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Comparison of Crop Evapotranspiration by FAO, BREB and Pristley-Taylor methodsin mustard Crop in Central Bihar Region

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ABSTRACT

Untimely sowing, poor crop stands and absence of lack of high yielding varieties and lack of zone specific crop production technology, moisture stress and uncertain and extreme weather conditions are the major factor which govern the productivity of rapeseed-mustard in eastern India particularly in Bihar. This study was conducted in the experimental farm of ICAR Research Complex for Eastern Region, Patna, Bihar during 2011-12 and 2012-13. Bowen ratio energy balance (BREB) method is a micrometeorological method by combining Bowen ratio with energy balance equation of earth surface. The climate of the experimental site is semi-arid with dry hot summer and mild winters. Summers are long (early April–August) with monsoon setting in between July and September. May and June are the hottest months with mean daily maximum temperature ranging from 30 to 40°C. At 11.00 to 12.00 hours, the Rn reaches the maxima and its value reduces drastically after 15.00 hours. ET0 calculate by established empirical equation was compared with the pan evapotranspiration (ETpan) data and it was observed that PT method can be safely used to calculate ET0 in the study zone. The crop evapotranspiration (ETc) using Bowen Ratio Energy Balance method was also observed and compared with output from PT method. The ratio between LE/Rn attained the higher value at siliqua emergence (SE) and pod formation (PF) stages indicating higher water demand during the same crop growth period.

Keywords: Crop evapotranspiration, Mustard, Pristley-Taylor method

INTRODUCTION

The second most important edible oilseed crop in India after groundnut is rapeseed-mustard. It is one of the major sources of oil in India (Singh *et al.*, 2014a). Mustard oil is traditionally the most important oil for the different parts of the country. Untimely sowing, poor crop stands and absence of lack of high yielding varieties and lack of zone specific crop production technology, moisture stress and uncertain and extreme weather conditions, incidence of diseases and pests are the major factor which govern the productivity of rapeseed-mustard in eastern India particularly in Bihar(Singh *et al.*, 2014b and Singh *et al.*, 2014c). But well managed crop need irrigation during critical period of its growth. Enhancement of water productivity is the main challenge in Indian agriculture as water is the most prime input in agriculture of our country. Both solar radiation and temperature are playing the decisive role in determining the growth and production potentiality of rapeseed-mustard. The radiation pattern influences temperature pattern mostly. Major mustard producing states in the country are Rajasthan, accounting more than 50% of its production followed by Uttar Pradesh, Haryana, Madhya Pradesh and Gujarat. The overall area under rapeseed-mustard has increased by 1.85 lakh hectares to 67.17 lakh hectares during 2012-13 while the production is expected to jump by 12.32 lakh tonnes to 71.12 lakh tonnes, due to good subsoil moisture at the time of sowing, useful showers during January and February and hardly damaged (Anonymous, 2014). Management of natural resources needs accurate assessment. In field water balance one factor is evapotranspiration (ET). ETis the removal of water as vapour form from the soil plant system by direct evaporation and plant transpiration. It is the most important component of the hydrological cycle whose accurate calculation at the local and regional scale is needed to achieve an appropriate management of water requirements, in irrigation scheduling and planning, watershed hydrology, mechanistic crop growth models and other models that attempt to simulate the soil water budget. The reference evapotranspiration (ET_0) refers to water evaporation from a unit ground area completely covered by a 0.12m grass, healthy and unstressed and with ample water supply. There are different methods to measure evapotranspiration. Sun is the only source of all energy that takes part in the formation of consumable energy for animal and human being through the production of photosynthates. Both temperature and solar radiation play a great role in determining the growth and production potentiality of different crops. Radiation is needed for photosynthesis and normal plant growth. When radiation falls on a surface a part of it is absorbed, a part is reflected and rest is transmitted. Photosynthetically active radiation (PAR) and shortwave radiation have a very strong relationship. The proportion of PAR changed with intensity of incident irradiance and length of photoperiod. Net radiation and global solar radiation pattern varies diurnally. Moreover, their seasonal pattern changes along with changing canopy architecture and growth stages. The radiation pattern influences temperature pattern mostly. In general, growth is

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promoted when temperature rises and inhibited if the temperature falls. The changed climatic scenario has definite impact on plant.

