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Determination of crop-coefficients and estimation of evapotranspiration of rapeseed using lysimeter and different reference evapotranspiration models

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ABSTRACT

Accurate estimation of evapotranspiration of rapeseed is essentially required for irrigation scheduling and water management. The present study was undertaken during 2015-16 and 2017-18 in ICR Farm, Assam Agricultural University, Jorhat to determine the crop coefficients (Kc) and estimate evapotranspiration of rapeseed using lysimeter and eight reference evapotranspiration models viz. Penman-Monteith, Advection-Aridity (Bruitsaert-Strickler), Granger-Gray, Makkink, Blaney-Criddle, Turc (1961), Hargreaves-Somani and Priestly-Tailor models. During 2015-16, the crop coefficients were developed by these models. Actual evapotranspiration was determined by three weighing type lysimeters. During 2017-18, evapotranspiration was estimated by multiplying reference evapotranspiration with Kc derived by different models and compared with actual evapotranspiration estimated by lysimeter during similar growing periods. All the models except Turc (1961) showed less than 10% deviation between actual and estimated ET. The estimated evapotranspiration using Penman-Monteith and Priestly-Tailor reference evapotranspiration recorded the lowest MAE and RMSE. The study revealed that estimated evapotranspiration using Penman-Monteith reference evapotranspiration gave the best estimate of evapotranspiration of rapeseed followed by Priestly-Tailor. The crop coefficients for initial, mid and end stages were 0.83, 1.20 and 0.65, respectively for Penman-Monteith and 0.70, 1.05 and 0.55, respectively for Priestly-Tailor.These results can be used for efficient management of irrigation water for rapeseed.

Keywords : Evapotranspiration, crop coefficient, rapeseed, reference evapotranspiration weighing lysimeter

Due to the scarcity of water resources, the correct evaluation of water losses by the crops as evapotranspiration is very important (Bhavsar and Patel, 2016).Plant water needs are estimated based on climatic parameters including air temperature, solar radiation, relative humidity and wind speed recorded by weather stations (Incrocci *et al.,* 2014). These parameters help to determine the reference evapotranspiration (ET0) that can be calculated by many mathematical models. The actual crop evapotranspiration (ETc) determined using lysimeters and divided by reference evapotranspiration (ET_0)is defined as crop coefficient (Kc). The crop coefficient (Kc) value represents crop-specific water use and is required for accurate estimation of irrigation requirement of different crops grown under different climatic conditions (Doorenbos and Pruitt, 1977). Development of crop coefficient (Kc) for rapeseed is important to accurately determine irrigation water requirements of the crop. Using lysimeters to measure crop water use and prescribed methods to compute reference evapotranspiration rates, the crop coefficients can be calculated on a daily basis; and averaged on a monthly basis, for practical use when calculating irrigation requirements. The adoption of the exact or correct amount of water and correct timing of application is very essential for scheduling irrigations to meet the crop's water demands and for optimum crop production (Mehta and Pandey, 2016). On average, obtaining a better understanding of the actual crop water requirement based on modern technologies could save at least 50% of irrigation water (Ragab *et al.,* 2017). Among the empirical models, the Food and Agricultural Organization hasrecommended the Penman-Monteith equation (FAO-PM) asa standard method for ET estimation (Allen *et al.,*1998). FAO- PM equation requires meteorological parameters such astemperature, humidity, wind speed, sunshine hours and net radiation to determine ET. Empirical models like Hargreaves-Somani, Turc,Blaney-Criddle etc., have also been used by several working as they require less number of meteorological parameters (Dar *et al.,* 2017; Phad *et al.,* 2019). As such, it is required to develop Kc values for different models for the estimation of evapotranspiration. Based on the above, this experiment was undertaken in order to determine the crop coefficients (Kc) and estimate evapotranspiration of rapeseed using eight reference evapotranspiration models.

