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SENSITIVITY ANALYSIS OF REFERENCE EVAPOTRANSPIRATION UNDER DIFFERENT PROTECTED CULTIVATION STRUCTURES

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Abstract

Precise estimation of reference evapotranspiration (ET_o) plays an important role in crop water requirement studies whereas sensitivity analysis of climatic variables for estimation of ET_o plays a key role in irrigation and water management. In the present study, ET_o was estimated by using FAO56-Penman-Monteith method. Additionally, impact of climate variables in the ET_o estimation was assessed by sensitivity analysis under open field condition as well as four different protected cultivation structures viz. poly house, polytunnel, shade net house, and shadow hall. Results indicate that ET_o is maximum for open field condition and minimum for polyhouse. The sensitivity analysis results revealed that solar radiation is the most sensitive input variable for ET_o estimated by using FAO-Penman-Monteith method wind speed is least sensitive for all structures and open field conditions.

Key words: Reference evapotranspiration; Sensitivity analysis; Protected cultivation

Introduction

Protected cultivation is a kind of farming system used to maintain a controlled or partially controlled environment suitable for maximum crop production (Singh et al. 2016). Protected cultivation structures viz. greenhouse, shade net house, polytunnels create an appropriate environment for better crop growth. The presence of different covers and shade nets causes a change in the climatic conditions compares to those in the open field. The property of cladding materials alters the magnitude and quality of solar radiation incidence in the greenhouse, thereby affecting the microclimate of the greenhouse. UV stabilized diffused film does not allow the shadow formation of the top canopy on the lower leaves. Diffused radiation penetrates deeper into plants canopy in comparison to direct radiation; thus, it is desirable to use diffused film. At high irradiation, diffused film greenhouse cover leads to better light distribution, lower plant temperature, decreased transpiration, and increased photosynthesis and growth (Hemming et al. 2008). Whereas in shade net house due to the presence of shade net a certain percentage of solar radiation is cut off, as a result, the inside microclimate in the shade net house remains less hot than that of the ambient. In the case of Polytunnel due to the absence of ventilation, the inside thermal energy storage is greater compared to the greenhouse and shade net house.

Estimation of reference evapotranspiration (ET_o) is crucial for irrigation scheduling of crop. The total water requirement of crop is calculated by multiplying the ET_owithcrop coefficient (K_c)(Debnath et al. 2015).The Foodand Agriculture Organization recommendedFAO-56 Penman-Monteith (FAO-56 PM) method as a sole and standard methodif all the required data are available(Allen et al. 1998).The FAO-56 PM method integrates climatic variables such as temperature, solar radiation, relative humidity, and wind speed, which may be affected by climate change (Irmak et al. 2006). Therefore, it is very important to know the sensitivity of

$ET_o$with respect to the variation of each climatic variables which also provide information regarding accuracy required during measurement of climatic variables.

A large number of studies has done to investigate the sensitivity analysis of ET_o to the variation of climatic variables (Ambas and Baltas 2012,Debnath et al. 2015, Djaman et al. 2016, Liang et al. 2008, Tabari and Talaee 2014). Estevez et al. (2009) studied the sensitivity of ET_o with respect to temperature, R_s, RH, and u_2 in a semi-arid climate of southern Spain. They concluded that RH, temperature, and R_s were the main climatic variables that influence ET_o. Ambas and Baltas (2012) studied monthly and annual variation of ET_o from fifteen stations in a semi-arid climate in China over the period 1961-2003 as well asanalyzed sensitivity of ET_oestimated byFAO-PM method to a maximum temperature (T_{max}), minimum temperature (T_{min}), mean temperature (T_{mean}), wind speed (u_2), sunshine duration (R_s) and relative humidity (RH). Results indicated that the ET_o was more sensitive to variation in RH followed by R_s, u_2, and air temperature. Djaman et al. (2016) focused on the sensitivity analysis of ET_o to climatic variables in West Africa. They found that $T_{max}$and $R_s$are the two variables that have more influence on ET_o at Saint-Louis weather station in the Senegal River Delta. Although the various study of sensitivity analysis is performed for the FAO-56 PM method for different study areas, no literature is available on sensitivity analysis of ET_ounder different protected cultivation structures. Therefore, the objectives of the study are (i) to estimate ET_o by using FAO- 56 PM method under open field condition as well as four different protected cultivation structures- poly house, polytunnel, shade net house and shadow hall;and (ii) to analyze the sensitivity to $ET_o$with respect to climate variablesfor different protected cultivation structures.

