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# Estimation of water requirement for soybean (*Glycine max*) and wheat (*Triticum aestivum*) under vertisols of Madhya Pradesh

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ABSTRACT

The present study was undertaken to evaluate various methods of estimating evapotranspiration to predict water requirement of soybean and wheat crops for nine selected districts of Madhya Pradesh under vertisols. Four methods (Penmann-Montieth, Hargreaves, SCS-Blaney-Criddle and Thornthwaite) of reference evapotranspiration ($ET_0$) estimation were compared for assessing their predictive capability for Bhopal and Indore districts using meteorological data. Reference evapotranspiration was estimated by using Penmann-Montieth method for two districts (Bhopal and Indore) for which data on solar radiation were available and Hargreaves method for remaining seven districts (Chhindwara, Dhar, Guna, Hoshangabad, Jabalpur, Khandawa and Raisen). Crop water requirements were determined through field experiments conducted during 2008 to 2010 for soybean and 2008-09 to 2010-11 for wheat crops using non-weighing type lysimeters at research farm of Central Institute of Agricultural Engineering, Bhopal. The study revealed that among the four methods, Hargreaves method estimated $ET_0$ values with minimum deviation (4.24%) for Bhopal as compared to Penmann-Monteith. The water requirement of soybean and wheat estimated by Penmann-Monteith method was in close agreement (-2.58% and 9.26% deviation) with the measured average water requirement (401.6 and 352.2 mm) respectively followed by Hargreaves method for Bhopal district. It is also inferred that in absence of solar radiation data Hargreaves method could be considered for predicting water requirement of soybean and wheat crops. These water requirement values are useful for effective planning of irrigation scheduling of the soybean and wheat crops in the State.

**Key words :** Crop co-efficient, Evapotranspiration, Soybean, Vertisols, Water requirement, Wheat

Agriculture continues to draw a major share (90%) of available water resources and the demand is likely to increase further (Amarasinghe *et al.* 2008). The increasing worldwide shortages of water and costs of irrigation are leading to an emphasis on accurate assessment of crop water requirement for precise irrigation water application to various crops. Madhya Pradesh (MP) remains a state of developmental paradoxes of a gross cropped area of 20.760 Mha, only 6.506 Mha is net irrigated area during 2008-09. In spite of technological advances and annual rainfall (800 to 1600 mm) productivity and success of agriculture in rainfed areas continues to be governed by vagaries of rains.Bhopal district falls under 5$^{th}$ Agro-climatic region (Vindhya Plateau) of MP having medium black to deep black soils (vertisols) and wheat crop zone. MP has a unique distinction of having more than 87% soybean (*Glycine max*) (Dwivedi *et al.* 2006) area of the country and is rightly designated as Soya State. Soybean followed by wheat (*Triticum aestivum*) is the main cropping sequence of the state especially in vertisols.

Irrigation scheduling for different crops requires planning and knowledge of water requirement. Due to variation in crop canopy with time, water requirement of crops varies during growing period (Gerson *et al.* 2001). The key feature for water requirement is evaporation demand. Evapotranspiration (ET) is the combined process of evaporation from the soil and transpiration from the plants (Thornthwaite 1948). Several popular approaches have been used to estimate ET by the researchers (Sikka *et al.* 2001). Many methods have been suggested in the literature to estimate reference evapotranspiration ($ET_0$) from which crop water requirement can be calculated. The determination of water requirement of crops using lysimeter is laborious and quite expensive. Hence efforts have been made to correlate the measured crop water requirements in the field with the estimated crop water requirements by different methods using agro-meteorological data (Doorenbos and Pruitt 1977, Allen 1993, Allen *et al.* 1998). Jensen *et al.* (1990) considered twenty well-established and widely used methods to estimate ET for comparison of their performance under different climatic conditions using data from 11 stations worldwide.

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The ranks were given to all methods of ET estimation for three climatic regions and these ranks are considered as American Society of Civil Engineers (ASCE) rank (Swarnkar *et al.* 2002). In India, different evapotranspiration estimation methods were evaluated using climatological data and compared in different regions by many researchers (Kashyap and Panda 2001, Saha 2011).

In India limited lysimetric studies on measurement of ET for soybean and wheat crops were carried out by many researchers in different regions. Maniyar *et al.* (2010) established a relationship between the measured value of ET by lysimeter and the estimated potential ET by different empirical formulae for soybean under Marathwada region at Parbhani (Maharashtra). The study revealed that the modified Penman method is found to be the most suitable and accurate in estimation as compared with the Blaney and Criddle, Thornthwaite and pan evaporation methods. The total seasonal measured ET (353.59 mm) for soybean at Parbhani is found to be less than the seasonal water requirement.The Blaney and Criddle and pan evaporation estimation methods under estimated the values when compared with lysimetric data (Kamble *et al.* 2010). The estimated seasonal ET was 10% lower than the measured lysimetric ET values for soybean in Akola region of Maharashtra. The regression equation of estimated mean ET values over mean measured ET values was Y = 0.8427x + 4.2571, having a correlation coefficient (r) of 0.9579 (Patil *et al.* 2000).