MATERIALS AND METHODS

Location of experiment

The experiment was conducted at Instructional-cum-Research (ICR) Farm, Assam Agricultural University, Jorhat-13 during 2015-16 and 2017-18. The ICR Farm is situated at 26°47' N latitude, 94°12' E longitude and at an altitude of 87.0 metres above mean sea level. The climatic condition of Jorhat is subtropical humid with hot summer and cold winter. The average annual rainfall is 1864.8 mm. Out of this, 1194.8 mm, 467.1 mm, 151.4 mm and 51.5 mm are received during monsoon, pre-monsoon, post-monsoon and winter, respectively. The minimum monthly temperature of 9.7 °C and maximum monthly temperature of 32.4 °C are observed in January and August, respectively. During January and March, maximum (morning) and minimum (evening) monthly relative humidity of 94.8% and 61.1%, respectively are observed (Sarma and Das, 2017).

Measurement of actual evapotranspiration

The components of the water balance equations were measured by 3 weighing type lysimeters with dimensions of 1.3 m × 1.3 m × 0.9 m each. Each lysimeter was filled up with soil and rapeseed was grown. Fertilizers were applied as basal @ 60-40-40 kg N-P_2O_5-K_2Oha^{-1} in the form of urea, SSP and MOP, respectively.The texture of the soil was sandy loam and acidic(pH 5.1) in nature.The field capacity of the soil was found to be 25.9% and the permanent wilting point was 8.92%. The rapeseed variety TS 38 was sown on 30 October, 2015 and 30 October 2017 during the first and second year, respectively maintaining a spacing of 30 cm between row to row and 5-7 cm between plant to plant. During 2016, the experiment could not be conducted as the lysimeters were used for another experiment. The crop was harvested on 31 January, 2016 and 31 January, 2018. The same variety of rapeseed crop was sown inside and outside the lysimeters to eliminate boundary effects. Fluctuations in weight of lysimeters were recorded at 8.30 a.m. everyday and daily loss of weight was replenished by irrigation. During 2015-16 and 2017-18, 81.10 mm and 24.40 mm rainfalls were received.

Actual evapotranspiration of rapeseed was measured using the soil water balance equation. The water balance equation can be expressed as follows:

$$ET = P + (I - D) + S$$

Where, ET = Evapotranspiration; P = Precipitation; I =Irrigation water; D = Excess water drained from the bottom; S = Increase or decrease in the storage of soil moisture

Change in soil moisture (S) is the difference in the moisture content of each consecutive days and it was calculated by deducting the moisture content of the day from the previous day starting from sowing to the last harvest. The drained outwater accumulated at the bottom tank of the lysimeter. This water was pumped out with the help of a pedal pump and the volume was measured. Dividing the volume by the area of the lysimeter, drainage depth of water was calculated.

Estimation of ET_0 by different models

The reference evapotranspiration (ET_0) was estimated by Penman-Monteith, Advection-Aridity (Bruitsaert-Strickler), Granger-Gray, Makkink, Blaney-Criddle, Turc (1961), Hargreaves-Somani and Priestly-Tailor models (Table 1).

Calculation of crop coefficient (Kc)

The crop coefficient is defined as the ratio of crop evapotranspiration to the reference crop evapotranspiration. During 2015-16, the crop coefficient (Kc) was determined by the following equation:

$$K_c = ET_c / ET_0$$

Where, ETc = Measured actual crop evapotranspiration; ET0 = Reference crop evapotranspiration

The entire crop period of rapeseed was divided into four sub-periods viz. initial period (1-13 DAS); development period (14-33 DAS); mid-period (34-65 DAP); and late period (66-93 DAP). The crop coefficients for initial (Kc ini), mid (Kc mid) and end (Kc end) periods for different models viz. Penman-Monteith, Advection-Aridity (Bruitsaert-Strickler), Granger-Gray, Makkink, Blaney-Criddle, Turc (1961), Hargreaves-Samani and Priestly-Tailor were determined from Fig. 1.

The crop coefficients of the development and late periods were determined by the following equation (Allen *et al.,* 1998):

$$K_{ci} = K_{cprev} + \left[\frac{i - \Sigma(L_{prev})}{Lstage}\right] \times (K_{cnext} - K_{cprev})$$

Where,

Kci = Kc on day 'i' ; i = Day number within the growing season; Kcprev = Kc of the previous stage; Kcnext = Kc of the next stage

