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Modelling of Evaporation and Meteorological Parameters inside Polyhouse

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A B S T R A C T

The study was undertaken at Plasticulture Farm, Department of Soil and Water Engineering, Collage of Technology and Engineering, Udaipur, Rajasthan. The area is under subhumid climate located at 582.17 m above mean sea level in 24° 35 N –latitude, 73° 44 E–longitude. The important factors to control the polyhouse evapotion are solar radiation, air temperature, relative humidity and wind speed. The study was undertaken to analysis and modelling of the evaporation and meteorological parameters like air temperature, relative humidity and wind speed inside Polyhouse (1008 m^2). For purpose of achieving the objectives, the Dalton model, Combination model and Christian model were selected and were critically tested under polyhouse conditions of Udaipur region. The average annual evaporation rate was found to be 1.6 mm day^{-1}, average annual temperature was found to be 24.9 ^oC and average annual relative was found to be 72 % inside polyhouse. It was favorable and very good condition for growing high value vegetables crops like capsicum, tomato and cucumber inside Polyhouse. The modified Christiansen model was found better than other models for this region inside polyhouse.

Introduction

Polyhouse technology is a breakthrough in the agriculture production technology that integrates market driven quality parameters with production system profits. Cultivation of crops in polyhouse is increasing from high altitude and temperate regions to the warmer regions of tropics and subtropics. Although, polyhouse protects crops from external bad weather, high temperature and low humidity during summer months cause adverse effect on crop production in tropical region (Pek and Hayles, 2004).

It is known that water is a major issue almost all part of the world especially for countries which have insufficient water source. With this great expansion of greenhouse cultivation, the need of proper irrigation management is important. Accurate estimations on the crop water requirement is needed to avoid the excess or deficit water application, with consequent impacts on nutrient availability for plants, soil salinity and groundwater contamination (Blanco and Folegatti, 2004). This can be done by using appropriate method to determine the reference evapotranspiration (ETo). The plastic covering utilized on greenhouses significantly changes the radiation balance relatively to the external environment, because of the attenuation (absorption and reflexion) of the incident solar radiation, resulting in a reduction of the internal radiation balance and, consequently, affecting evapotranspiration (Sentelhas, 2001). The aim of the present work was to analysis and modelling of important meteorological parameters like evaporation, solar radiation, air temperature, Relative Humidity and wind speed inside polyhouse.

Description of the Study Area

Experimental Location

The experiment was conducted at the Plasticulture Farm of College of Technology and Engineering, Udaipur shown in Fig.1. The study area falls in 24° 35 N – latitude, 73° 44 E–longitude and at an altitude of 582.17 m above mean sea level.

Climatic Conditions

The average rainfall of the area is 65.43 cm, most of the received during the period of July to September and winter is almost rainless. The annual rainfall in the region is 662.5 mm and more than 80% of this amount is received as a part of south – west monsoon during the period of 16th June to 15th September.

Instrument used for Measurements of Parameters

HTC^{TM} 288-CTH THERMO/HYGRO sensor and technical specifications

A combined humidity and air temperature meter and HYGRO thermometer installed in polyhouse, which having the following technical specifications as under. The temperature ranges from -50 °C to +70 °C, resolution is 0.1 °C and accuracy is ±1°C. The relative humidity ranges from 10 % to 99 %and accuracy is ±5 % (35 RH % to 75 % RH), and else 10 %.

Class ‘A’ Pan Evaporimeter

The USWB Class ‘A’ pan Evaporimeter is 122 cm in diameter and 25 cm deep. The bottom, supported on a wooden frame, is raised 15 cm above the ground surface to allow free circulation of air beneath it. The pan Evaporimeter is placed on level ground inside the Meteorological Observatory. The water surface in the pan is kept 5 to 7.5 cm below the rim of the pan. The evaporation is measured each morning by means of hook gauge in stilling well which provides an undisturbed water surface around the hook gauge and the support of the gauge.

Automatic Weather Station

Automatic weather station of Davies Vantage Pro 2 installed inside polyhouse. It measures temperature, relative humidity, solar radiation, wind speed, wind direction and heat index with the help of console. Specification of weather station console is given below:

Collection of Evaporation and Meteorological Data

Data acquisition

Meteorological data has been collected from Meteorological Observatory located at C.T.A.E., Udaipur. The internal temperature and relative humidity has been measured using temperature and RH sensors throughout polyhouse. Solar Radiation inside polyhouse has been measured through Automatic Weather Station. Daily evaporation reading inside polyhouse at 10:00 AM was taken Class A Pan which is installed in Polyhouse.

Observation of evaporation and meteorological parameteres inside polyhouse has been taken for period during June 2013 to June 2014.