Materials and Methods

Study area and data collection

The research field of Precision Farming Development Centre (PFDC), Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur is selected as study area (Fig. 1). It is having the geographical location of 22°18' N latitude, 87°19' E longitude and an elevation of 48 m above mean sea level. The local climatic condition is sub-humid with an average rainfall of 1390 mm, and almost 80 % of rain occurs from June to October. The mean temperature varies between 12°C to 40°C, and the relative humidity varies from 35% to 96%.

Fig 1. Location of the study area

Climatic data viz. maximum temperature, minimum temperature, relative humidity, solar radiation, and wind speed data for open field as well as for all four above mentioned protected cultivation structures are taken from Precision Farming Development Centre (PFDC), Agricultural and Food Engineering Department, IIT Kharagpur from 1st January, 2017 to 31st December, 2017.

Protected Cultivation Structures

Protected cultivation is characterized as a technique in which in order to protect the crop from adverse weather, the microclimate around the plant is entirely, partly or altered (Debnath et al. 2020). Four different protected cultivation structures, namely- Naturally ventilated greenhouse, Shade net greenhouse, Polytunnel and Shadow hall are selected in this study (Fig. 2).In new greenhouse buildings and in retrofits of existing greenhouses, natural ventilation is more widespread today. This is due to raising fan activity energy costs and the need for more uniform cooling in the region of the crop.Shade net is a polyethylene (HDPE) material capable of changing the control environment, enhancing the climate and improving plants, realizing protection or high-yield, high-quality agricultural cultivation techniques in the growth of adverse climate conditions.Polytunnels offer much easierregulation of its air circulation.Shadow hall is a structure like a modified Quonset type greenhouse, which is covered with shade net but partly it is covered with polythene film. The used cladding materials are 200 µm U.V stabilized polythene film and shade net with shading percentage 50 %.

Fig. 2. Different protected cultivation structures- (a) Naturally ventilated greenhouse, (b) Shade net greenhouse, (c) Polytunnel and (d) Shadow hall.

Estimation of reference evapotranspiration

In the present study, the FAO-56 PM method was considered for daily ET_o estimation.Theequationcan be written as

$$ET_o = \frac{0.408\Delta(R_n - G) + \frac{900\gamma u_2}{t+273}(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad \text{(i)}$$

Where, ET_o = Potential evapotranspiration,

R_n=net radiation, G = soil heat flux,

u_2 = wind speed at 2 m height,

(e_s-e_a) = vapour pressure deficit,

Δ= slope of vapor pressure vs. temperature graph and

γ = psychometric constant.

Sensitivity analysis and sensitivity coefficients calculation

The sensitivity analysis is conducted in this study to find the change in ET_o with the change of the input climatic variables like mean temperature, solar radiation, relative humidity, wind speed.

If *y* is expressed as a function of $x_1, x_2, \ldots, x_n$

$$y = f(x_1, x_2, \ldots, x_n) \quad \text{(ii)}$$

Then sensitivity coefficient of y for variable x_i can be expressed as

$$C_i = \frac{\partial y}{\partial x_i} \quad \text{(iii)}$$

For i=1, 2, 3, …., n

Since ET_o is expressed the function of maximum temperature, minimum temperature, wind speed, solar radiation. Therefore, the sensitivity coefficients of ET_o for different climatic variables are obtained by differentiating ET_o expression i.e. FAO-56 PM equation partially with respect to the climatic variables.