Table 1: Various model used for computing ET0

Model	Formula	Reference
Penman-Monteith	$\frac{0.404\Delta(R_n - \mathrm{G})\ \frac{900}{\mathrm{T}+273}\mathrm{u}_2(\mathrm{e_s} - \mathrm{e_a})}{+\ (1 + 0.34\mathrm{U}_2)}$	Allen *et al.,* 1998
Advection-Aridity (Bruitsaert -Strickler)	$(2 \propto_{PT} - 1)\frac{\Delta}{\Delta +}\frac{R_n}{\lambda} - \frac{\Delta}{\Delta +}f(u_2)(\mathrm{e_s} - \mathrm{e_a})$	Brutsaert and Strickler, 1979
Granger-Gray	$\frac{\Delta G_g}{\Delta G_g +} - \frac{R_n - G}{\lambda} + \frac{\Delta G_g}{\Delta G_g +}E_a$	Granger and Gray, 1989
Makkink	$0.61[\frac{\Delta}{\Delta +}\frac{R_s}{2.45} - 0.12]$	de Bruin, 1981
Blaney-Criddle	$(0.0043RH_{min}nN - 1.41) + b_{var}P_y(0.46T_a + 8.13)$ $b_{var} = e_0 + e_1RH_{min} + e_2\frac{n}{N} + e_3u_2 + e_4RH_{min}\frac{n}{N} + e_5RH_{min}u_2$	Allen and Pruitt, 1986
Turc (1961)	$0.013(23.88R_s + 50\frac{T_a}{T_a + 15}$	Turc, 1961
Hargreaves-Somani	$0.0135C_{HS}\frac{R_a}{\lambda}(T_{max} - T_{min})^{0.5}(T_a + 17.8)$	Hargreaves and Somani, 1985
Priestly-Tailor	$\propto_{PT}[\frac{\Delta}{\Delta +}\frac{R_n}{\lambda} - \frac{G}{\lambda}]$	Priestley and Taylor, 1972

αPT = Priestly Tailor parameter; Δ= Slope of the saturated vapour pressure at air temperature (kPa/°C); Rn = Net radiation (MJ/m2 /day); ϒ = Psychrometric constant (kPa/°C); λ= Latent heat of vaporization (MJ/kg); u_2 = the average daily wind speed (m/s); es = Saturation vapour pressure (kPa); ea = Actual vapour pressure (kPa); f(u2) : Penman (1948) wind function; aPT = Priestley–Taylor constant (1.26 for "advection-free" saturated surfaces); Gg = a dimensionless evaporation parameter; Ea = Drying power of the air; Rs = Incoming shortwave solar radiation (MJ/m2 /day); RHmin = Minimum relative daily humidity (%); n/N = Measured sunshine hours divided by the possible daily sunshine hours; Py = Percentage of actual daytime hours for the day compared to the day-light hours for the entire year; Ta = the average daily air temperature (oC); u_2 = Average daily wind speed (m/s) at 2 m; e_0 = 0.81917; e_1 = -0.0040922; e_2 = 1.0705; e_3 = 0.065649; e_4= -0.0059684; e_5 = -0.0005967; CHS = Emperical constant; Tmax = Maximum average daily temperature (°C); Tmin = Minimum average daily temperature (°C); Ra = Extraterrestrial radiation (MJ/m2 /day)

$\Sigma(L_{prev})$ = Sum of the lengths of all previous stages (days)

L_{stage} = Length of the stage under consideration (days)

Estimation of evapotranspiration (Est Etc)

Evapotranspiration of rapeseed under the climatic condition of Jorhat was estimatedby multiplying the calculated reference evapotranspiration of 2017-18 with Kcderived in 2015-16 by different models during the similar growing period.

Comparison of different models

During 2017-18, actual evapotranspiration (ETc) was measured using lysimeter and estimated evapotranspiration (Est ETc) for the same period using different models was compared with average error (AE), mean absolute error (MAE), mean bias error (MBE) and root mean square error (RMSE). These were calculated as follows:

$$AE = \frac{EstET_c - ET_c}{ET_c} \times 100\%$$

$$MAE = \sum_{i=1}^{n}[|EstET_c - ET_c|]/n$$

$$MBE = \sum_{i=1}^{n}[EstET_c - ET_c]/n$$

$$RMSE = \left[\sum_{i=1}^{n}[EstET_c - ET_c]^2/n\right]^{1/2}$$

Where, n = number of observation

RESULTS AND DISCUSSION

Crop coefficients of different models

The crop coefficients of rapeseed developed by lysimeter experiment during 2015-16 for initial (Kc ini), mid (Kc mid) and end period (Kc end) by different models using Fig. 1 are presented in Table 2. The Kc values integrate the effect of characteristics that distinguish a typical field crop from the grass reference, which has a constant appearance and a complete ground cover. The changing characteristics of the crop over the growing season have an effect on the Kc.In the study, the crop coefficients were lowest in the early crop growth period, gradually increased and reached a peak during 34-65 DAS and then decreased.At the last, the crop coefficient value decreased steadily due to maturity and senescence of leaf. Allen *et al.* (1998) also found that the crop coefficient depended on the type of crop, its stageof growth, canopy cover and crop density.