Materials and Methods

Variation of Climatic Parameters with respect to Time

For studying the microclimate inside a plastic greenhouse, the following parameters were selected for monitoring.

Evaporation

Daily evaporation reading inside polyhouse at 10:00 AM was taken Claas A Pan Evaporimeter which is installed in Polyhouse.

Air temperature

Air temperature plays an important role in the vegetative growth and photosynthetic activity of the plants. The maximum (day-time) and minimum temperature is of particular agricultural significance, since young plants are susceptible to injury from temperature extremes. So the measurement of the maximum and minimum temperature inside the polyhouse.

Relative humidity

Relative humidity is the actual amount of water vapour of the air relative to the amount of water vapour, which the air would hold when saturated at the same temperature and expressed as percentage. It is largely dependent on atmospheric temperature and vegetation. The humidity is induced by evapotranspiration. The study of relative humidity profile inside a polyhouse is of most importance, as it governs the most of metabolic and photosynthetic activities.

Description of Evaporation Models

For purpose of achieving the objectives, the following three models were selected and were critically tested under polyhouse conditions of Udaipur region. The test was carried out on weekly basis to study the comparative reliability of the models

Dalton Model

Dalton (1802) enunciated the fundamental principle of evaporation from a free water surface. According to this principle, evaporation is a function of the difference in the vapour pressure of the water body and the vapour pressure of the surrounding air. The concept may mathematically be presented as follows:

$$E = f(w).\ (e_s - e_d) \quad ...(1)$$

where, E = evaporation rate, mm day^{-1}

e_s = Saturated vapour pressure at mean air temperature, mbar

e_d = Saturated vapour pressure at mean dew point temperature (actual vapour pressure in the air), mbar

$$f(w) = \text{wind function} = 0.26.(1.0+0.54U_2) \quad ...(2)$$

U_2 = wind speed 2.0 m from the ground, m sec^{-1}

Weekly values of each of the component of Dalton's model where calculated based on the background data to determine the estimated evaporation and compared with observed values of evaporation on weekly basis to study the deviation of estimated values from actual observed values.

Combination Model

The combination model developed by penman (1948) combines the energy budget and mass transfer models. The method combines fundamental physical principles and empirical concepts based on meteorological observation inside polyhouse and hence reliable. The model was developed for humid area no far from the ocean. For free water surface evaporation, the model may be mathematically represented as follows:

$$E = \left[\frac{\Delta}{\Delta+\gamma}.R_n + \frac{\gamma}{\Delta+\gamma}.E_a\right] \quad ...(3)$$

where,

E = open surface evaporation, mm day^{-1}

Δ = Slope saturated vapour pressure curve at mean air temperature, mbar

γ = Psychrometric constant, mbar

Ea = drying power of air, mm day^{-1}

= 0.35 (e_s - e_d) (1.0 + U_2/160)...(4)

U_2 = wind speed 2.0 m from the ground, m sec^{-1}

Weekly mean values of different component of the model were calculated based on the observation recorded over one year (2013 - 2014). Based on various analyses of various components, the weekly values of evaporation were calculated using the Equation (4). The estimated of value evaporation were compared with observed values of evaporation on weekly basis to determine the deviations occurring and causes associated.

Christiansen Model

Christiansen (1968) proposed a revised model involving empiricism, originally developed by him in 1996, to estimate pan evaporation data when reliable measured pan evaporation data are no available. The model relates evaporation to different coefficients developed on the basis of monthly climatic data and elevation of the station of measurements.

Following is the Christiansen's revised model developed at Logan (UItah), USA, for estimating pan evaporation:

E = K.Ra.Ct.Cw.Ch.Cs.Ce.Cm...(5)

where,

E = computed pan evaporation equivalents to Class A pan evaporation, mm day^{-1}

K = dimensionless empirical constant = 0.473, Ra = extraterrestrial radiation, mm day^{-1}

Ct (temperature coefficient) = 0.393 + 0.02796(T) + 0.0001189 (T^2)

Cw (wind speed coefficient) = 0.708 + 0.000339(W) – 0.00000039(W^2)

Ch (humidity coefficient) = 1.25 – 0.37(H) – 0.60 (H^5)

Cs (sunshine hour coefficient) = 0.542 + 0.80(S/So) – 0.4993 $(S/So)^2$ + 0.3174 $(S/So)^3$

Ce (elevation coefficient, for elevation), E, in meter and Eo = 582 m = 0.970 + 0.030 (E/Eo)

Cm = Coefficient by which all basic formulae would have to multiplies to obtained measured evaporation. The value of Cm mostly range between 0.90 and 1.10 vary from latitude to latitude and from season to season.

