}2)\text{-}0.004(RH_{min}\text{-}45)] (h/3)^{0.3}} \qquad (4)$$

where
$K_{C\ mid\ (TAB)}$ = tabulated value of $K_{C\ mid}$
U_2= mean value of daily wind speed at 2.0 m height over grass during the mid-season growth stage (ms^{-1}) for 1 $ms^{-1} \le U_2 \le 6\ ms^{-1}$,
RH_{min} = mean value of daily minimum relative humidity during the mid-season growth stage (per cent) for 20 % $\le RH_{min} \le$ 80 %
h = mean plant height during the mid season stage (m) for 0.1 m$\le$h$\le$10 m.

The value of $K_{C\ mid}$ is less affected by wetting frequency than $K_{C\ ini}$, as vegetation during this stage is generally near full ground cover so that the effect of surface evaporation on $K_{C\ mid}$ are smaller. During the mid-season stage of wheat, mean wind speed was 0.724 m s^{-1}, mean value of minimum relative humidity was 36 per cent and height of the crop was 1.0 m. The $K_{C\ mid}$ for mustard was worked out to be 1.28 and FAO recommended value is 1.2

The values of $K_{C\ end}$ reflects crop and water management practices. If the crop is irrigated frequently until harvested fresh, the top soil remains wet and $K_{C\ end}$ value will be relatively high. On the other hand, crops that are allowed to senesce and dry out in the field before harvest receive less frequent irrigation or no irrigation at all during late season stage. Consequently both the soil surface and vegetation are dry and the value for $K_{C\ end}$ will be relatively small. More arid climates and conditions of greater wind speed will have higher values for $K_{C\ end}$. More humid climates and conditions of lower wind speed will have lower values for $K_{C\ end}$. For specific adjustments in climates where value of minimum relative humidity differs from 37 per cent or where U_2 is larger or smaller than 2.0 m s^{-1}, $K_{C\ end}$ values are determined from the following expression:

$$\mathbf{K_{C\ end} = K_{C\ end(TAB)} + [0.04(U_2\text{-}2)\text{-}0.004(RH_{min}\text{-}45)] (h/3)^{0.3}} \qquad (5)$$

where

$K_{C\ end\ (TAB)}$ = tabulated value of $K_{C\ end}$

U_2 = mean value of daily wind speed at 2 m height over grass during the mid-season growth stage (ms^{-1}) for 1 $ms^{-1} \leq U_2 \leq 6\ ms^{-1}$,

RH_{min} = mean value of daily minimum relative humidity during the mid-season growth stage (per cent) for 20 % $\leq RH_{min} \leq 80$ %

h = mean plant height during the mid season stage (m) for 0.1 m $\leq h \leq$ 10 m.

Equation (5) is only applied when the tabulated values of $K_{C\ end}$ exceeds 0.45. Therefore, value of $K_{C\ end}$ for mustard was taken as 0.66 and FAO recommended value is 0.6

Using values of $K_{C\ ini}$, $K_{C\ mid}$ and $K_{C\ end}$ the crop coefficient curve for mustard was developed which is presented in Figure 3. A comparison is made between the crop evapotranspiration estimated from the FAO-56 curve method and measured crop evapotranspiration by weighing lysimeter. The relationship is plotted in Figure 4. It is shows that there exists a linear relationship between crop evapotranspiration estimated from the FAO-56 curve method and measured crop evapotranspiration by weighing type lysimeter. The correlation coefficient was found to be 0.77 and standard error was found to be 0.75 mm day^{-1}. However, FAO-56 curve method underestimates ET_M by 16.80 per cent. Wang Yu-Min et al (2011) investigates missing data procedure developed by FAO and to verify its suitability under the climatic environment of Malawi. The performance of the procedure was analysed by regressing ETo estimated from the world wide recommended FAO penman Monteith (F-P-M) model with full data set versus F-P-M value computed with limited data. The coefficients of determination (r^2), standard errors of estimates (SEE) and estimates rates (Rate) were used for evaluating the model performance in five production sites in Malawi including Karonga, Chitedze, Kasungu, Chileka and Ngabu. The study reveals the suitability of the FAO procedure to estimate other climatic variables which are required in F-P-M model when only temperature data is available under the semi arid environment of Malawi. Therefore, this method does not appear to predict mustard evapotranspiration accurately under climatic conditions mid hill zone of Himachal Pradesh India.