In all the models except Blaney-Criddle, Kc mid recorded the highest values indicating highest evapotranspiration during the mid-period of growth followed by Kc ini. The Kc mid values for Penman-Monteith, Granger-Gray and Makkink models were higher than 1.0 which indicated higher ETc than estimated ET0 under these models during the mid-period. The leaf area index, wind turbulence and leaf temperature are possible reasons for the increase in crop requirement above reference evapotranspiration (Kokilavani *et al.,* 2018).The lowest value was recorded for Kc end. The developed Kc ini, Kc mid and Kc end values for Penman-Monteith were 0.83, 1.20 and 0.65. Granger-Gray model recorded higher Kc ini value than the Penman-Monteith model; however, Kc midvalue was equal to Penman-Monteith. Other models recorded lower Kc ini values than Penman-Monteith. Granger-Gray, Makkink and Blaney-Criddle models recorded slightly higher Kc end values. Kc end values for the rest of the models were smaller than the Penman-Monteith model.This variation is due to the differences in the estimation of reference evapotranspiration by different models.Tahashildar *et al.* (2017) also observed wide variations of reference evapotranspiration estimated by different empirical models inthe mid-hill region of Meghalaya.

Comparison of estimated evapotranspiration derived from different methods

Estimated evapotranspiration (Est ETc) of rapeseed during 2017-18 using the reference evapotranspiration and crop coefficients developed by different models during 2015-16 indicated slight average error from actual evapotranspiration (ETc) (Table 3). The ETc of the crop during the initial, development, mid and late periods were 27.90 mm, 36.90 mm, 61.86 mm and 42.41 mm, respectively with a total of 169.13 mm.The total ET loss estimated throughthe Penman-Monteith method for rapeseed during the entire season of the crop was 168.86 mm with -0.16% average error.In case of other models, the sum total ET losses were found to be 159.54 mm, 158.17 mm, 170.28 mm, 159.37 mm, 151.59 mm, 167.45 mm and 171.44 mmwith average error of -5.67%, -6.47%, 0.68%, -5.77%, -10.37%, -0.99% and 1.37% usingAdvection-Aridity (Bruitsaert-Strickler), Granger-Gray, Makkink, Blaney-Criddlel,Turc (1961), Hargreaves-Samani and Priestly-Tailor models, respectively.Thus all the models except Turc (1961) showed less than 10% deviation between actual and estimated ET. Penman-Monteith slightly underestimatedand Makkink and Priestly-Tailor models slightly overestimated the evapotranspiration. Contrary to it, Prajapati and Subbaiah (2019) found that adjusted FAO Kc overestimated evapotranspiration in Bt cotton in Junagadh. It suggested that local variability of meteorological conditions is important for estimation of reference evapotranspiration by different models. In the present study, the Penman-Monteith, Makkink and Priestly-Tailor models were also very consistent in different growth stages (except for developmental period) with average error within + 1.5%.Bhat *et al.* (2017) found that Makkink model fits best with the Penman-Monteith model and it was followed by Priestley-Taylor. Khavse *et al.* (2017) also found the Penman-Monteith model to be more appropriate as this method is rationalizing the weightage factor of different meteorological parameters.

The performance of the model was evaluated in termsof error analysis (Table 4). The ET estimated using Penman-Monteith and Priestly-Tailor reference evapotranspiration recorded the lowest MAE and RMSE indicating the lowest magnitude of average error. This can be attributed to the fact that the Penman-Monteith model takes into consideration both radiation as well as aerodynamic components in the estimation of evapotranspiration (Allen *et al.,* 1998). Tomar (2016) found that the Priestley-Taylor method could estimate compatible ET0 values as estimated by the Penman-Monteith method.