The evapotranspiration from some crops (rice, wheat and jowar) in three semi-arid, and one dry sub-humid, climatic locations of Maharashtra were estimated from climatic parameters. The estimated seasonal ET for wheat was found to be 278-373 mm for wheat. The measured lysimetric ET values were higher than the estimated ET values (Subramaniam A R 1989). Lysimetrically measured seasonal ET of *rabi* wheat under Pantnagar tarai region of Uttaranchal ranged between 520.7 and 524.9 mm. PET estimated by a newly developed weather data based equation was found to be correlated with measured ET at 0.1% level of significance (r = 0.956 to 0.969) with the least under/overestimation (–0.9 to +1.9%) ( Singh 2002). Daily, weekly, and seasonal crop evapotranspiration of wheat was measured directly from sensitive weighing-type lysimeters at Karnal, India (Tyagi *et al.* 2000). Measured Kc values were significantly different from those suggested by the Food and Agricultural Organization of the United Nations. Daily evapotranspiration from a winter wheat field on the North China Plain measured by large-scale weighing lysimeter was linearly related to that measured by the Bowen ratio energy balance (BREB) technique (Zhang *et al.* 2002).The information on crop evapotranspiration values for soybean and wheat crops for places having vertisols in Madhya Pradesh are not available for irrigation scheduling.

Therefore, the present study was undertaken to estimate $ET_0$ for predicting water requirement of soybean and wheat crops in identified nine districts of State and to compare predicted/estimated water requirements with measured crop water requirements for one location (Bhopal district) through field experiments using lysimeters.

## MATERIALS AND METHODS

The study was carried out at research farm of Central Institute of Agricultural Engineering (CIAE), Bhopal (23° 18' to 23° 20' N latitude and 77°24' to 77° 25' E longitude) with 495 m altitude. Winter temperature varies from 10°C to 25°C and summer temperature varies from 25°C to 42°C. Average annual rainfall is 1090 mm confined mainly from mid-June to mid-September. The monthly variations in the climate parameters for selected nine districts are presented in Table 1.

The Penmann-Monteith (PM) method is ranked first for estimating $ET_0$ where solar radiation (SSH) data are available (Jenson *et al.*1990). For the places with available temperature, relative humidity (RH), wind velocity data, three methods, i.e. Hargreaves (Ranked as 11 by ASCE), SCS Blaney-Criddle (ASCE Rank 15) and Thornthwaite (ASCE Rank 20) can be used for estimating $ET_0$. Daily meteorological data of about 20 years period (1985 to 2006) of nine identified districts of Madhya Pradesh namely Bhopal, Chhindwara, Dhar, Guna, Hoshangabad, Indore, Jabalpur, Khandawa and Raisen were obtained from India Meteorological Department (IMD), Pune, Maharashtra. Daily meteorological data (i.e. maximum and minimum daily air temperature, maximum and minimum relative humidity (RH), sun shine hours (SSH), and wind speed were analyzed to generate parameter values for the considered four methods of $ET_0$ estimation under present study as given in Table 2.

The comparison among these four methods of $ET_0$ estimation was made for two identified districts (Bhopal and Indore) for which daily solar radiation data were available. For the places where solar radiation (SSH) data were not available other methods were used. Estimated monthly $ET_0$ values by PM method (*CROPWAT Software*) were used for estimation of crop evapotranspiration for Bhopal and Indore districts. Estimated $ET_0$ values using Hargreaves method (suggested alternative method of $ET_0$ estimation by FAO), were used to calculate crop evapotranspiration values for remaining seven districts. In order to calculate the crop evapotranspiration from equation (1) the crop coefficient ($K_c$) are also required.

$$ET_c = K_c * ET_0 \quad (1)$$

where, $ET_c$, Crop evapotranspiration; $ET_0$, Reference crop evapotranspiration; $K_c$, = Crop coefficient

The $K_c$ values used in computation of estimated $ET_c$ from $ET_0$ for soybean and wheat crops were obtained from literature (Doorrenhos and Pruitt 1977 and Allen *et al.* 1998). Based on $K_c$ values the entire cropping period is divided into four growth stages, i.e. initial (0.3 – 0.35), development