T = mean ambient temperature, ^{o}C, H = mean relative humidity, expressed decimally

On the basis of various components, the weekly values of evaporation were calculated using the Equation (5). The estimated of value evaporation were compared with observed values of evaporation on weekly basis to determine the deviations occurring and causes associated.

Results and Discussion

Variation of Climatic Parameters with respect to Time

Pan evaporation

The variation of pan evaporation data inside polyhouse obtained from US Weather Bureau Class A pan Evaporimeter are depicted in Fig.5. and also given in Table 1. Fig.5. Shows that maximum evaporation of 3.1 mm day^{-1} occurs during May 21 –

May 27 and minimum evaporation of 0.6 mm day^{-1} occurs during December 03-09 inside polyhouse. The average annual evaporation rate was found to be 1.6 mm day^{-1}. It is evident from Fig. 5. There is a considerable variation from average value of pan evaporation.

Air temperature

Fig. 6. shows the variation of maximum, minimum and mean air temperature with respect to time. The mean air temperature data were obtained by automatic weather station installed inside polyhouse. It is evident from Fig. 6. that the air temperature of 47.4 ^{o}C occurs during April 30 – May 6 and minimum air temperature of 21.7 ^{o}C occurs during January 8 – 14. The average annual temperature inside polyhouse was found to be 24.9 ^{o}C.

Relative humidity

Maximum, minimum and mean relative humidity is depicted in Fig.7. with respect to time. The mean relative humidity data were obtained by automatic weather station installed inside polyhouse. It is evident from Fig. 7. The relative humidity of 99 % occurs during August 13 – 19 and minimum relative humidity of 12 % occurs during May 21 – 27. The average annual temperature inside polyhouse was found to be 72 %.

Wind speed

In Fig.8. shows that the variation of maximum, minimum and mean wind speed with respect to time. The maximum wind speed occur during 0.62 m s^{-1} June 4-10 and the inside polyhouse wind speed was less. The average annual vale of wind speed at 2 m height was found to be 0.32 m s^{-1}.

Pan Evaporation as related to Meteorological Parameters

Evaporation from a water surface depends on supply of heat energy and the vapor pressure gradient, which urn depends on different meteorological parameters. The significance of the meteorological parameters, viz air temperature, relative humidity, bright sunshine duration and wind speed influencing pan evaporation was evaluated through linear regression and correlation analysis.

A linear regression analysis was performed on weekly evaporation and meteorological parameters to establish a linear relationship between them and to observe the effect of individual parameters on the evaporation. The results of the relationship between weekly observed pan evaporation and meteorological parameters, viz. maximum and minimum temperature, maximum and minimum relative humidity, mean temperature, mean relative humidity, solar radiation and wind speed inside polyhouse are graphically presented in Fig. 9.

Relative humidity and maximum air temperature have been found to correlate well with pan evaporation on weekly basis inside polyhouse. Relative humidity has shown consistently the higher negative correlation coefficient with pan evaporation inside polyhouse. This holds true that evaporation is inversely related to relative humidity. The higher the atmospheric humidity, the smaller will be the evaporation. During evaporation process, the water molecules move from higher moisture to lower moisture levels.

The rate of this movement is governed by the difference of moisture content of polyhouse atmospheric air. Hence, if the air humidity is more, evaporation will be less and vice-versa. Maximum air temperature has also shown consistently positive correlation with pan evaporation inside polyhouse. This also holds true that evaporation is directly related to air temperature where it increases as the air temperature increases. The warmer the air, the stronger the temperature gradient and the higher rate of evaporation. Due to this reason, the evaporation loss is comparatively more in summer season than in winter season. The regression results are significant and coefficient of determination. Minimum air temperature was poorly correlated with pan evaporation inside polyhouse.

Minimum air temperature, Maximum and mean air temperature have shown a significant and have positive correlation coefficients with weekly evaporation. It was observed that maximum air temperature with the strong correlation coefficient of 0.69 inside polyhouse.

The maximum air temperatures have significant influence with pan evaporation inside polyhouse. Mean air temperature is also good correlated with pan evaporation inside polyhouse. The relationship between pan evaporation and maximum air temperature indicates positive correlation inside polyhouse. The relationship between pan evaporation and mean air temperature indicates positive correlation inside polyhouse.

It was observed that minimum relative humidity with the correlation coefficient of 0.20 inside polyhouse. The minimum relative humidity has significant influence with pan evaporation inside polyhouse. It was observed that maximum relative humidity with the correlation coefficient of 0.64 inside polyhouse.