The estimated ET using Penman-Monteith reference evapotranspiration also recorded thelowest deviation (-0.003) in terms of MBE followed by ET estimated through Makkink (0.01), Priestly-Tailor (0.02) and Hargreaves-

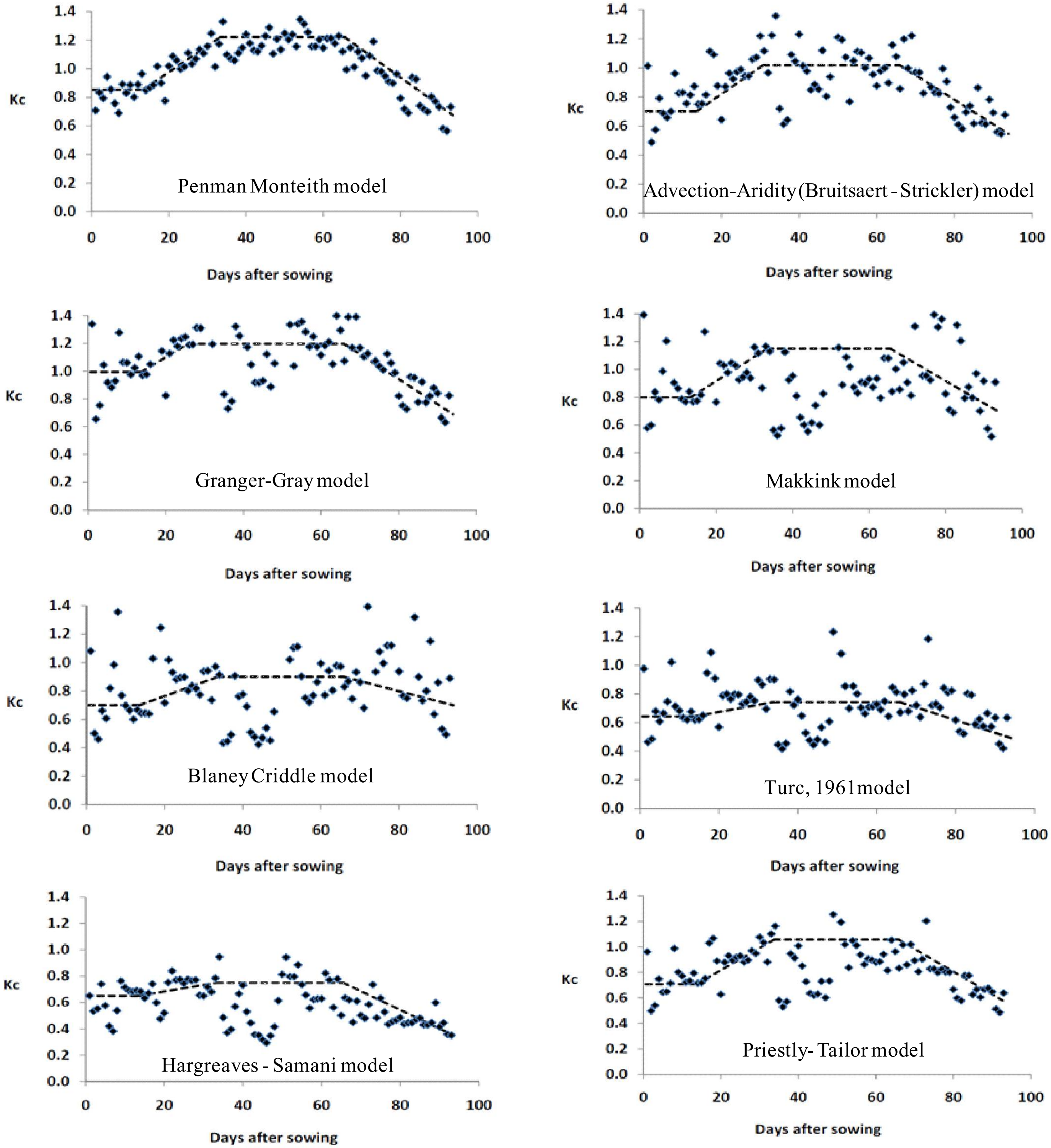

Fig. 1: Crop coefficient of rapeseed developed with different models

Somani (-0.02) reference evapotranspiration. As such, estimated ET using Penman-Monteith and Hargreaves-Somani underestimate the crop evapotranspiration by 0.003 mmday^{-1} and 0.01 mmday^{-1}. On the other hand estimated ET using Makkink and Priestly Tailor overestimate the crop evapotranspiration by 0.01 mmday^{-1} and 0.02 mmday^{-1}. Naiduand Majhi (2019) observed large deviations of Hargreaves, Turc and Blaney-Criddlereference evapotranspiration from Penman-Monteith reference evapotranspiration