Table 1 Climatological data of nine identified districts of Madhya Pradesh

| Month | Bhopal | | | | Indore | | | | Khandwa | | | Dhar | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean temp. (°C) | RH (%) | WS (km/h) | SSH (h) | Mean temp. (°C) | RH (%) | WS (km/h) | SSH (h) | Mean temp. (°C) | RH (%) | WS (km/h) | Mean temp (°C) | RH (%) | WS (km/h) |
| Jan | 18.9 | 45 | 6.6 | 9.0 | 18.7 | 60.3 | 5.1 | 8.9 | 18.9 | 44.8 | 2.4 | 17.7 | 56.6 | 3.5 |
| Feb | 21.4 | 35 | 7.9 | 9.7 | 20.9 | 52.5 | 6.2 | 9.6 | 21.4 | 34.6 | 3.4 | 20.7 | 50.3 | 4.6 |
| Mar | 25.8 | 25 | 8.9 | 9.2 | 25.7 | 35.5 | 7.6 | 9.3 | 25.7 | 25.4 | 4.3 | 25.2 | 41.4 | 4.8 |
| Apr | 30.6 | 20 | 10.2 | 10.0 | 30.1 | 25.9 | 10.0 | 10.0 | 30.6 | 19.9 | 6.0 | 29.9 | 40.9 | 5.4 |
| May | 33.2 | 32 | 12.7 | 10.1 | 32.7 | 27.7 | 13.8 | 10.2 | 33.2 | 31.5 | 10.1 | 31.9 | 51.8 | 8.3 |
| Jun | 30.3 | 55 | 13.9 | 6.9 | 30.5 | 55.9 | 15.2 | 6.9 | 30.3 | 54.6 | 10.7 | 29.1 | 72.7 | 9.3 |
| Jul | 26.2 | 72 | 12.3 | 3.6 | 26.7 | 77.0 | 14.9 | 3.5 | 26.6 | 72.4 | 9.8 | 25.6 | 86.2 | 9.0 |
| Aug | 25.5 | 77 | 10.9 | 3.2 | 25.5 | 83.5 | 12.1 | 3.1 | 25.5 | 77.0 | 7.6 | 24.7 | 85.9 | 7.4 |
| Sep | 26.3 | 58 | 8.4 | 6.1 | 26.0 | 76.0 | 8.2 | 6.0 | 26.3 | 67.9 | 5.2 | 25.2 | 74.6 | 5.2 |
| Oct | 25.5 | 51 | 5.9 | 8.7 | 25.4 | 61.5 | 4.6 | 8.5 | 25.5 | 51.3 | 2.2 | 25.4 | 61.6 | 2.6 |
| Nov | 22.0 | 41 | 5.9 | 9.1 | 22.5 | 57.3 | 3.7 | 8.7 | 22.0 | 41.0 | 1.9 | 22.1 | 56.1 | 2.9 |
| Dec | 19.0 | 43 | 5.5 | 8.7 | 19.4 | 60.8 | 3.9 | 8.5 | 19.0 | 43.2 | 1.6 | 19.8 | 56.9 | 2.7 |

Table 1 Climatological data of nine identified districts of Madhya Pradesh (Continued)

| Month | Guna | | | Chhindwara | | | Hoshangabad | | | Jabalpur | | | Raisen | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean temp (°C) | RH (%) | WS (km/h) | Mean temp (°C) | RH (%) | WS (km/h) | Mean temp (°C) | RH (%) | WS (km/h) | Mean temp (°C) | RH (%) | WS (km/h) | Mean temp (°C) | RH (%) | WS (km/h) |
| Jan | 16.9 | 56.4 | 4.0 | 18.9 | 46.9 | 3.8 | 17.6 | 60.3 | 2.8 | 17.6 | 60.3 | 2.8 | 16.5 | 57.3 | 2.6 |
| Feb | 19.6 | 46.5 | 4.3 | 21.3 | 40.4 | 4.5 | 20.5 | 52.5 | 3.5 | 20.5 | 52.5 | 3.5 | 19.2 | 47.4 | 3.7 |
| Mar | 25.0 | 32.0 | 4.9 | 25.6 | 43.1 | 5.7 | 25.5 | 35.5 | 4.1 | 25.5 | 35.5 | 4.1 | 24.1 | 37.0 | 5.0 |
| Apr | 30.3 | 24.1 | 5.6 | 30.9 | 36.7 | 5.3 | 30.8 | 25.9 | 4.6 | 30.8 | 25.9 | 4.6 | 30.6 | 30.2 | 6.8 |
| May | 34.1 | 27.8 | 7.2 | 33.5 | 39.2 | 7.7 | 34.3 | 27.7 | 5.7 | 34.3 | 27.7 | 5.7 | 34.5 | 31.2 | 10.1 |
| Jun | 32.7 | 48.9 | 8.4 | 30.7 | 57.8 | 8.0 | 32.0 | 55.9 | 6.7 | 32.0 | 55.9 | 6.7 | 31.9 | 59.5 | 11.0 |
| Jul | 28.3 | 75.5 | 7.3 | 27.0 | 67.2 | 8.2 | 27.9 | 77.0 | 6.3 | 27.9 | 77.0 | 6.3 | 26.8 | 81.1 | 9.4 |
| Aug | 26.9 | 83.0 | 5.8 | 25.7 | 68.6 | 8.0 | 26.8 | 83.5 | 5.4 | 26.8 | 83.5 | 5.4 | 26.4 | 84.1 | 7.8 |
| Sep | 27.2 | 71.5 | 4.8 | 26.0 | 65.7 | 6.1 | 27.2 | 76.0 | 4.5 | 27.2 | 76.0 | 4.5 | 27.3 | 75.1 | 5.6 |
| Oct | 25.8 | 50.8 | 3.4 | 25.1 | 51.3 | 4.8 | 25.9 | 61.5 | 3.2 | 25.9 | 61.5 | 3.2 | 24.7 | 57.0 | 3.4 |
| Nov | 21.9 | 49.0 | 2.8 | 21.6 | 51.1 | 3.9 | 21.7 | 57.3 | 2.5 | 21.7 | 57.3 | 2.5 | 19.4 | 57.0 | 2.5 |
| Dec | 18.1 | 55.0 | 3.0 | 18.7 | 46.5 | 3.4 | 18.2 | 60.8 | 2.1 | 18.2 | 60.8 | 2.1 | 16.3 | 57.8 | 2.2 |

