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Comparison of different reference evapotranspiration (ET_0) models and determination of crop-coefficients of french bean (*Phesiolus vulgaris.)* in mid hill region of Meghalaya

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ABSTRACT

The water requirement and crop evapotranspiration (ET_c)is determined using reference evapotranspiration (ET_0) and crop-coefficient (k_c). Numerous models are available for estimation of ET_0,among which Penman-Monteith (FAO-56) model is considered to be the most accurate and universally acceptable. In present study eight models for estimation of ET_0*viz.* Modified Penman method, Hargreaves equation, Samani-Hargreaves equation, Thornthwaite equation, Solar radiation method, Net radiation method, Blaney-Criddle method and Radiation method were compared with Penman-Monteith model to find out the accuracy of prediction with limited weather parameters. Among these, Net radiation and Solar radiation models were found to yield relatively closer values. A field experiment was also conducted withfrench bean (*Phesiolus vulgaris.)* crop in UMS-GmbH cylindrical field lysimeter of 30 cm diameter and 120 cm deep for determination of crop coefficient taking Penman-Monteith FAO-56 model as the base model for ET_0 estimation. The values of ET_c as determined in field lysimeter varied from 3.80 mm-d^{-1} to 5.89 mm-d^{-1}. The k_c for initial, mid and maturity were found to be 0.45, 1.01 and 0.39, respectively.

Key words: Crop-coefficient, reference evapotranspiration, crop evapotranspiration, lysimeter, french bean *(Phesiolus vulgaris.)*

Water is one of the vital inputs in crop production. Its judicious use demands scientific approach towards irrigation scheduling. The estimation of crop water requirement using the reference evapotranspiration (ET_0) and crop coefficient (k_c) is one of the best methods. The crop evapotranspiration is effected by different weather parameters, crop factors, management practices and environmental conditions (Allen *et al.,* 1998). Because of their interdependence, spatial and temporal variability, formulation of a single specific equation for actual ET estimation for various crops under different condition is difficult.

Reference evapotranspiration (ET_0) is defined as the rate of ET from an extensive surface of green grass of uniform height 8 to 15 cm tall actively growing, completely shading the ground, and not short of water (Doorenbos and Pruitt 1977; Jensen *et al.,* 1990).There are about 50 empirical methods available for estimating ET_0, yielding inconsistent results due to many factors. Food and Agriculture Organization (FAO) recommends the Penman–Monteith (PM) method as the standard to estimate reference evapotranspiration because it closely approximates grass ET_0 at the location evaluated and is physically based (Allen *et al.,* 1998). Penman–Monteith has been used in comparative studies with other methods that are less demanding in climatic data, carried out in different parts of the world (Tyagi *et al.,* 2000).

The crop coefficient (k_c) is a crop specific value depends on the crop variety, duration and growth stages of the crop and a characteristic that can distinguish field crops from the reference crop with a crop factor (Allen *et al.*, 1998).In absence of derived crop coefficient, to estimate actual evapotranspiration based on the local weather parameters the recommended k_c values by FAO-24 (Doorenbos and Pruitt, 1977) are used worldwide. But the actual values differ considerably from the tabulated values if the crop duration and morphology are not matched.Allen *et al*. (1998) also recommended that the determination of crop coefficient values are to be done in local climate conditions by observed data using lysimeter when the accuracy is highly concerned.