The maximum relative humidity has significant influence with pan evaporation inside polyhouse. It was observed that mean relative humidity with the correlation coefficient of 0.60 inside polyhouse. The relative humidity have significant influence with pan evaporation inside polyhouse is also good correlated with pan evaporation inside polyhouse. The relationship between pan evaporation and minimum relative humidity indicates negative correlation inside polyhouse. The relationship between pan evaporation and mean relative humidity indicates negative correlation inside polyhouse. Wind speed and solar radiation shown as positive correlation with pan evaporation inside polyhouse. It was observed that the wind speed record ranging between 0.6 to 2.4 km/hr. From this result it can be deduced that wind moves with a non significantly to that surrounding the pan.

Evaluation of Evaporation Estimation Models

Several estimation models have been developed under specific range of data type and climatic condition inside polyhouse. In this study, three commonly used evaporation estimation models. These models are: (1) Dalton model (2) Penman combination model (3) Christiansen model.

Tests were carried out to study the comparative reliability of these model based on inside polyhouse climatic data recorded during the period from July 2013 to July 2014. The tests involved estimation of each of the component of the model with the help of available climatic data with help of automatic weather station installed in polyhouse. Evaporation was estimated weekly basis using the three selected models with the help of metrological data inside polyhouse of region of Udaipur. Estimates of evaporation were evaluated against their respective observed pan evaporation records. The best model is selected on basis of lowest standard error, lowest absolute difference, the intercept closet to one and highest correlation coefficient. The results are discussed as under:

Dalton model

Weekly evaporation rates were estimated using Dalton model is as given equation (1). The variation of observed pan evaporation and estimated evaporation as well as relationship between observed and estimated pan evaporation was evaluated with the help of linear regression and correlation analysis and are presented in Fig.10. It was observed that observed pan evaporation and estimated evaporation 0.83, correlation coefficient was obtained inside polyhouse.

Table.1 Specification of automatic weather station parameters

Variable	Resolution	Range	Nominal Accuracy (+/-)
Temperature	0.1 °C	0 to + 60 °C	**0.5 °C**
Relative humidity	1 %	0 to 100 %	**3 % RH; 4 % above 90 %**
Wind speed	0.1 ms^{-1}	0.1 to 79 ms^{-1}	**-**
Solar radiation	**1 Wm^{-2}**	**0 to 1800 Wm^{-2}**	**5 % of full scale**

Table.2 Correlation coefficient, standard error and linear regression equation showing relationship of estimated evaporation and measured by various methods inside polyhouse

S No	Name of model	Linear regression equation	Standard Error (mm/day)	Correlation Coefficient
1	**Dalton Model**	E_D = 0.4497 Ep - 0.045	0.24	0.64
2	**Combination Model**	E_C = 0.9727 Ep + 0.7602	0.31	0.76
3	**Christiansen Model**	**E_{CH} = 0.7217 Ep + 1.1462**	**0.26**	**0.80**
	Modified Christiansen Model	E_{CHM} = 0.922 Ep + 0.0907	0.27	0.80

Fig.1 Location map of the Plasticulture Farm and Polyhouse

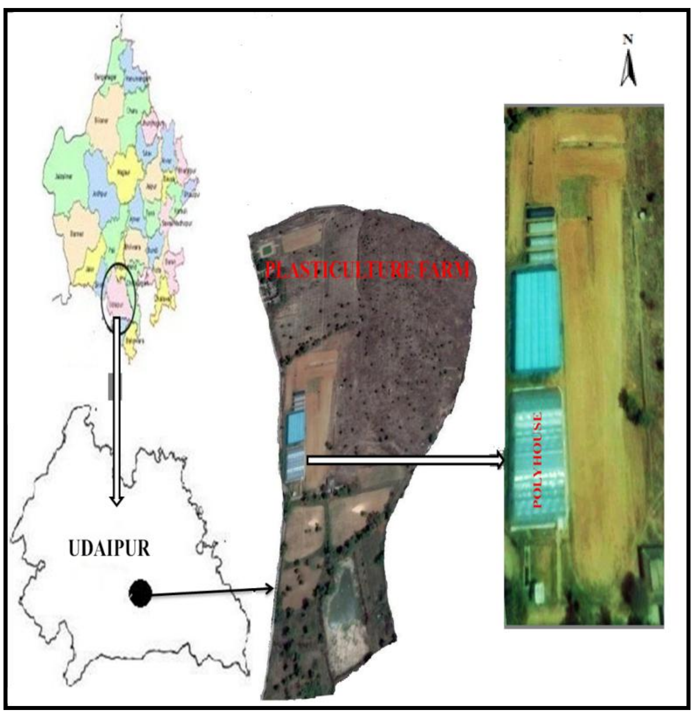


Fig.2 HTC™ 288-CTH THERMO/HYGRO Sensor

Fig.3 Schematic Diagram of instrument Class A Pan Evaporimeter

Fig.4 Automatic weather station, Class A Pan and HYGRO sensor installed in Polyhouse