3.2 Modified FAO-56 Curve Method:

The FAO-56 curve method was modified by using the actual values of crop coefficient of mustard (K_{CM}). This method is, therefore, designated as modified FAO-56 curve method. Crop coefficient values were calculated as ratios of measured crop evapotranspiration (ET_M) by weighing lysimeter to estimate reference evapotranspiration (ET_0) by Penman-Monteith method. Figure 3 shows the daily K_{CM} values during growing season of mustard crop. The growing season of mustard divided into four stages viz. (i) initial stage (17days), (ii) crop development stage (30 days), (iii) mid season stage (35 days) and (iv) late season stage (25 days). During the initial stage, the leaf area is small and evapotranspiration is predominantly in the form of soil evaporation. The K_{CM} for initial stage was found to be 0.23, which is shown by a horizontal line in Figure 3.

As the crop develops and shades more and more of the ground, evaporation becomes more restricted and transpiration gradually becomes the major process. Figure 3 shows that the K_{CW} values increase during the crop development stage. The increase is linear from the end of initial stage to the beginning of mid–season stage. The mid-season stage runs from effective full cover to the start of maturity. The start of maturity is indicated by senesce of mustard leaves. It is evident from Figure 3 that at the mid-season stage the values of K_{CM} are higher than that at other stages of mustard crop. Allen *et al.,* (1998) indicated that some crop coefficient values may be higher following wetting of soil by irrigation or rainfall. These higher values may be neglected while constructing crop coefficient curve. Neglecting the higher values, the K_{CM} value for mid season stage was found to be 1.28. Mohawesh.,O.E.,(2011) investigate daily outputs from eight evapotranspiration models were tested against reference evapotranspiration (ETo) data computed by FAO-56 P-M to assess the accuracy of each model in estimating ETo. Models were compared at eight stations across Jordan. Results show that Hargreaves modified models were the best in light of mean biased error (MBE), root mean square error (RMSE) and mean absolute error (MAE).

The K_{CM} values reduce during the late season stage. The reduction is linear from the end of mid season stage to the end of maturity. The K_C value at the end of late season stage was found to be 0.66 . By joining the all stages the modified K_{CM} curve was constructed which is shown in Figure 3. It is clear from Figures 3 and 6 that in the initial and mid season stages the values of $K_{CM}$are higher in modified FAO-56 curve in comparison to FAO-56 curve. This suggests that utilizing the measured values of crop evapotranspiration, K_{CM} curve should be developed for achieving satisfactory results. A comparison is made between the crop evapotranspiration estimated by the modified FAO-56 curve (ET_{MM}) and crop evapotranspiration measured by weighing lysimeteric (ET_M) for mustard. There exists a linear relationship between ET_{MM} and ET_M. The correlation coefficient was found to be 0.870,. The standard error was found to be 0.84 mm day^{-1}. Modified FAO-56 curve underestimates ET_M by only 8.33 per cent. The performance of modified FAO-56 curve method for estimation of ET_M was found to be better than FAO-56 curve methods.