In the present study the sensitivity analysis of ET_o,which is calculated by using FAO-56 PM method, is done on open field and four other structures viz. polyhouse (floor area 14m × 6m), polytunnel (floor area 17 m × 5 m), shade net house (floor area 17 m × 5 m) and shadow hall (floor area 17 m × 5 m).

Results and Discussion

Variation of evapotranspiration

The ET_o values were estimated by the FAO-56 PM method for different protected cultivation structures using mean dailyclimate data related to T_{mean}, R_s, RH, and u_2. Figure 3 shows estimated mean daily ET_ovalues for open field condition and four protected cultivation structures.ET_o was maximum for open field condition (4.64 mm/day) and minimum for Poly house (4.22 mm/day) among the experimental conditions. In the mid-year ET_o values were higher ascompared to start and end of the year for all the experimental conditions. For FAO-56 PM estimated daily ET_o values, the meanand standard deviation were found to be 4.64, 4.22, 4.48, 4.49 and 4.49 mm, and 1.22, 1.28,1.45, 1.32 and 1.40 mm for open field, Naturally ventilated greenhouse, Shade net greenhouse, Polytunnel and Shadow hall, respectively.

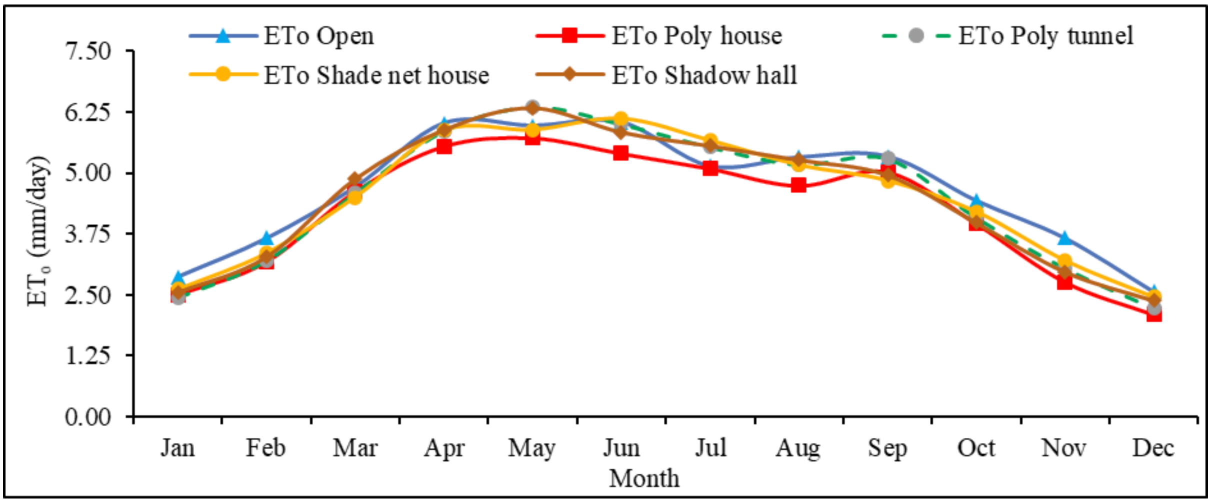

Fig 3. Variation of $ET_o$with respect to different protected cultivation structures

Change in ETowith respect to change in climatic variable

The change in$ET_o$with respect to different climatic variablein different protected cultivation structures is shown in Fig. 4.The results of sensitivity analysis indicate that increasing and decreasing of T_{mean}, R_s, $u_2$increases and decreases ET_o,respectively whereas reverse is observedfor RH. It is observed that R_s(varies from -24.39% to 24.39%) is most sensitive to ET_ofollowed by T_{mean}(varies from -20.32% to 22.46%), RH (varies from -7.36% to -6.38%) and u_2(varies from -3.06% to 3.2%). The maximum changes in ET_odue to changes in R_s, $T_{mean,}$ and RH occur for polytunnel as it has no ventilation, and it is fully covered with polythene film.Therefore, high heat is stored due to the entrapment of solar radiation as well as RH also much due to the absence of ventilation for air passage. Changes in ET_o due to u_2 are maximum in the open field asit is very much lower in the protected cultivation structures, hence in the other structures, such lower wind speed is affecting the ET_oin very minimal amount.