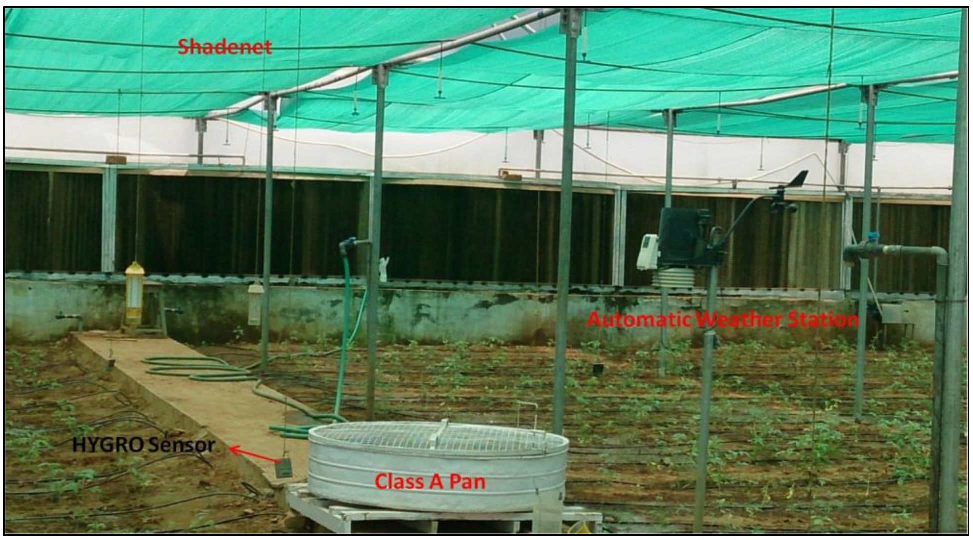


Fig.5 Variation of weekly pan evaporation inside polyhouse for one year (June 2013- June 2014) at Udaipur

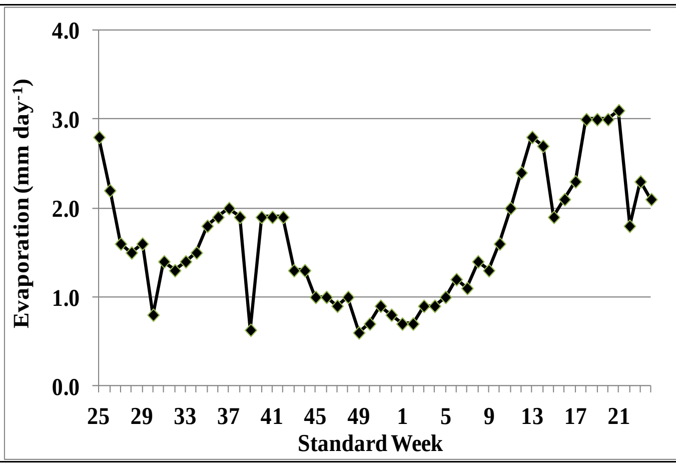


Fig.6 Variation of weekly maximum, minimum and mean air temperature inside polyhouse for one year (June 2013- June 2014) at Udaipur

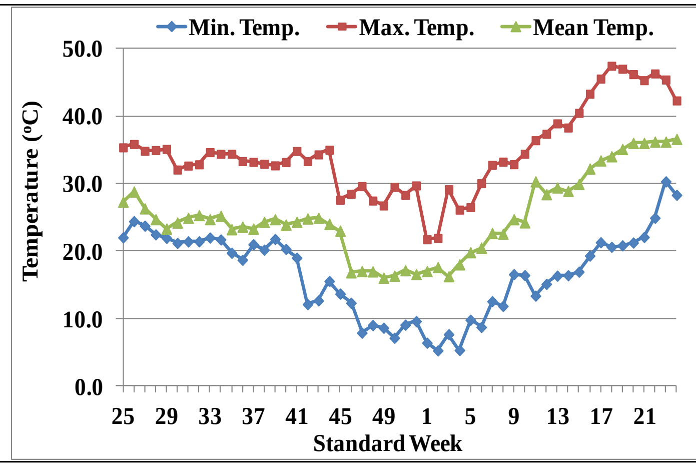


Fig.7 Variation of weekly maximum, minimum and mean relative humidity inside polyhouse for one year (June 2013- June 2014) at Udaipur