The growth rate of plants does not continue to increase indefinitely with temperature rise. Temperature increases transpiration and thus reduces turgor and growth, especially during the day.Transpiration involves the use of about 90% of the water that enters the plants through the roots. Soil temperature is another important factor in achieving plant growth.Under the present and future climatic scenario; it can be stated without any doubt that water is the prime problem. To manage it we have to manage it properly. Bowen ratio energy balance (BREB) method is a micrometeorological method by combining Bowen ratio with energy balance equation of earth surface (Tanner, 1960, Ashktorab *et al*. 1989, Nkemdirim and Haley 1973, Malek and Bingham 1993, Jegede 2002 and Mukherjee *et al*., 2012). This method has been used to estimate energy (both sensible and latent heat parts) and mass (ET) fluxes to quantify water use of crop calculation of crop coefficients (Malek and Bingham, 1993), evaluate crop water use models (Todd *et al*., 2000 and Mukherjee *et al*., 2015), measurement of emission of trace gases like methane and nitrous oxide etc., from soil or crop surface and to measure carbon dioxide assimilate rate in crops (Chan *et al*., 1998) and energy balance studies above the crop surface (Hatfield,1990 and Mokate *et al*.,1995). Moreover, evapotranspiration (ET) is the main monitoring tool of water management. So keeping in view the present study was carried out with the objective to compare crop evapotranspiration by different approaches.

MATERIALS AND METHODS

Location: This study was conducted in the experimental farm of ICAR Research Complex for Eastern Region, Patna located at 25°35'37" N latitude and 85°05' E longitude and at an altitude of 51.8 m above mean sea level. The land area of experimental field had a fairly level topography.

Climate: The climate of the experimental site is semi-arid with dry hot summer and mild winters. Summers are long (early April–August) with monsoon setting in between July and September. May and June are the hottest months with mean daily maximum temperature ranging from 30 to 40°C. Mean annual rainfall is 1200 mm, of which 80% occurs during southwest monsoon from July to September. The mean daily pan evaporation reaches a high of 9.0 mm per day in June and a low of 1.5 mm per day in January.

Soils: The soil at the experimental site belongs to the major group of Indo-Gangetic alluvium. A soil type was clay loam and good texture with neutral pH 7.3. Organic carbon was 0.65% and bulk density was 1.45 Mg/m^3.

Crop management: Mustard crop sown in 3rd week of October in both the years. The seed rate was 6 kg/ha. The row spacing was maintained 30 cm and plant to plant was 10 cm. Fertilizers were applied in a ratio of 60:40:40:20 (N: P: K: S) per ha. FYM (@ 8-10 t/ha) and 2-3 t/ha vermicompost 20-30 kg before sowing were also applied. Two irrigation were given at flower and siliqua initiation. Crop was maintained according to standard package and practices of the state.

Evapotranspiration (ET) from Bowen ratio:

The energy balance equation over the surface is

$$Rn = H + LE + G. \qquad [Eq. 1]$$

After transferring the (Rn) to the right hand side

H = Rn – LE- G

Deviding both the side by LE

H/LE = {(Rn-G)/LE}-1

β+1 = {(Rn-G)/LE}

LE = (Rn-G)/1+β

H and LE has been computed using BREB technique. For daily measurement 'G' value can be neglected (Watanabi and Nakayama, 2004)

As the latent heat of vaporization is 2.45 MJ Kg^{-1}. So to evaporate 1 mm of water energy density of 2.45 MJ m^{-2} is needed. This conversion has been used to obtain ET estimate for period of an hour or less.