MATERIALS AND METHODS

The study was conducted in two parts: firstly

Table 1: Various model used for computing (ET_0) at Umiam, Meghalaya

Methods		Formula	Reference
Combination method	Penman Monteith	$ET_0 = \frac{0.408\,\Delta\,(R_n - G$ [redacted] $+ \gamma \frac{900}{T+273} u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34 u_2}$	Allen *et al.* (1998)
	Modified Penman	$ET_0 = c\,[W.R_n + (1-W)x\,f(u)x(e_a - e_d)]$	Doorenboos and Pruitt (1977)
Temperature based	Hargreaves method	$ET_0 = 0.0023\,(T_m + 17.8)\,[\surd(T_{max} - T_{min})]\,R_a$	Hargreaves *et al.* (1985)
	Samani Hargreaves	$ET_0 = 0.0135\,(KT)\,(T_C + 17.8)\,[\surd TD)]\,R_a$	Hargreaves *et al.* (1985)
	Thornthweithe equation	$ET_0 = 16\,X\,(10Ti / I)^a\,(N / 12)\,(1 / 30)$	Thornthwaite, W. (1948)
	Blaney Criddle method	$ET_0 = c[p\,(0.46 \cdot T_{mean} + 8)]$	Blaney and Criddle. (1950)
Radiation based	Net radiation method	$ET_0 = 0.489 + 0.289R_n + 0.023T_{mean}$	Irmak *et al.* (2003)
	Solar radiation method	$ET_0 = -0.611 + 0.149R_s + 0.079T_{mean}$	Irmak et al. (2003)
	Radiation method	$ET_0 = c\,(W.R_s)$	Doorenboos and Pruitt. (1977)

comparison of eight ET_0 models *viz.* Modified Penman method, Hargreaves equation, Samani Hargreaves equation, Thornthwaite equation, Solar Radiation method, Net Radiation method, Blaney-Criddle method and Radiation method with Penman-Monteith equation and secondly determination of crop coefficient of French bean with the help of field lysimeter.

Location of experiment

The experiment was conducted during 2014 growing seasons at a 100 m^2 experimental farm located at Umiam, Meghalaya (25.68^0 E latitude 91.93^0 N longitude, 951 m above mean sea level) having mean annual precipitation of 2,000 mm. An automatic weather station (Davis Vintage Pro-2) was installed within the area for collecting real time weather data.

Comparison of ET_0 estimation methods

The estimation of reference evapo-transpiration (ET_0) by nine different methods (Table 1) including Penman-Monteith method (Allen *et al.,* 1998) as a standard model was done using daily weather data *viz.* maximum & minimum temperature, relative humidity, wind speed and net radiation as collected in the Automatic Weather Station. The comparison was done for french bean crop season (26^{th} July to 23^{rd} September).

Statistical tools such as scatter plots and paired *t*-test were used to compare the estimated values of these models with that of Penman-Monteith equation so that these models may also be applicable in any situation where all the weather parameters are not be available.

Description of lysimeter and tensiometer

Two weighing type of lysimeters (UMS-GmbH) were installed within crop area of the experimental field. The UMS-GmbH lysimeter consists of a cylindrical lysimeter with 30 cm diameter and 120 cm soil column inserted in it. Five moisture sensors (EC5), tensiometer (T4) and vacuum cup (SK20) were fixed on the wall of the lysimeter at different depth (10 cm, 30 cm, 55 cm, 80cm and 115 cm) for collecting leachate under suction. EC5 measures dielectric constant of the soil in order to find the volumetric water content. T4 tensiometer is a precision tensiometer developed for outdoor monitoring works. Here only ceramic cup is filled with water for highest accuracy. VS Pro Vacuum system is also fitted to create constant vacuum condition at suction of -400 hPa to drain out excess water from the soil profile. SK20 vacuum cup is a simple ceramic cup with removable shaft. All the sensors including the load cell is connected to a data logger for continuous data collection at pre-determined interval. The gravitational water or the leachate is taken out through the vacuum cups and collected in the bottles kept in a buried chamber. The ceramic plate at the bottom of lysimeter is also connected to the vacuum pump to collect the excess water beyond field capacity. The lysimeter cylinder fitted with all the sensors and vacuum cups then inserted in a PVC casing and buried in the field.