Table 2 Different empirical methods used for estimation of ET

| Methods | Equation | Descriptions |
|---|---|---|
| Penmann-Monteith (PM) | $ET_{PM} = R_d + A_d$ | Rd, radiation term (mm/d); Ad, aerodynamic term (mm/d), Rd = $(\Delta/\Delta + \beta)$ (Rn – G), where Rn, net radiation (mm/d) and G, soil heat flux (mm/d), $\beta$, psychrometric constant |
| Hargreaves (HG) | ETHG = $0.0023\ R_A \sqrt{(TD)}\ (T_{Mean} + 17.8)$ | TD, the difference between mean monthly maximum and mean monthly minimum temperatures in °C; RA , extraterrestrial solar radiation in MJ $m^{-2}\ d^{-1}$; $T_{Mean}$, mean monthly air temperature in °C |
| SCS Blaney-Criddle (BC) | $ET_{BC} = C + D(0.46Tm + 8.13)P$ | C, Constant dependent on relative humidity and sunshine hours; D, constant dependent on relative humidity, sunshine hours and day time wind speed; Tm, mean monthly air temperature (°C) and P, monthly percentage of annual sunshine hours in the year |
| Thornthwaite (TW) | $ET_{TW} = 1.6\ (10\ T/I)^{\alpha}$ | T average daily temperature (°C) of the month i, I = annual or seasonal heat index |
| | $I = \Sigma_{i=1}^{12}(Ti/5)$ | Where $\alpha$ is a constant and $\alpha = 67.5 \times 10^{-8} I^3 - 77.1 \times 10^{-6} I^2 + 0.0179I + 0.492$ |

(0.725 – 0.775), mid (1.15 – 1.20) and maturity (0.25 – 0.50). Soybean and wheat crops growing periods were considered 110 days and 130 days respectively.

The seasonal water requirements of soybean and wheat crops were measured using non-weighing type lysimeter during *kharif* (year 2008 to 2010) and *rabi* (year 2008-09 to 2010-11) seasons at CIAE research farm. Wheat (variety HI-1544) and soybean (variety JS-335) crops were cultivated with recommended agronomical practices in non-weighing type lysimeter. The following water balance equation was used for crop water requirement measurement:

$$P + I = RO + S + DL + CWU \tag{2}$$

where: P is total rainfall during crop period, I is irrigation water applied, RO is total surface water runoff, S is change in soil moisture storage, DL is deep percolation losses and CWU is crop water use. Daily data on rainfall, soil moisture, surface water runoff, deep percolation losses were recorded. The soil moisture data were recorded daily throughout crop season using digital indicative type pre-calibrated soil moisture meter with gravimetric method of soil moisture measurement.

## RESULTS AND DISCUSSION

### *Reference evapotranspiration*

The estimated reference evapotranspiration rates by four methods and measured crop evapotranspiration rates for Bhopal district are graphically presented in Fig 1 and monthly average $ET_0$ (mm/day) values for Bhopal are given in Table 3. The estimated average monthly $ET_0$ values using PM method were found to be 5.39 mm for Bhopal. Estimated evapotranspiration values were high during the summer (March to June) due to high temperature, low humidity and strong winds prevailing at that time. Relatively low evapotranspiration was observed during rainy and winter season (July to February). The $ET_0$ values are significantly influenced by the temperature. The average mean monthly maximum temperature (40.62 to 40.93°C) is observed in May month and minimum (10.93 to 11.63°C) in December month.

