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Performance Evaluation of Crop Evapotranspiration of Bhendi (*Abelmoschus esculentus)* by Using FAO Method and SVAT Model

S. Vinitha *, A. Mani, R. Lalitha, S. Vallalkannan

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ABSTRACT

Soil-vegetation-atmosphere-transfer (SVAT) model combined with the energy balance equation is commonly used to estimate the sensible heat and latent heat fluxes. In this research work, a simple two layer model with varying aerodynamic resistance to measure the sensible heat flux using temperature data at different height of plants from the ground surface. The field experiment was conducted by using drip irrigated Bhendi crop at AEC and RI, Kumulur, Tamil Nadu. The daily crop evapotranspiration (ETC) was calculated by using both SVAT model and the results were compared with Penman-Monteith (FAO-56) method. The SVAT model shows poor correlation coefficient when compared with the Penman-Monteith method ($R^2 = 0.36$, RMSE =1.94). This proposed model can be considered as a simple and efficient tool to estimate the turbulent fluxes. This method will be used only when the local measurements of surface temperature, wind speed and solar radiation are easily available.

Keywords : Crop evapotranspiration, Penman-Monteith method, SVAT model, Sensible heat flux, Latent heat flux.

S. Vinitha*,
Post Graduate Student,
Department of Soil and Water Conservation Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur 621712, Trichy, India

A. Mani,
Assistant Professor,
Department of Soil and Water Conservation Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur 621712, Trichy, India

R. Lalitha
Professor and Head,
Department of Soil and Water Conservation Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur 621712, Trichy, India

S. Vallalkannan
Assistant Professor (Agronomy),
Department of Irrigation and Drainage Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur 621712, Trichy, India
Email:vinithavalasai@gmail.com
*Corresponding author

INTRODUCTION

Day by day, the usage of water goes beyond the limit. In many regions, water resources depletion, industrial development, population increase and drought conditions, land degradation and poor water quality leads to use the water more efficiently. In many situation, evapotranspiration (ET), is the largest component of the hydrologic cycle and it is defined as the sum of evaporation from soil, plant and open water surface and transpiration through plant canopy. The concept of reference evapotranspiration (ET_0) was introduced to study the evaporative demand of the atmosphere independent of crop type, crop development and management practices (Allen *et al.* 1998).

Improved techniques are very much needed for accurate quantification of evapotranspiration on a field, watershed and regional scale to enhance efficient use of water resources and protect the environment and water quality. The existing standard FAO- 56 method is commonly used as a reference to estimate the ET. In this research study, more efficient and rational use of water for the okra crop was estimated under drip irrigation. The SVAT models which are mainly used for estimating evapotranspiration, surface-energy exchanges and water balance components.

The soil vegetation-atmosphere transfer (SVAT) is defined as the model parameterization of the interaction between a land surface and atmosphere (Jamal *et al.* 2012). These SVAT model have been used in conjunction with atmospheric data to estimate accurate turbulent fluxes. The primary aim of this model is to estimate the latent and sensible heat fluxes between the land surface and atmosphere (Franks *et al.* 1997). Kustas and Norman (1999), stated that the soil-vegetation heat flux prediction as a two source model which is based on the surface temperature. Most of these investigations consist of estimating sensible heat flux, net radiation and soil heat flux from the atmospheric data and calculating the latent heat flux as a residual term of the energy balance equation.

All fluxes of energy should be considered when deriving an energy balance equation. The equation for an evaporating surface can be written as,

$$Rn - G - LE - H = 0 \quad (1)$$

Where, Rn – Net radiation, LE – Latent heat flux, G – Soil heat flux, H – Sensible heat flux. So, the present study aims to estimate the crop evapotranspiration (ETC) under standard FAO-56 method. Then, it is used to simulate the SVAT model that involves to the fluxes and potential-resistance network for a two layer model of heat transfer. From that, the estimated ETC values from the SVAT model were compared with the standard FAO-56 method.

MATERIALS AND METHODS

Study area

The experimental field study was conducted at the Central Farm, AEC and RI, Kumulur, Trichy District in Tamil Nadu from August to December 2019. It has the latitude of 10°55' 49" N and longitude of 78°49' 39" E with elevation of 70 m above MSL. During the experimental period, the seasonal rainfall was recorded as 571.5 mm. Both the physical and chemical properties of soil were determined and it is shown in Table 1.

Experimental design and field layout

An area of 15 m × 14 m (5 cents) portion of the farm field was ploughed thoroughly to bring the soil into fine tilth for effective seedbed preparation. The size

Table 1. Physical and chemical characteristics of soil of the experiment field.