Crop coefficient

The actual evapotranspiration (ET_c) was determined from lysimeter data as recorded by EC5 sensors and load cell taken on daily basis using water balance approach. The ratio between the actual evapotranspiration (ET_c) to the reference evapotranspiration (ET_0) gave the crop coefficient (k_c).

$$k_c = ET_0 / ET_c$$

Table 2: Average weekly ET_0 (mmd^{-1}) estimated by different methods from July25 to September 23, 2014 at Umiam, Meghalaya

Week/ period	Penman-Montieth	Modified Penman	Hargreaves	Samani Hargreaves	Thornthwaite	Solar radiation	Net radiation	Blaney-Criddle	Radiation
July25-31	4.72	7.46	10.00	11.60	14.91	4.00	4.48	4.04	10.98
Aug. 1-7	4.99	7.75	8.83	10.97	14.91	4.01	4.54	3.97	11.63
Aug. 8-14	5.34	8.06	9.59	11.15	15.20	4.20	4.80	3.98	12.53
Aug. 15-21	5.89	8.91	7.71	10.98	15.93	4.58	5.18	4.08	14.09
Aug. 22-28	5.64	8.42	9.90	10.82	15.93	4.49	5.01	4.06	14.21
Aug. 29- Sep.04	5.39	8.18	9.45	11.43	15.93	4.15	4.80	4.31	13.58
Sep. 5-11	5.02	7.59	8.13	10.74	15.93	4.11	4.57	4.09	13.36
Sep. 12-18	4.69	6.88	7.16	9.70	15.49	3.84	4.32	4.18	12.03
Sep. 19-23	3.80	5.59	8.11	10.22	15.41	3.46	2.31	4.84	10.52
Total	370.0	465.1	527.8	652.7	724.4	247.5	278.6	285.9	759.0

Table 3: Regression statistics between Penman Monteith and different methods of ET_0

Variables	Modified Penman	Hargreaves Equation	Samani Hargreaves Equation	Thornthwaite Equation	Solar Radiation	Net Radiation	Blaney Criddle	Radiation
Regression line slope (m)	1.519	0.125	0.253	0.002	0.558	0.694	0.018	2.302
Regression line intercept (c)	-0.024	8.154	9.583	12.10	1.269	1.090	4.861	0.868
Coefficient of determination (R^2)	0.926	0.001	0.039	0.001	0.651	0.943	0.002	0.712
t-test (T-critical=2.001)	-42.16	12.89	42.71	75.53	17.77	14.60	3.47	41.44

RESULT AND DISCUSSION

Comparison of ET_0 derived from different methods

The trend of estimated ET_0 during French bean growing period (26th July to 23rd September) reflected a wide range starting from 3.80 mmd^{-1} to as high as 5.89 mmd^{-1} by Penman-Monteith method with a mean value of 5.05 mmd^{-1}. In the last week of the crop, the senescence of the plant leaves and the gradual lowering of atmospheric temperature lowered the average ET. The trend of ET_0 found to be in agreement of the general understanding of the ET_0 estimated based on the weather parameters. The total ET loss estimated by Penman-Monteith method for french bean during the entire season of the crop was 370.0 mm. In case of other methods, the sum total ET_0 losses were found to be 465.1 mm by Modified Penman method, 527.8 mm by Hargreaves method, 652.7 mm by Samani-Hargreaves method, 727.4 mm by Thornthwaite method, 247.5 mm by Solar radiation method, 278.6 mm by Net radiation method, 285.9 mm by Blaney-Criddle method and 759.0 mm by Radiation method (Table 2). Thus Radiation method, Thornthwaite method, Samani-Hargreaves method and Hargreaves method highly over estimated the ET_0 at Umiam during french bean crop season while Blaney-Criddle method, Solar radiation method and Net radiation method under estimated the ET_0.

The linear regression values obtained between the Penman-Monteith method and other methods (Table 3) revealed that Hargreaves and Samani-Hargreaves, Thornthwaite and Blaney-Criddle methods failed to follow the trend as in case of Penman-Monteith method as R^2 values were very less (<0.04). The Modified-Penman, Solar radiation, Net radiation and Radiation methods could estimate ET_0 values with similar trend as in case of Penman-Monteith method. The *t*-statistics confirmed that none of the method could estimate ET_0 values which were significantly similar.