Variations of sensitivity coefficients

The sensitivity coefficients (C_i) can provide important information on howET_o responds to each climate variable in different experimental conditions. Monthly values of $C_i$were computed for each variable in the study area (Table 1).The sensitivity coefficients vary from 0.25 to 0.34 for R_s, 0.16 to 0.34 for the T_{mean} and -0.002 to -0.025 for the RH and from 0.00- to 0.003 for u_2 for four different protected cultivation structures and open condition. The results reveal higher value ofsensitivity coefficients for $R_s$irrespective of experimental condition whereas u_2 is in very low range and negative for RH. Further, the sensitivity coefficient for T_{mean} has fluctuating trends throughout the year for the protected cultivation structures. This is due to the dynamic changes in the inside temperature of the protected cultivation structures, and as the wind speed inside those structures is very less, therefore, the sensitivity of ET_o for u_2 is also very less.

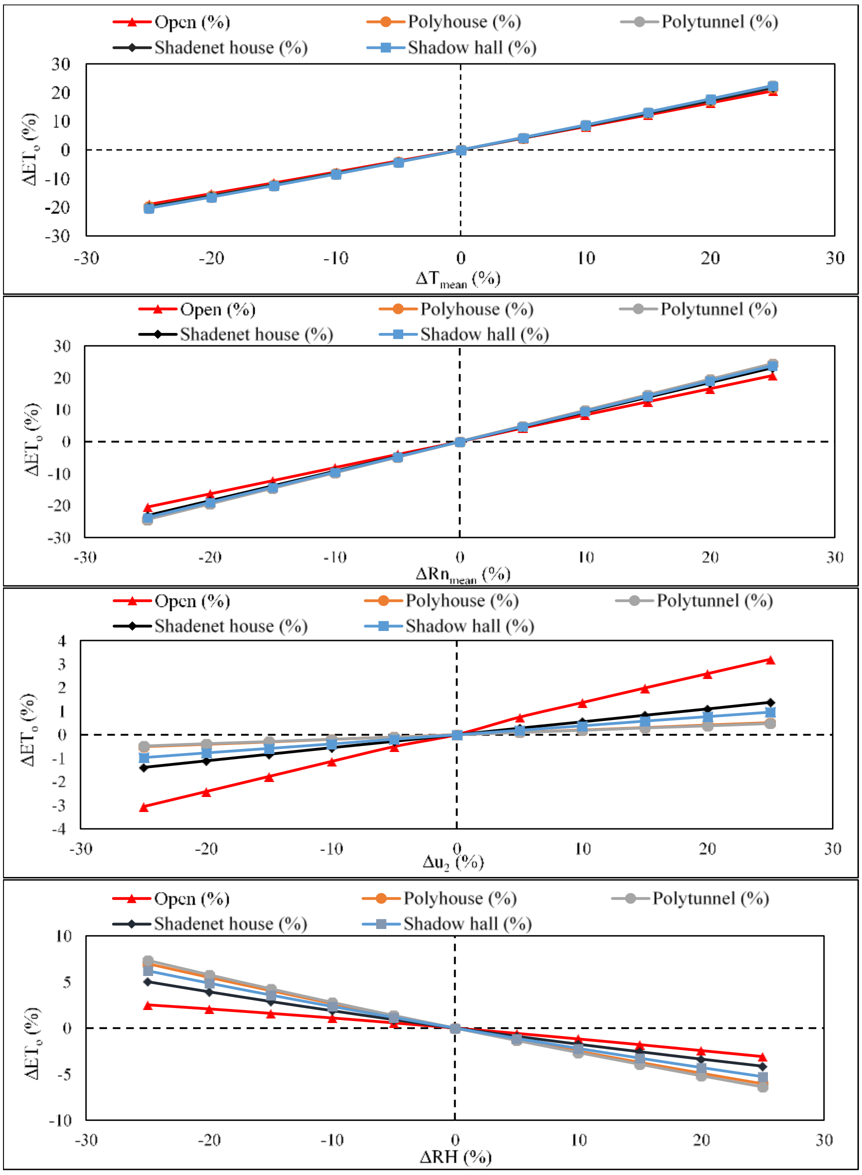

Fig. 4. Change in reference evapotranspiration (ET_o) with respect to change in climate variables under different protected cultivation structure.

Table1. Monthly average value for sensitivity coefficients for T_{mean}, R_s, u_2 and RH for open field and other four structures

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Open	$C_{T_{mean}}$	0.157	0.202	0.234	0.222	0.232	0.229	0.228	0.233	0.232	0.273	0.251	0.193
	C_{R_S}	0.253	0.277	0.296	0.296	0.303	0.301	0.308	0.302	0.298	0.299	0.278	0.261
	C_{u_2}	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.004	0.003
	C_{RH}	-0.016	-0.015	-0.019	-0.025	-0.023	-0.023	-0.014	-0.018	-0.019	-0.020	-0.025	-0.015
Poly house	$C_{T_{mean}}$	0.218	0.241	0.298	0.299	0.340	0.312	0.293	0.263	0.191	0.223	0.196	0.188
	C_{R_S}	0.292	0.299	0.322	0.329	0.335	0.332	0.329	0.322	0.310	0.306	0.287	0.276
	C_{u_2}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	C_{RH}	-0.002	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.002	-0.002