Soil characteristics	Particulars	Composition
Physical composition	Sand,%	43.5
	Silt,%	25
	Clay,%	31.5
Soil class		Sandy clayey Loam soil and Red Laterite soil
	Field capacity, %	23.81
	Permanent wilting point, %	13.48
Chemical composition	pH	7.8
	EC (ds/m)	0.1
	Organic carbon (%)	0.51
	Available nitrogen(kg/ha)	198
	Available phosphorus (kg/ha)	12
	Available potassium (kg/ha)	194

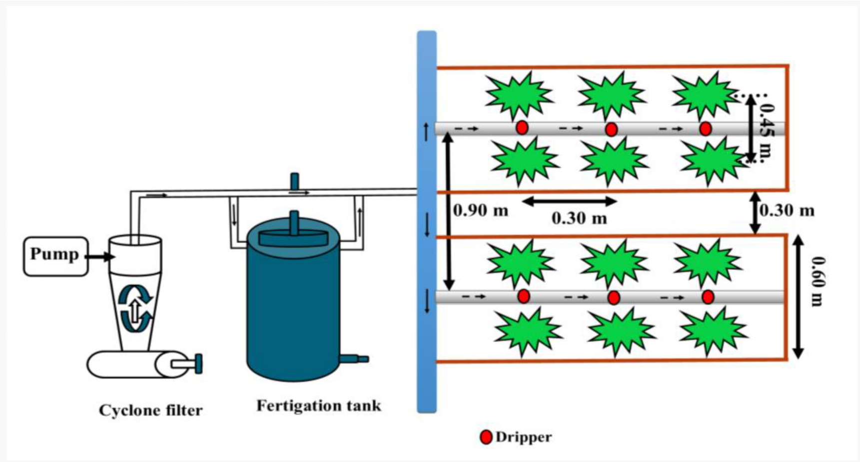

Fig. 1. Experimental layout of Bhendi crop under drip irrigation system.

of raised bed was chosen as 60 cm × 30 cm. The most popular variety of Bhendi viz., TNAU Hybrid CO^{-4} was sown at spacing of 45 cm × 30 cm. The experimental field layout is shown in Fig. 1. Various cultural practices such as thinning, weeding and insect pests and diseases control were carried out timely. In this research work, the drip fertigation (irrigation water along with water soluble fertilizers) system was followed. Jayapiratha *et al.* (2010) reported that by adopting the drip irrigation system for okra crop, the water saving was high up to 60 %. The drip irrigation system was laid on with dripper spacing of 30 cm and lateral spacing of 90 cm. The capacity of dripper is about 4 liters per hour (l ph) and the variation of discharge (Vq) was found to be 8.42 % .

Penman-Monteith method

The Penman-Monteith (PM) method is FAO recommended method and it requires data as input at a greater extent. Daily meteorological data of maximum and minimum temperatures, wind speed, relative humidity, bright sunshine hours and solar radiation data are required by this standard method.

According to FAO (Allen *et al.* 1998) the Penman-Monteith method for reference evapotranspiration (ET_0) is given in equation (2).

$$\lambda ET = \frac{\Delta (R_n - G) + \left(\rho_\alpha c_\rho \frac{e_s - e_\alpha}{r_a} \right)}{\Delta + \gamma \left(1 + \left(\frac{r_s}{r_a} \right)\right)} \qquad (2)$$

Where,

λET = Latent heat of vaporization (MJ kg^{-1}),
Δ = Slope vapor pressure curve (kPa $°C^{-1}$),
R_n = Net radiation (MJ m^{-2} day^{-1}),
G = Soil heat flux density (MJ m^{-2} day^{-1}),
ρ_a = Mean air density at constant pressure (kg m^{-3}),
c_ρ = Specific heat of the air (MJ kg^{-1} $°C^{-1}$),
e_s-e_a = Vapor pressure deficit of the air (kPa),
γ = Psychometric constant (kPa $°C^{-1}$),
r_s = Surface canopy resistance (s m^{-1}),
r_a = Aerodynamic resistance (s m^{-1}).

SVAT model

The soil vegetation atmosphere transfer (SVAT) model is simulated along with an energy balance is given by equation (1). Courault *et al.* (2005) stated that the latent heat flux (LE) gives as a good indicator for plant water status. The following equation is used to estimate the ET_0 value of okra crop.

$$LE = R_n — G — H \qquad (3)$$

Where,

LE	=	Latent heat flux (W m^{-2}),
R_n	=	Net radiation (W m^{-2}),
G	=	Soil heat flux (W m^{-2}),
H	=	Sensible heat flux (W m^{-2}).