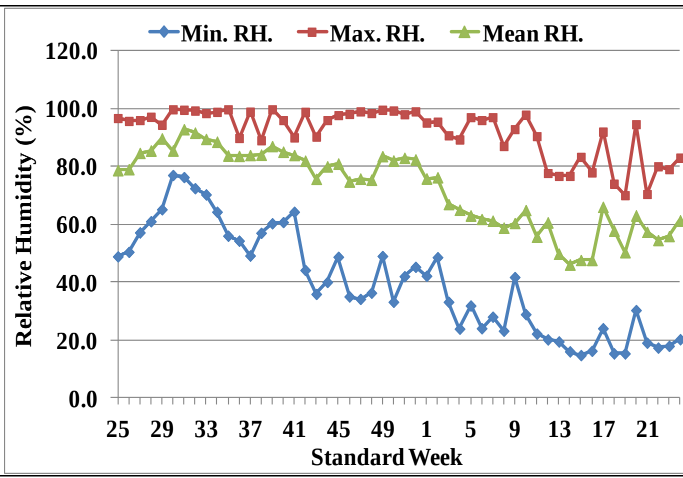


Fig.8 Variation of weekly wind speed inside polyhouse for one year (June 2013- June 2014) at Udaipur

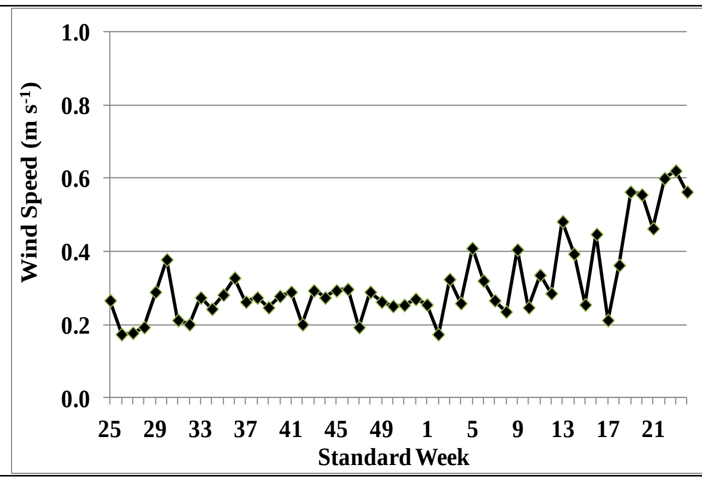


Fig.9 Relationship between weekly pan evaporation and meteorological parameters inside polyhouse