Poly tunnel	$C_{T_{mean}}$	0.188	0.218	0.295	0.275	0.337	0.295	0.298	0.251	0.212	0.251	0.255	0.212
	C_{R_S}	0.283	0.294	0.322	0.327	0.336	0.331	0.330	0.321	0.315	0.312	0.302	0.284
	C_{u_2}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	C_{RH}	-0.002	-0.002	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.002
Shade net house	$C_{T_{mean}}$	0.204	0.209	0.289	0.268	0.286	0.270	0.278	0.227	0.217	0.243	0.288	0.222
	C_{R_S}	0.282	0.287	0.315	0.321	0.324	0.325	0.322	0.312	0.308	0.306	0.304	0.281
	C_{u_2}	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	C_{RH}	-0.007	-0.007	-0.008	-0.008	-0.009	-0.009	-0.008	-0.008	-0.008	-0.008	-0.008	-0.007
Shadow hall	$C_{T_{mean}}$	0.213	0.239	0.324	0.301	0.339	0.281	0.276	0.229	0.220	0.273	0.309	0.241
	C_{R_S}	0.287	0.296	0.324	0.328	0.334	0.326	0.325	0.316	0.312	0.311	0.310	0.290
	C_{u_2}	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	C_{RH}	-0.005	-0.005	-0.006	-0.006	-0.006	-0.006	-0.006	-0.005	-0.005	-0.005	-0.005	-0.005

Conclusions

As the standard method for estimating ET_o, the FAO-56 PM method is recommended if all the appropriate climate data is available.The aim of this study was to calculate ET_o by using FAO 56 PM method and to analyze the sensitivity of $ET_o$to mean temperature, solar radiation, wind speed and relative humidity under open field condition as well as in poly house, polytunnel, shade net house, shadow hall structure. A positive and negative variation of 25% (step of 5%) were consideredto determine the sensitivity coefficient in the study. Results showed that the minimum and maximum values of ET_0 fluctuate around 2 and 6.5 mm/day under different structures. The highest values of ET_owere observed in April and May the lowest in December. The sensitivity analysis showed overall that the change in ET_o is much more sensitive to changes in solar radiation followed by mean temperature. The effects of relative humidity showed an opposite relation with ET_o and wind speed are the least significant.

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