Table 3 Comparison of estimated average $ET_0$ values of the year by different methods

| District | Monthly $ET_0$ values (mm/day) | | | | Deviation (% Dv) from PM method | | |
|---|---|---|---|---|---|---|---|
| | PM | HG | BC | TW | HG | BC | TW |
| Bhopal | 5.39 | 5.23 | 5.41 | 4.53 | 4.24 | 9.61 | -20.23 |

### *Comparison of estimated $ET_0$ values*

The average monthly $ET_0$ values estimated using HG, BC and TW methods vary from 4.53 to 5.41 mm/day for Bhopal district. The $ET_0$ estimated by HG and BC methods are higher as compared to PM method with mean deviations

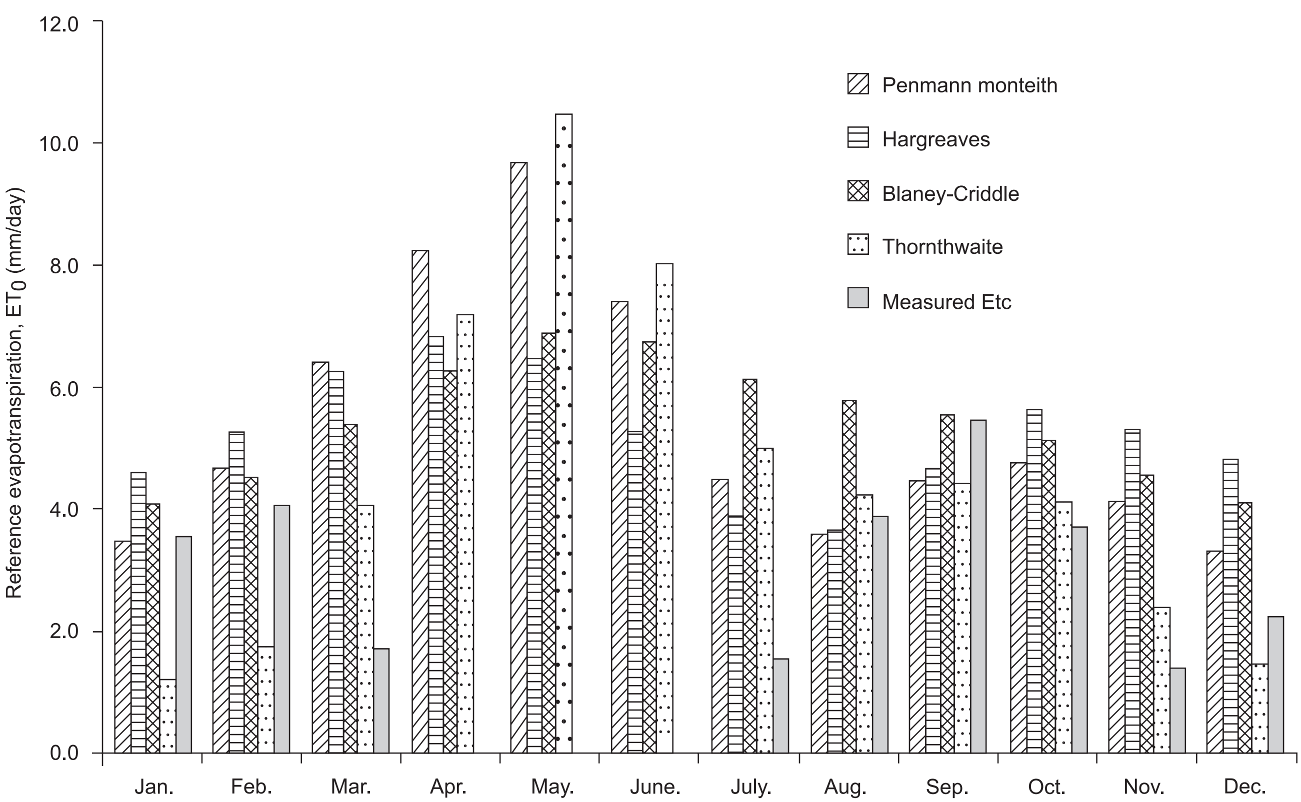


Fig 1 Reference evapotranspiration estimated by various methods for Bhopal

Table 4 Reference evapotranspiration in (mm/day) for identified districts

| Month | Bhopal | Indore | Khandawa | Dhar | Guna | Chhindwara | Hoshangabad | Jabalpur | Raisen |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 3.45 | 3.17 | 4.04 | 3.36 | 4.63 | 4.73 | 4.81 | 4.51 | 5.14 |
| Feb | 4.68 | 4.19 | 4.96 | 4.36 | 5.28 | 5.34 | 5.45 | 5.10 | 5.82 |
| Mar | 6.41 | 5.97 | 6.48 | 5.61 | 6.28 | 5.70 | 6.60 | 6.13 | 6.72 |
| Apr | 8.27 | 8.22 | 7.60 | 7.00 | 6.85 | 6.26 | 7.28 | 6.69 | 7.47 |
| May | 9.71 | 10.15 | 7.92 | 7.37 | 6.67 | 5.83 | 6.95 | 6.47 | 7.05 |
| Jun | 7.41 | 7.51 | 6.78 | 6.21 | 5.60 | 4.71 | 5.60 | 5.17 | 5.77 |
| Jul | 4.47 | 4.42 | 5.13 | 4.42 | 4.14 | 3.53 | 4.10 | 3.81 | 3.98 |
| Aug | 3.57 | 3.44 | 4.57 | 4.23 | 3.95 | 3.27 | 3.86 | 3.61 | 4.20 |
| Sep | 4.46 | 4.18 | 4.99 | 4.43 | 4.90 | 3.95 | 4.93 | 4.33 | 5.06 |
| Oct | 4.77 | 4.27 | 5.24 | 4.66 | 5.89 | 5.15 | 5.83 | 5.29 | 6.20 |
| Nov | 4.12 | 3.47 | 4.57 | 3.95 | 5.56 | 5.09 | 5.46 | 5.19 | 5.75 |
| Dec | 3.31 | 2.91 | 4.00 | 3.46 | 4.96 | 4.76 | 4.97 | 4.71 | 4.99 |
| Average | 5.39 | 5.16 | 5.52 | 4.92 | 5.39 | 4.86 | 5.49 | 5.08 | 5.68 |