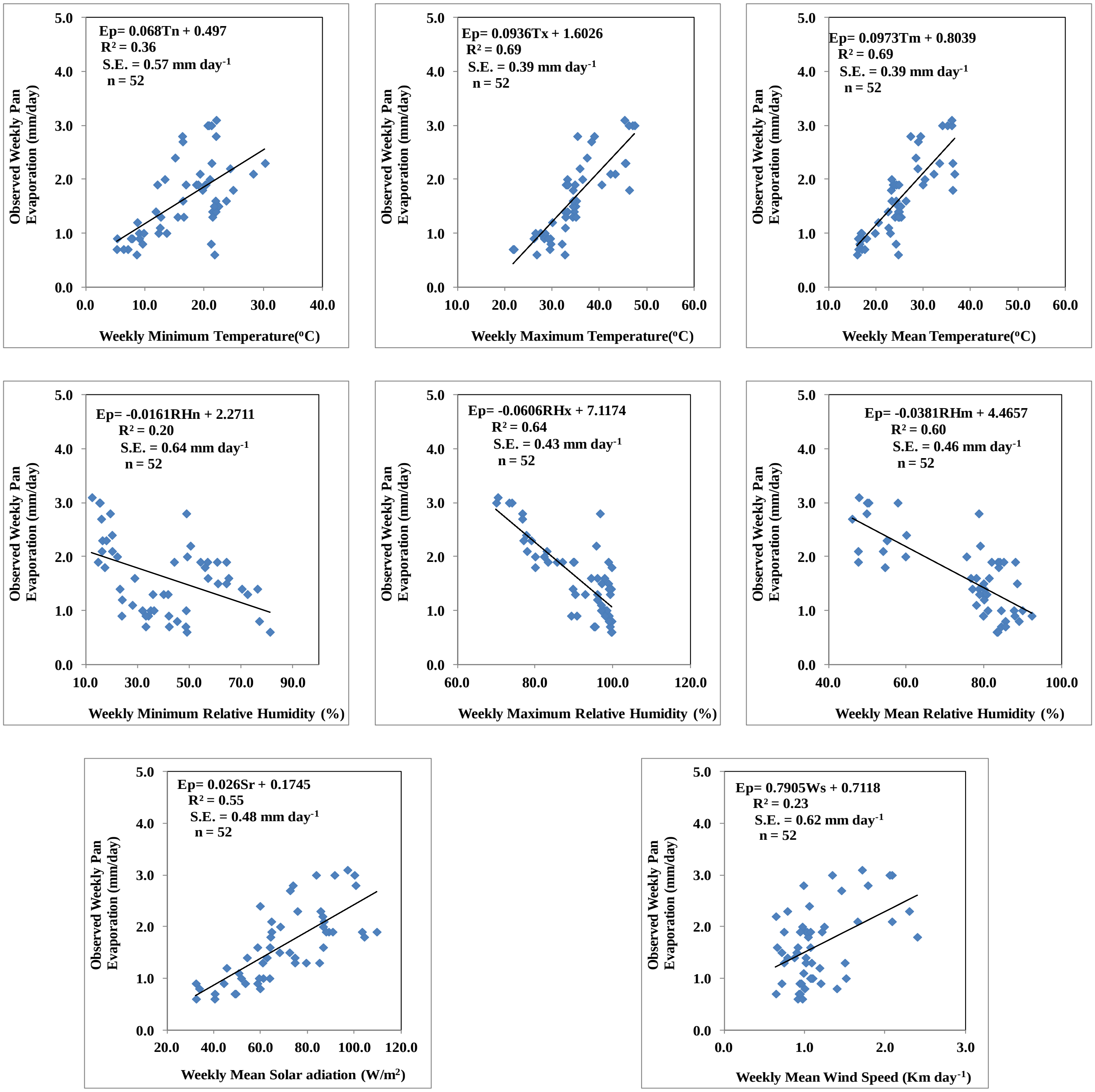


Fig.10 Variation of estimated evaporation by Dalton model (E_D) and measured evaporation (Ep) inside polyhouse

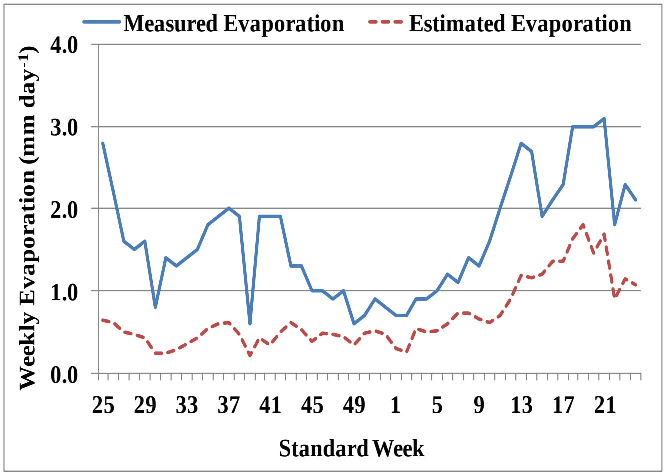


Fig.11 Relationship between estimated evaporation by Dalton model (E_D) and measured evaporation (Ep) inside polyhouse

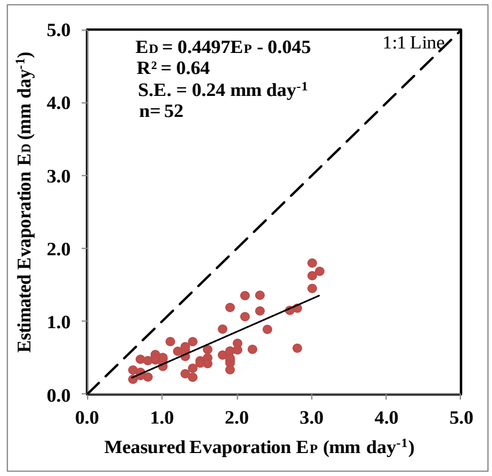


Fig.12 Variation of estimated evaporation by Penman Combination model (E_C) and measured evaporation (Ep) inside polyhouse

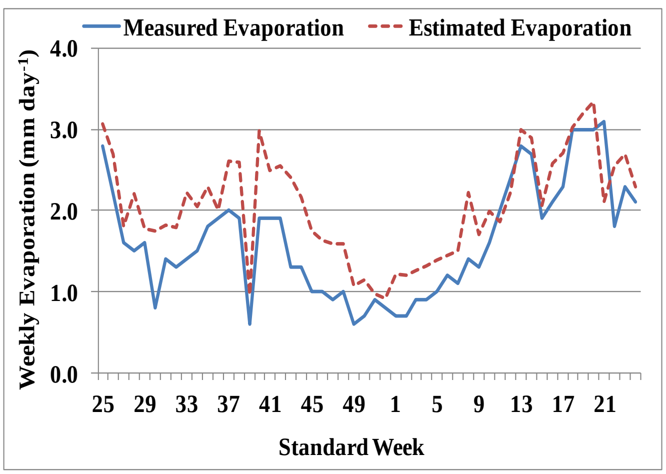


Fig.13. Relationship between estimated evaporation by Penman Combination model (E_C) and measured evaporation (Ep) inside polyhouse