Previous research also indicated that Hargreaves and R_s-based methods resulted in the overestimation of ET_0 relative to the FAO 56-PM method. Temesgen *et al*. (1999) have indicated that high humidity conditions might result in an overestimation of ET_0 by the Hargreaves method whereas the conditions with high wind speed might result in the underestimation of ET_0. Lower ET_0 was obtained in Solar radiation method as compared to other methods. Two radiation based methods were giving closer estimate to that

Table 4: Crop coefficient for french bean

Week starting with the date	ET_0(mm)	ET_c(mm)	k_c
July, 25-31	4.72	1.23	0.26
Aug. 1-7	4.99	2.24	0.45
Aug. 8-14	5.34	3.06	0.57
Aug. 15-21	5.89	4.06	0.69
Aug. 22-28	5.64	5.05	0.90
Aug. 29- Sep,04	5.39	5.42	1.01
Sep. 5-11	5.02	4.46	0.89
Sep, 12-18	4.69	2.60	0.55
Sep. 19-23	3.80	1.48	0.39

of Penman-Monteith method. Tomar (2016) also found that radiation methods such as FAO-24, Jensen-Haise and Priestley-Taylor method could estimate compatible ET_0 values as estimated by Penman-Monteith method.

From the present study, it was found that Solar radiation and Net radiation (Irmak *et al.*, 2003) methods could be used with certain degree of accuracy. As per the recommendation of FAO, the Penman-Monteith method is always the preferred model for ET_0 estimation irrespective of climate and location. These two methods can be used if only solar radiation and mean temperature data are available without going for extensive scheme of calculation as in case of Penman-Monteith method.

Crop evapo-transpiration and crop-coefficients for french bean

The values of ET_c as measured and calculated through lysimeter varied from 1.25 mmd^{-1} to 5.42 mmd^{-1} during the crop season (Table 4). The highest values was obtained during the period of maximum vegetative growth. During early stage the ET_c as recorded in the lysimeter is due to evaporation alone. Hence the effective evapotranspiration from theinitial period has been taken from the trend from the plot developed bewteen days after sowing and k_c values. The k_c values obtained for intial period, mid season with maximum vegetative growth and end stage were 0.45, 1.01 and 0.39, respectively (Fig.1).The values given in FAO 56 are 0.5, 1.05 and 0.9, respectively for the same growth stages. The $k_{c,end}$ value in our experiment was found to be lower because it was considered after the fourth harvesting of crop. The canopy of the crop was not present due to human disturbance during harvesting and leaves senescence. Mehta and Pandey (2016) found the k_c values for green gram crop as 0.4, 1.05 and 0.6 for initial, mid and end stages, respectively after correction over FAO tabulated values. As green gram posses similar canopy structure that of French bean with progressive harvesting, our values are found to be in agreement.

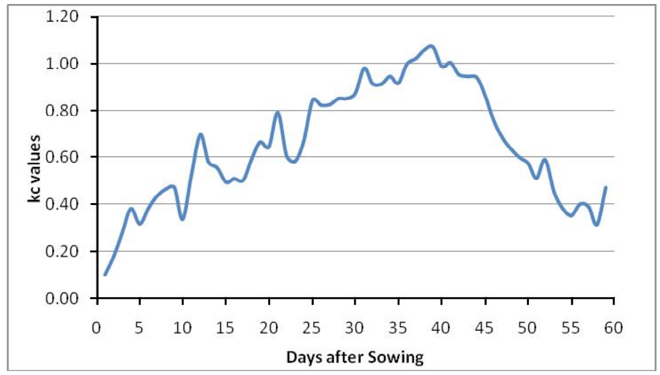

Fig.1 : Daily crop coefficient of french bean using Penman-Monteith method

CONCLUSION

Based on regression analyses of the tested methods with Penman-Monteith method it was found that Solar radiation and Net radiation methods gave better results and compatible to Penman-Monteith method, hence can be used in absence of all the requisite data in North Eastern Hilly Region of India. French bean had crop coefficient for initial, mid and end stages as 0.45, 1.01 and 0.39, respectively.

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