Reference Evapotranspiration by Priestley-Taylor (ET0_PT):

The Priestley- Taylor (P-T) equation (Eq. 2) for the calculation of ET_0 (Priestley and Taylor, 1972) is a simpler, semi-empirical model that has been successfully applied in many areas (e.g., Jamieson, 1982; Steiner *et a*l., 1991; Rana, 1998; German, 1999). The P-T model is useful for conditions where Penman-Monteith cannot be applied due to the lack of required weather data.

$$ET_0 = \frac{1}{\lambda} \cdot \frac{s.(Rn - G)}{s + \gamma} \cdot \alpha \qquad [Eq. 2]$$

Where,

λ (MJ kg^{-1}) :the latent heat of vaporization(2.45)

Rn (MJ m^{-2} d^{-1}) :the net radiation

G (MJ m^{-2} d^{-1}) :the soil heat flux

s (kPa °C^{-1}) :the slope of the saturation vapour pressure-temperature relationship

γ (kPa °C^{-1}) :the psychrometric constant (1.26)

α :Priestley-Taylor coefficient

The slope of the relationship between saturation vapour pressure (es, kPa) and air temperature (T, °C), s (kPa °C-1), is given by eq. 3 (Tetens, 1930; Murray, 1967).

$$s = \frac{4098\left(0.6108.e^{17.27T/T+237.3}\right)}{(T+237.3)^2} \qquad [Eq. 3]$$

The psychrometric constant, γ (kPa °C-1), is the ratio of specific heat of moist air at constant pressure, Cp (MJ kg^{-1} °C^{-1}), to latent heat of vaporization, λ (MJ kg^{-1}) (Campbell, 1977):

The psychrometric constant is calculated as follows (Eq.4)

$$\gamma = \frac{C_p . P}{\varepsilon . \lambda} \qquad [Eq.4]$$

where,

P (kPa) : the atmospheric pressure,

ε (unitless) : the ratio of molecular weight of water to dry air (equal to 0.622).

Cp : equal to 0.001013 MJ kg-1 °C^{-1}.

λ (MJ Kg-1) : the latent heat of vaporization

Reference Evapotranspiration by FAO (ET0 _ FAO):

From the original Penman-Monteith equation and the equations of the aerodynamic and surface resistance, the FAO Penman-Monteith method to estimate ETo can be derived (Eq. 5).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \qquad \text{[Eq.5]}$$

Where,

ETo : 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}],
T : mean daily air temperature at 2 m height [°C],
U2 : wind speed at 2 m height [m s^{-1}],
es : saturation vapour pressure [kPa],
ea : actual vapour pressure [kPa],
es-ea : saturation vapour pressure deficit [kPa],
D : slope vapour pressure curve [kPa °C-1],
γ : psychrometric constant [kPa °C-1].

RESULTS AND DISCUSSION

Estimation of Reference Evapotranspiration by using Priestley-Taylor (P-T) method

The Reference Evapotranspiration (ET_0) was estimated at different crop growth stages of Brassica using the Priestley and Taylor method. It was observed that during flower bud initiation (FBI) and flowering stages, the ET_0 values were more than that of pod formation (PF) and siliqua maturity stages (SM) (Fig. 1). The variation of ET_0_P-T is due to variation in radiation patter in growth stages. Comparatively higher radiation intensity during November and first week of December may cause the higher ET0 during the period of the crop season. Higher leaf area during pre-pod formation stage be another cause. In 2011-12, higher values of ET_0 were observed (compared to other crop growth season) and it varied from 1.56 mm/day to 2.43 mm/day. In 2012-13 the ET_0 varied from 1.41 to 2.14 mm/day. The ET_0_PT was compared with the reference evapotranspiration values (ET_0) values calculated from pan evaporimeter data. The pan evaporation data when multiplied with the pan coefficient (Kp), the reference evapotranspiration (ET_0) is obtained (Allen, 1998) which is here termed as ET_0_Pan. Comparison of ET_0_P-T and ET_0_Pan was shown through Fig.2 in which it was observed that except very high and low ET_0 values, they are very close to 1:1 line.