(4.24% and 9.61%) respectively. The average $ET_0$ values by TW method were underestimated as compared to PM method with mean deviation -20.23%. The $ET_0$ values estimated by HG, BC and TW methods followed the similar trend. This indicates that HG and BC methods also gave reasonable estimates of $ET_0$ over TW method when compared to PM method and can be used for estimation of $ET_0$ values for the places not having solar radiation data.

*Estimation of crop evapotranspiration for identified districts of MP*

$ET_0$ values estimated using PM method for Bhopal and Indore districts and using Hargreaves method for remaining seven districts are given in Table 4. Relatively low evapotranspiration was observed during rainy and winter season (July to February). It is clear from the Table 4 that maximum $ET_0$ was observed in the month of May that varied from 5.83 to 10.15 mm/day and minimum crop evapotranspiration varying from 2.91 to 4.99 mm/day was estimated for the month of December. The average annual daily $ET_0$ values were estimated to be 5.39, 5.16, 5.52, 4.92, 5.39, 4.86, 5.49, 5.08, 5.68 mm/day for Bhopal, Indore, Khandawa, Dhar, Guna, Chhindwara, Hoshangabad, Jabalpur, and Raisen districts respectively.

The seasonal $ET_c$ values were obtained by using $ET_0$ and $K_c$ values in equation-1 for soybean and wheat crops of different crop durations cultivated in identified districts. The computed seasonal $ET_c$ values for soybean and wheat crops are presented in Table 5. The average $ET_c$ values of soybean are estimated 389.7 (370.0 to 409.5) mm and that of wheat 438.5 (394.5 to 474.8) mm respectively.

The $K_c$ values increases with crop growing season, reaches its peak in mid stage and thereafter decreases in maturity stage. The variation in crop coefficients is mainly due to plant water requirement in commensuration with canopy development (Kashyap and Panda 2001). The $K_c$ values for different growth stages for soybean ($K_{cs}$) and wheat ($K_{cw}$) crops are presented graphically in Fig 2. The average daily crop evapotranspiration of soybean ($ET_{cs}$) and wheat ($ET_{cw}$) crops were found to be minimum at initial stage of growth and maximum during mid-stage of growth as indicated in Fig. 2. The maximum value of $ET_c$ in the mid stage can be attributed to more crop water demand due to full canopy development in addition to evaporative demand. At maturity stage the rate of evapotranspiration decreases due to decrease in physiological activities. The estimated seasonal $ET_c$ values using $K_c$ and PM method for soybean and wheat crops were 391.2 mm and 387.0 mm respectively for Bhopal district.

Table 5 Estimated seasonal crop evapotranspiration values in mm for nine identified districts of MP

| Crop | Crop duration (Days) | Sowing month | Districts | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bhopal | Indore | Jabalpur | Khandawa | Dhar | Guna | Raisen | Hoshan-gabad | Chhind-wara | Avg. |
| Soybean | 90-100 | Jul | 365.7 | 335.4 | 348.6 | 413.5 | 370.7 | 387.9 | 401.9 | 385.4 | 321.0 | 370.0 |
| | 100-110 | Jul | 391.2 | 368.1 | 390.1 | 452.8 | 405.2 | 434.2 | 450.5 | 431.3 | 361.7 | 409.5 |
| Wheat | 110-120 | Nov | 335.9 | 302.2 | 420.4 | 381.7 | 326.7 | 436.5 | 468.0 | 447.1 | 431.9 | 394.5 |
| | 120-130 | Nov | 387.0 | 348.6 | 471.6 | 434.1 | 372.6 | 489.2 | 526.6 | 502.1 | 484.1 | 446.2 |
| | 130-140 | Nov | 415.0 | 373.5 | 500.3 | 462.8 | 398.0 | 519.1 | 559.0 | 532.8 | 512.8 | 474.8 |