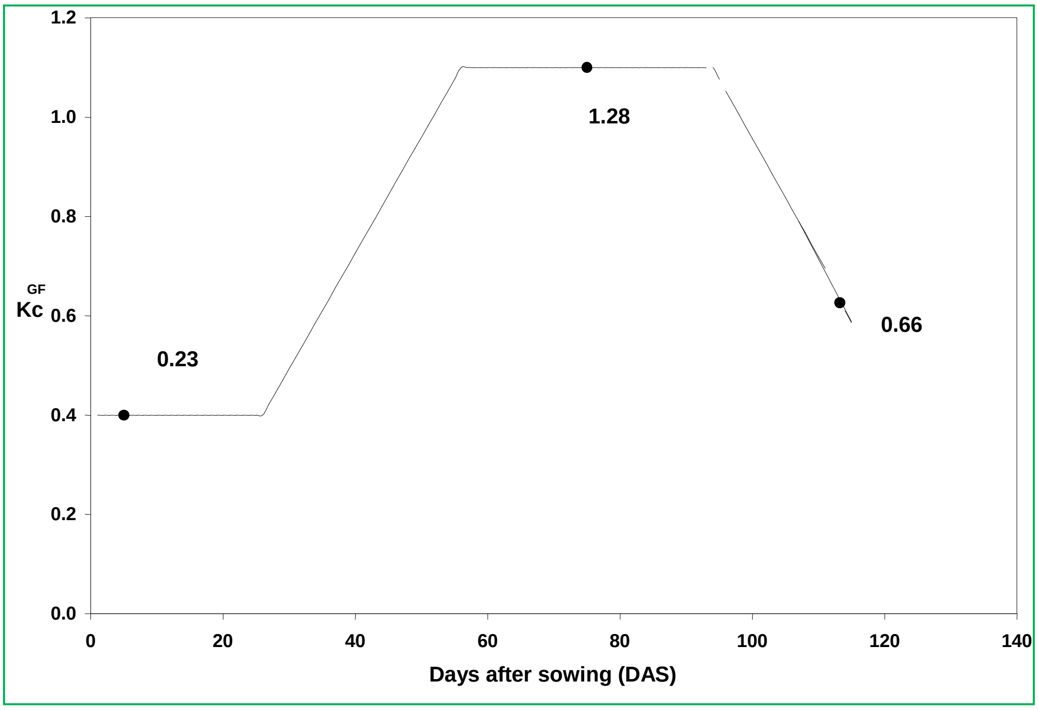

Figure 3: Crop coefficient curve by FAO-56 method during growing period of mustard crop

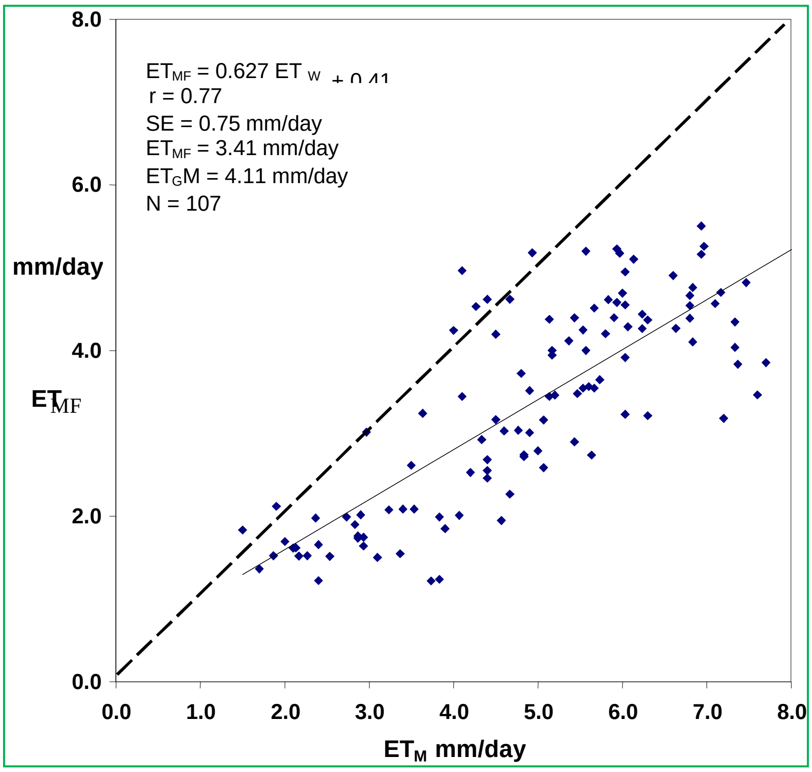

Figure 4: Comparison of estimated wheat evapotranspiration by FAO-56 curve (ET_{MF}) and measured wheat evapotranspiration (ET_M)

4.0 Conclusion:

The process of crop coefficient Development (calibration) is depends on reference evapotranspiration model used for computation of crop evapotranspiration. FAO recommended stage wise crop coefficients for mustard are used to calibration of crop coefficient. The following conclusions are drawn from the present study:

1) The crop coefficient curves were developed for mustard crop by FAO-56 curve method and modified FAO-56 curve method. The FAO-56 curve method underestimates mustard evapotranspiration by 16.80 per cent. Therefore, FAO-56 curve method does not appear to predict mustard evapotranspiration accurately.
2) The modified FAO-56 curve method underestimates mustard evapotranspiration only by 8.33 per cent. Therefore, performance of modified FAO-56 curve method was found better than FAO-56 curve method for estimation of mustard evapotranspiration.
3) Different reference evapotranspiration models result in predicting different crop water requirement, when used in combination with literature based or locally calibrated crop coefficients. This postulates the influence of reference evapotranspiration model on crop coefficient calibration.

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