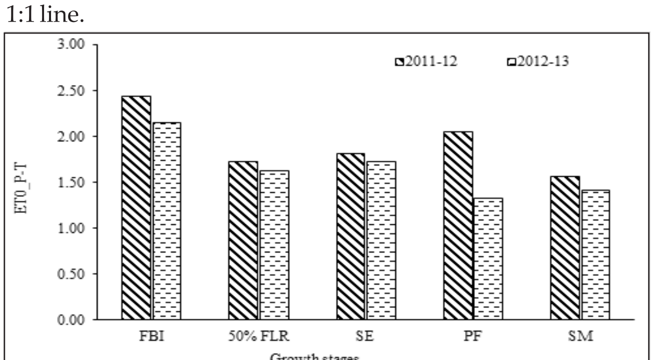

Fig. 1: Variation of Reference Evapotranspiration by Priestley-Taylor (ETo_P-T) method over different stages of mustard crop

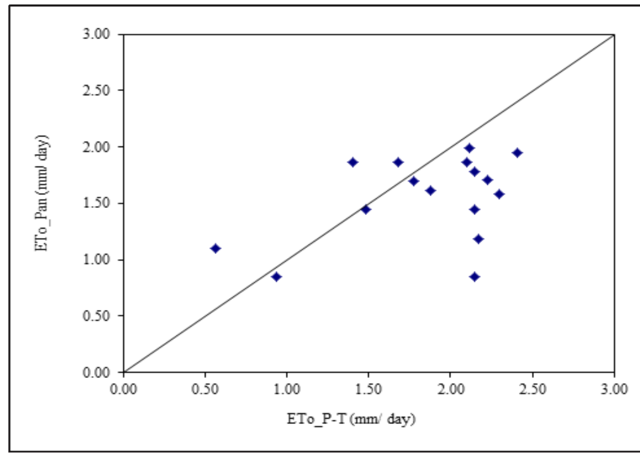

Fig.2: Comparison of Reference Evapotranspiration by Priestley-Taylor (ETo_P-T) method and calculated from Pan evaporimeter data (ETo_Pan) in mustard crop

Variation of Crop evapotranspiration by Priestley-Taylor method (ETc_P-T)

In 2011-12 crop evapotranspiration by Priestley-Taylor method (ETc_P-T) ranged from 1.02 to 2.54 mm/day and in 2012-13 values ranges from 0.73 to 2.15mm/day respectively. The seasonal variation ETc increases from FBI stage to SE and PF stage and then it decreases in SM stage for all the years. This indicates that crops were in high demand of water during active growing stage. So at these stages if crop is irrigated it will lead to higher productivity. The latent heat flux over the crop surface was highest during first years of crop growth season as compared to second year of observation. Variation of Crop evapotranspiration by Priestley-Taylor method are shown in the Fig.3.

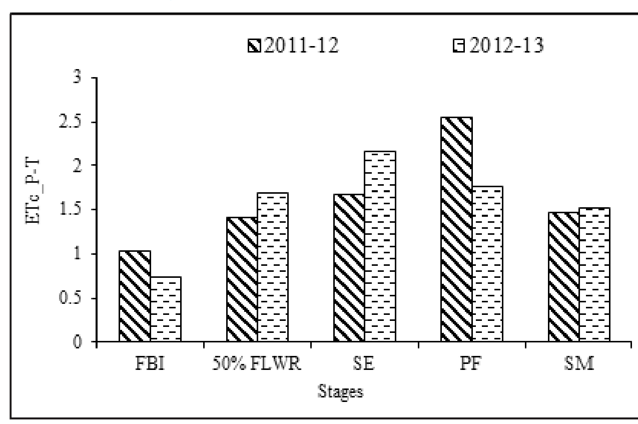

Fig. 3: Variation of Crop Evapotranspiration by Priestley-Taylor (ETc_P-T) method over different stages of mustard crop