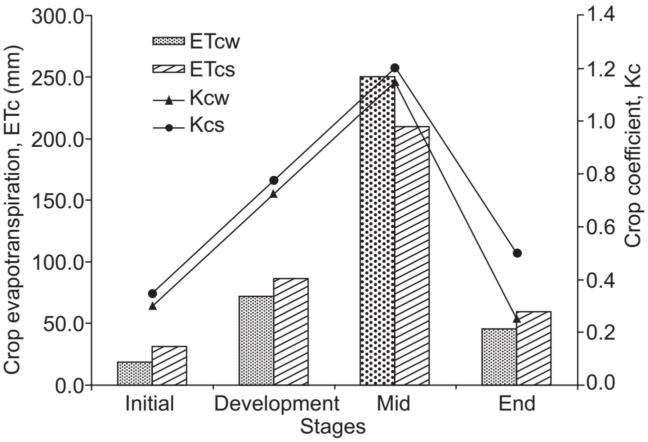


Fig 2 Crop coefficients and crop evapotranspiration for various stages

The rainfall at 75% probability and evapotranspiration of soybean and wheat are shown in Fig 3 for Bhopal district. Soybean is main crop during *kharif* season. It is observed that the rainfall received during the season is sufficient to meet the crop water requirement except September and October months. Hence, irrigation is needed during pod development stage of soybean crop in September. The wheat crop is predominantly grown in the region during *rabi* season. The rainfall during *rabi* season is negligible and wheat crop required irrigation during all stages of its growth.

*Measured crop water requirement of soybean and wheat for Bhopal*

The seasonal water requirement of soybean and wheat crops measured in lysimetric study and estimated using equation-2 for Bhopal district are given in Table 6. The predicted total water requirement using PM method and crop coefficients for soybean crop of 110 days duration and wheat crop of 130 days duration were 391.2 mm and 387.0 mm respectively. The average value of water requirement of wheat from field experimentation was observed to be 352.2 mm (349.5 to 360.7 mm) with 9.26% deviation and soybean was found to be 401.6 mm (393.2 to 411.8 mm) with -2.58% deviations from predicted $ET_c$ by PM method.

Table 6 Measured water requirement (mm) of soybean and wheat crops under field conditions at Bhopal

| Crop and variety | Year | $ET_c$ (mm) | Yield (tonnes/ha) |
|---|---|---|---|
| Soybean (variety JS-335) | 2008 | 399.7 | 1.52 |
| | 2009 | 393.2 | 1.61 |
| | 2010 | 411.8 | 1.87 |
| Average | | 401.6 | 1.67 |
| Estimated $ET_c$ by PM method | | 391.2 mm | |
| (%Dv from measured $ET_c$) | | (–2.58%) | |
| Estimated $ET_c$ by HG method | | 410.9 mm | |
| (%Dv from measured $ET_c$) | | (2.32%) | |
| Wheat (variety HI-1544) | 2008-09 | 349.5 | 4.28 |
| | 2009-10 | 360.7 | 5.23 |
| | 2010-11 | 352.4 | 4.72 |
| Average | | 352.2 | 4.74 |
| Estimated $ET_c$ by PM method | | 387.0 | |
| (%Dv from measured $ET_c$) | | (9.26%) | |
| Estimated $ET_c$ by HG method | | 483.5 | |
| (%Dv from measured $ET_c$) | | (37.24%) | |

The predicted total water requirements using HG method for soybean and wheat crops were 410.9 mm and 483.5 mm respectively. The percent deviation of water requirement of soybean and wheat estimated by HG method from that of measured water requirement was found to be 2.32% and 37.24% respectively. It is inferred that seasonal water requirement of soybean as predicted by HG method is in close agreement (Dv = 2.32%) with the measured water