Table 2: Crop coefficients of rapeseed developed by lysimeter experiment for initial, mid and end period using different models during 2015-16

Crop coefficient	Penman Monteith	Advection-Aridity model	Granger-Gray model	Makkink	Blaney-Criddle	Turc (1961)	Hargreaves-Samani	Priestly-Tailor
Kc ini	0.83	0.70	1.00	0.80	0.70	0.60	0.65	0.70
Kc mid	1.20	1.00	1.20	1.15	0.90	0.75	0.75	1.05
Kc end	0.65	0.55	0.70	0.70	0.70	0.50	0.35	0.55

Table 3: Actual ET and estimated ET of rapeseed using the reference evapotranspiration and crop coefficients (developed during 2015-16) for different models during 2017-18

		Estimated ET (mm)							
Crop period	Actual ET (mm)	Penman Monteith	Advection-Aridity model	Granger-Gray model	Makkink	Blaney-Criddle	Turc (1961)	Hargreaves-Samani	Priestly-Tailor
Initial period (0-13 DAS)	27.96	27.74 (-0.79%)*	28.12 (0.57%)	29.89 (6.90%)	27.74 (-0.79%)	27.30 (-2.36%)	25.91 (-7.33%)	26.42 (-5.51%)	27.73 (-0.82%)
Development period (14-33 DAS)	36.90	38.05 (3.12%)	36.65 (-0.68%)	36.20 (-1.90%)	37.72 (2.22%)	36.84 (-0.16%)	33.94 (-8.02%)	36.63 (-0.73%)	38.60 (4.61%)
Mid period (34-65 DAS)	61.86	61.02 (-1.36%)	55.60 (-10.12%)	53.35 (-13.76%)	61.99 (0.21%)	56.03 (-9.42%)	53.62 (-13.32%)	64.16 (3.72%)	62.58 (1.16%)
Late period (66-93 DAS)	42.41	42.05 (-0.85%)	39.17 (-7.64%)	38.73 (-8.68%)	42.83 (0.99%)	39.20 (-7.57%)	38.12 (-10.375)	40.24 (-5.12%)	42.53 (0.28%)
Total	169.13	168.86 (-0.16%)	159.54 (-5.67%)	158.17 (-6.47%)	170.28 (0.68%)	159.37 (-5.77%)	151.59 (-10.37%)	167.45 (-0.99%)	171.44 (1.37%)

* Data within parenthesis indicates average error

Table 4: Error analysis of ET estimation by different models

Parameters	Penman Monteith	Advection-Aridity model	Granger-Gray model	Makkink	Blaney-Criddle	Turc (1961)	Hargreaves-Samani	Priestly-Tailor
MAE (mm)	0.08	0.15	0.18	0.20	0.21	0.20	0.23	0.08
MBE (mm)	-0.003	-0.10	-0.12	0.01	-0.10	-0.19	-0.02	0.02
RMSE (mm)	0.11	0.19	0.22	0.24	0.27	0.24	0.29	0.11

CONCLUSION

The investigation was carried out to determine the crop coefficients (Kc) and estimate evapotranspiration of rapeseed using lysimeter and eight reference evapotranspiration models. The study revealed that estimated evapotranspiration using Penman-Monteith reference gave the best estimate of evapotranspiration of rapeseed followed by Priestly-Tailor. During the initial stage of the crops, the evapotranspiration was less and increased during the development stage, reached its maximum values during mid-season and reduced during crop maturation stages. The crop coefficients for initial, mid and end stages were 0.83, 1.20 and 0.65, respectively for Penman-Monteith and 0.70, 1.05 and 0.55, respectively for Priestly-Tailor. The information generated can be used in scheduling irrigation for rapeseedin Jorhat.

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