Crop Evapotranspiration (ETc) by Bowen ratio energy balance (ETc_BREB) method

Reference Evapotranspiration (ET_0) and crop evapotranspiration (ETc) showed higher values for 2011-12 sown crops compared to other 2012-13 sown crops. In 2011-12Etc_BREB varied from 1.59 to 2.42mm/day whereas in 2012-13 it varied from 1.64 to 2.74mm/dayrespectively. The variation of crop evapotranspiration (ETc) is due to more latent heat flux over the crop surface, which was highest during first year of crop growth season (Fig.4).

Comparision of Crop Evapotranspiration by FAO (ETc_FAO) vs Crop Evapotranspiration by BREB (ETc_BREB) method

The Crop Evapotranspiration (ETc) calculated by BREB method (ETc_BREB) was compared with ETc by FAO method (ETc_FAO). The ETc_BREBoverpredicts ETc value in comparision to FAO method. However, as the BREB technique matches well with the ETc by Priestley Taylor (ETc_PT) method and ETc by pan data (ETc_pan) it can be safely used for estimation of ETc for a region. Comparison of ETc_BREB and ETc_FAO are shown in Fig.5

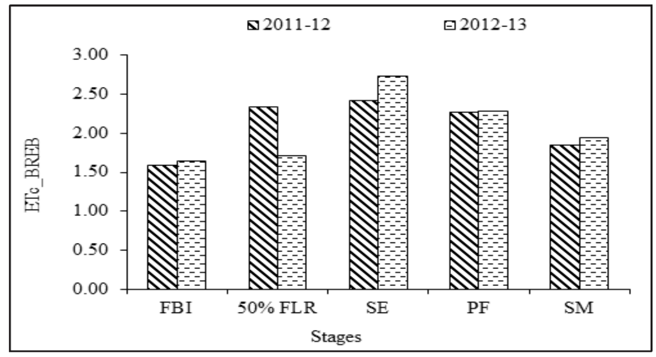

Fig. 4: Variation of CropEvapotranspiration by Bowen ratio energy balance (ETc_BREB) method over different stages of mustard crop

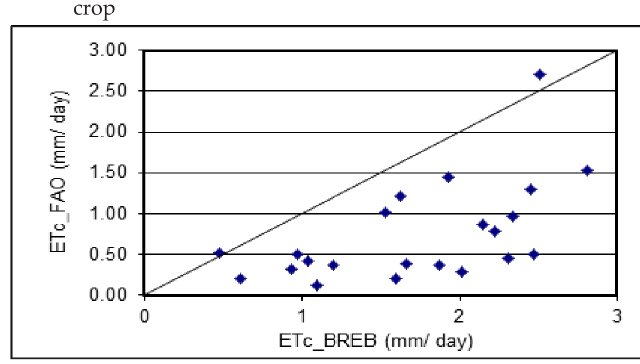

Fig.5: Comparison of Crop Evapotranspiration by Bowen ratio energy balance (ETc_BREB) method and crop Evapotranspiration by FAO (ETc_FAO) method.

CONCLUSION

The reference evapotranspiration (ET_0) was estimated at different growth stages of the crop using Priestley Taylor (PT) method and FAO technique. ET_0 calculate by established empirical equation was compared with the pan evapotranspiration (ETpan) data and it was observed that PT method can be safely used to calculate ET_0 in the study zone. The crop evapotranspiration (ETc) using Bowen Ratio Energy Balance method was also observed and compared with output from PT method. The ratio between LE/Rn attained the higher value at silique emergence (SE) and pod formation (PF) stages indicating higher water demand during the same crop growth period. Thus the radiation variation over a crop surface influences the in-situ thermal environment, governs the crop evapotranspiration (ETc) and study of radiation balance components give proper idea on water demand of the crop.

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