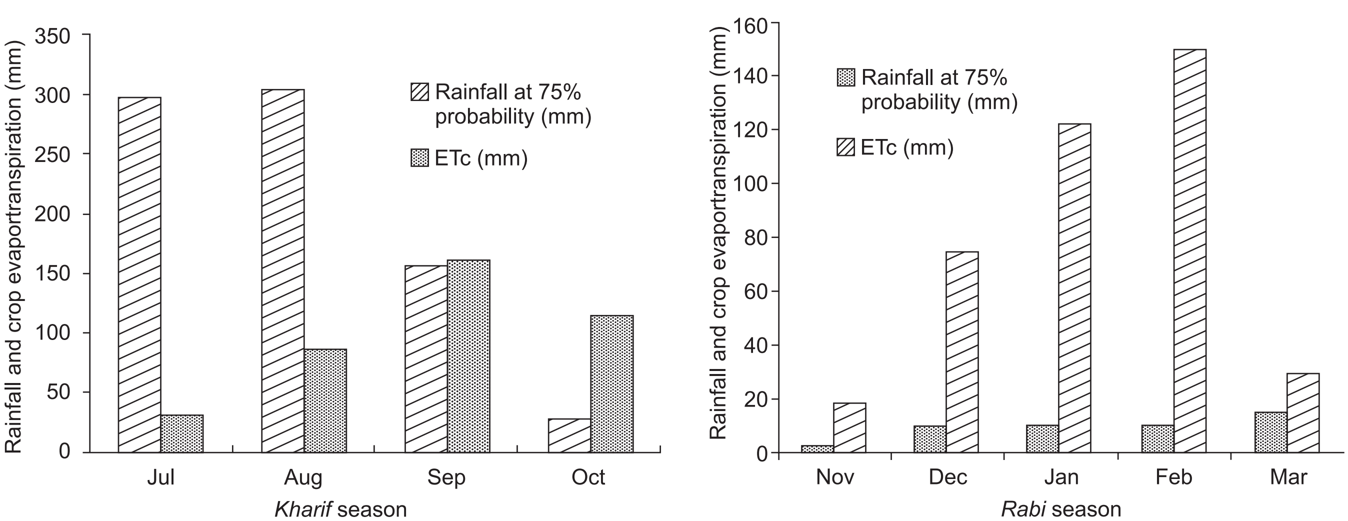


Fig 3 Comparison between rainfall at 75% probabilities and crop evapotranspiration for soybean (*kharif* season) and wheat (*rabi* season)

Table 7 Comparison of estimated, measured (Lysimeter) and reference evapotranspiration for Bhopal district

| Month | $ET_{estimated}$ (mm) | $ET_{estimated}$ (mm/day) | $ET_{measured}$ (mm) | $ET_{measured}$ (mm/day) | $ET_0$ (mm/day) | Absolute Residual ($ET_{Lys}$-$ET_0$) (mm/day) |
|---|---|---|---|---|---|---|
| Soybean | | | | | | |
| Jul | 31.3 | 1.57 | 30.1 | 1.51 | 4.47 | 2.96 |
| Aug | 112.2 | 3.62 | 119.8 | 3.87 | 3.57 | 0.3 |
| Sep | 160.4 | 5.35 | 163.2 | 5.44 | 4.46 | 0.98 |
| Oct | 87.3 | 3.64 | 88.5 | 3.69 | 4.77 | 1.08 |
| Total | 391.2 | | 401.6 | | | |
| Regression equation between estimated and measured ET (mm/day) | Y = 1.2539 X – 0.427 r = 0.998 | | | | | |
| t- table value ( $t_{0.95, 4}$ ) for one tailed distribution | 2.35 | | | 2.35 | | |
| Student's t test for mean ET | 1.51 | | | 0.88 | | |
| *Wheat* | | | | | | |
| Nov | 18.6 | 1.24 | 20.3 | 1.36 | 4.12 | 2.76 |
| Dec | 75.8 | 2.45 | 68.1 | 2.20 | 3.31 | 1.11 |
| Jan | 123.0 | 3.97 | 109.5 | 3.53 | 3.45 | 0.08 |
| Feb | 129.6 | 4.63 | 113.2 | 4.04 | 4.68 | 0.64 |
| Mar | 40.0 | 1.60 | 41.3 | 1.65 | 6.41 | 4.76 |
| Total | 387.0 | | 352.4 | | | |
| Regression equation between estimated and measured ET (mm/day) | | Y = 0.9877 X + 0.1262 r = 0.999 | | | | |
| t- table value ( $t_{0.95, 4}$ ) for one tailed distribution | 2.13 | | | 2.13 | | |
| Student's t test for mean ET | 1.62 | | | 2.12 | | |

requirement. However, there is significant difference (Dv = 37.24%) between the predicted seasonal water requirement of wheat by the same method.

Analysis further revealed that among the above four methods, HG method estimated $ET_0$ values with minimum deviations for Bhopal district as compared to PM method. The water requirement of soybean and wheat estimated by PM method was in close agreement with the measured average water requirements followed by Hargreaves method for Bhopal district. Hargreaves method is most suitable for estimation of water requirement of soybean and wheat crops in absence of solar radiation data.

The comparison of estimated, measured and reference mean monthly evaporation values for Bhopal district is presented in Table 7. The regression equation of estimated mean monthly ET over measured values was Y = 1.2539X-0.427, having a correlation coefficient (r) of 0.998. Similarly for wheat the regression equation of estimated mean monthly ET over measured values was Y = 0.9877 + 0.1262, having a correlation coefficient (r) of 0.999. The student t-test indicates that there is no significant difference between estimated and measured mean monthly ET values for soybean and wheat at 5% level of significance. The difference between measured monthly ET and $ET_0$ values was also not found to be significant. The high correlation coefficients indicate a close relationship between the measured and the estimated crop evapotranspiration.

During *kharif* season soybean requires at least one irrigation (in case of early withdrawal of monsoon) to meet the crop water requirement during September at pod development stage. During *rabi* season wheat requires irrigation from November to March which indicates necessity of storage of rainwater runoff in the region to meet crop water requirements for sustainable agriculture. The created database of crop evapotranspiration values for soybean and wheat crops for nine districts of Madhya Pradesh can be used for effective planning and precise irrigation scheduling of the crops.

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