From the equation (3), the net radiation value (Rn) is calculated from the meteorological data by using the equation as given in FAO-56 paper. The daily soil heat flux is taken as zero (Allen *et al.* 1998). The sensible heat flux (H) is calculated from the surface temperature of crop in different heights or levels. It is given in the equation (4).

$$H = \rho C\rho \frac{(T_o - T_\alpha)}{r_\alpha} \quad (4)$$

Where,
H= Sensible heat flux (W m^{-2}),
ρ= Mean air density at constant pressure (kg m^{-3}),
cp= Specific heat of the air (MJ kg^{-1} $°C^{-1}$),
T_0= Aerodynamic surface temperature (°C),
T_a= Potential air temperature at reference height (°C),
r_a= Aerodynamic resistance (s m^{-1})

The aerodynamic resistance is given by Jamal *et al.* (2012):

$$r_a = \frac{1}{ku_*} \left[\ln \left(\frac{Z_r - d}{Z_0} \right) - \psi_h (\varsigma) \right] \quad (5)$$

With,

$$U_* = \frac{ku_\alpha}{\ln \left(\left(\frac{Z_r - d}{Z_o} \right) - \psi_m (\varsigma) \right)} \quad (6)$$

In that,

$$\varsigma = \frac{(Z_r - d)}{L} \quad (7)$$

Where, L is the Monin-Obukhov length defined as, (Jamal *et al.* 2012).

$$L = - \frac{U_* \rho C_\rho T_\alpha}{K_g H} \quad (8)$$

For finding H value in above equation, the following formula can be used and it is expressed as:

$$H = C_0 * N \quad (9)$$

For determining the stability functions, for unstable surface layer is given by Hogstrom (1996).

$$\psi_m \left(\frac{Z}{L} \right) = \left(1 - 19 \frac{Z}{L} \right)^{-1/4} \quad (10)$$

$$\psi_h \left(\frac{Z}{L} \right) = 0.95 (1 - 11.6 Z/L)^{-1/2} \quad (11)$$

For the above equations from 4 to 12, the standard notation is given as below:

u =Wind speed at reference height (m s^{-1}),
u_* =Friction velocity (m s^{-1}),
ρ =Mean air density at constant pressure (kg m^{-3}),
c_p =Specific heat of the air (MJ kg^{-1} $ºC^{-1}$),
T_a =Potential air temperature at reference height (ºC),
g =Acceleration of gravity (m s^{-2}),
ς =Dimensionless parameter (Function of Monin-Obukhov length),
ψ =Non-dimensional stability function of heat (temperature),
ψ_m=Non-dimensional stability function of momentum (wind),
k =Von Karman's constant (0.41),
Z_0=Roughness length for momentum (m),
Z =Reference height (m),
Z =Reference height of wind speed (m),
L=Monin-Obukhov length (m),
d =Zero displacement height (m),
H =Sensible heat flux (W m^{-2}),
C =Constant (0.17),
N =Net radiation (W m^{-2}).

Estimation of crop evapotranspiration

The crop evapotranspiration (ET_C) is estimated by using the equation (12) as given by Allen *et al.* (1998).

$$ET_c = ET_0 * K_c \quad (12)$$

Where, ET_0 – Reference evapotranspiration (mm/day), K_C – Crop coefficient;

Patil and Tiwari (2018) have estimated the average crop coefficient (K_c) values of Bhendi crop as 0.51, 0.72, 0.92, 0.93 and 0.53 for different stages without plastic mulch.

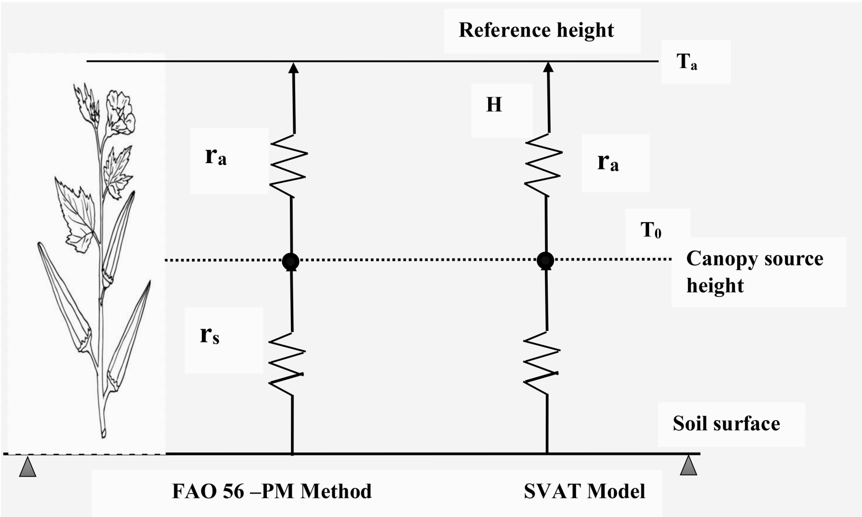

Fig. 2. Configuration of Two methods.
(T_a is air temperature at reference height and T_0 is air temperature at canopy source height.)

RESULTS AND DISCUSSION

Reference evapotranspiration (ET_0)

The daily reference evapotranspiration of the Bhendi was estimated by the Penman-Monteith equation as stated in the FAO-56 paper and the SVAT model. The variation of ET_0 values estimated by both FAO method as well as SVAT models are shown in the Fig. 2. From this, it is known that the estimated ET_0 values for Bhendi under SVAT model was found to be less when compared with the FAO method at all the growth stages from date after sowing (DAS).

Crop evapotranspiration (ET_C)

The daily crop evapotranspiration of the Bhendi was estimated by the Penman-Monteith equation as given in the FAO-56 paper and the SVAT model. The variation of ETc values estimated by both FAO method as well as SVAT models are shown in the Fig. 3. From the Fig. 4, we could observe that the estimated ETc values for Bhendi under SVAT model was found to be less when compared with the FAO method at all the

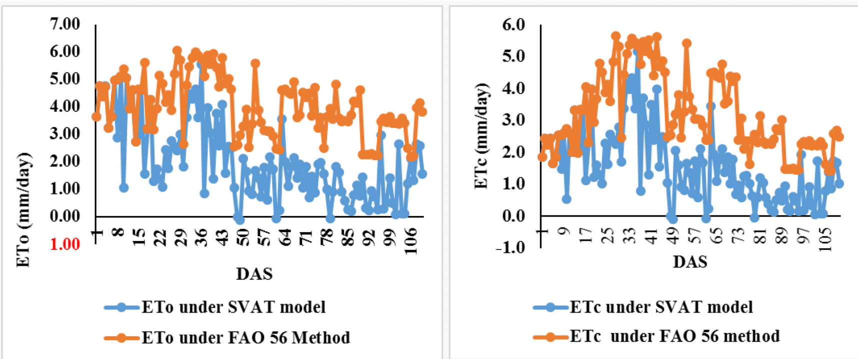

Fig. 3 and 4. Comparison of daily ETo and ETc values both estimated by FAO-56 method and SVAT model.

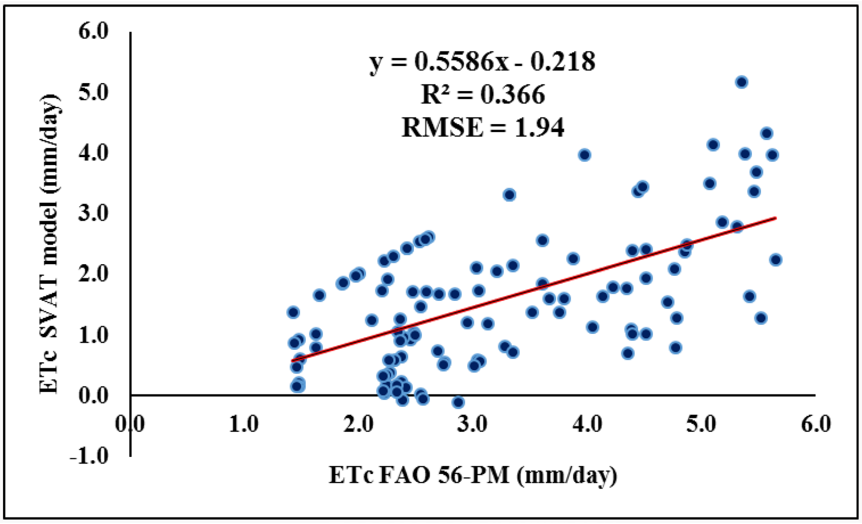

Fig. 5. Comparison between daily measured ETc and modelled ETc.

growth stages from date after sowing (DAS). The Fig. 5 shows that the linear correlation exhibited between the estimated values of ET_C by both FAO method as well as SVAT model with poor values of coefficient of determination (R^2 = 0.36). It means that the ET_0 values found by the SVAT model which mainly based on the changes in temperature, wind speed, radiation only and not connected to the available soil moisture in the field. Jamal *et al.* (2012) have expressed that the simulated latent heat flux under estimates of the observed latent heat flux. This change is related to the effect of atmospheric condition and the irrigation events.

This research study provides a valuable information about the soil-vegetation-atmosphere-transfer (SVAT) model. It is well-connected with the energy balance equation to estimate the sensible heat and latent heat fluxes. By applying of this SVAT model, scientists could derive the sensible heat flux and net available energy very easily. The proposed SVAT model can serve as a viable tool to the scientists and water resource engineers for estimation of both reference evapotranspiration as well as crop evapotranspiration under limited climatic data. It will be much helpful in the optimal design of irrigation system and the effective management of water in the agricultural sector.

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