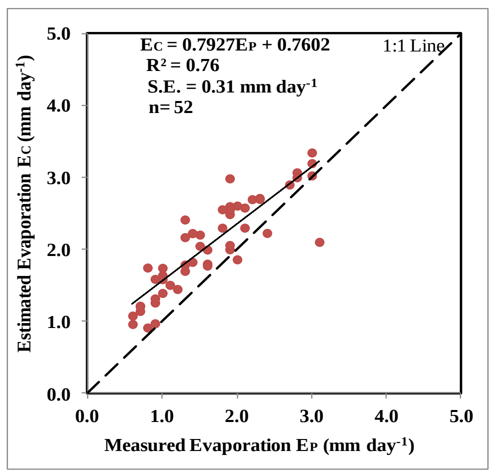


Fig.14 Variation of estimated evaporation by Christiansen model (E_{CH}) and measured evaporation (Ep) inside polyhouse

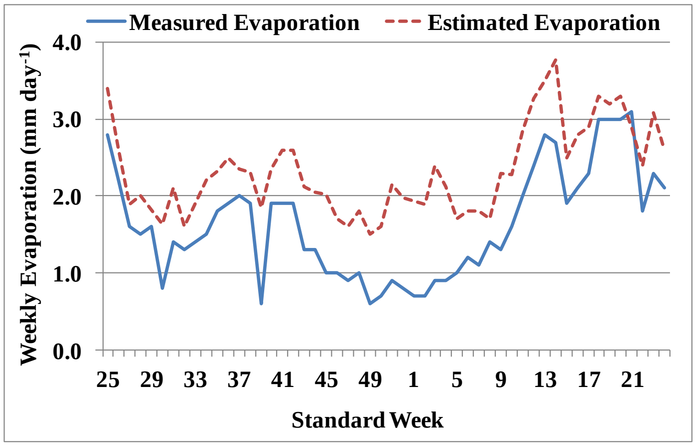


Fig.15 Relationship between estimated evaporation by Christiansen model (E_{CH}) and measured evaporation (Ep) inside polyhouse

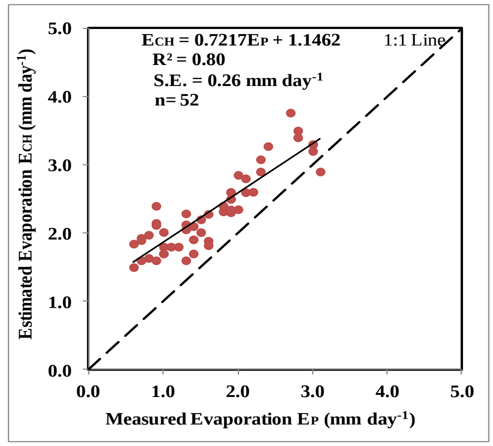


Fig.16 Variation of Christiansen coefficient (C_M) values with respect to time inside polyhouse

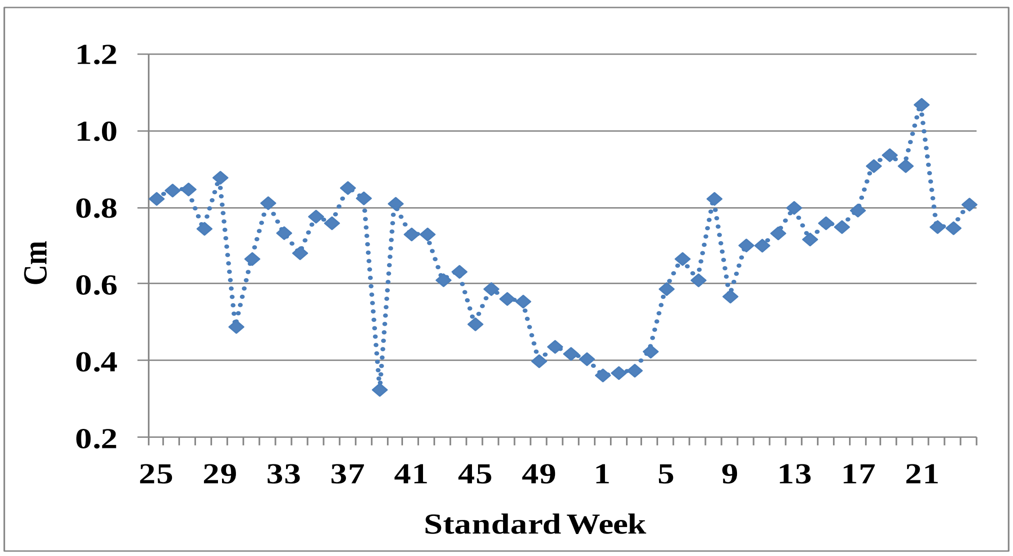


Fig.17 Variation of estimated evaporation by modified Christiansen model (E_{CH}) and measured evaporation (Ep) inside polyhouse

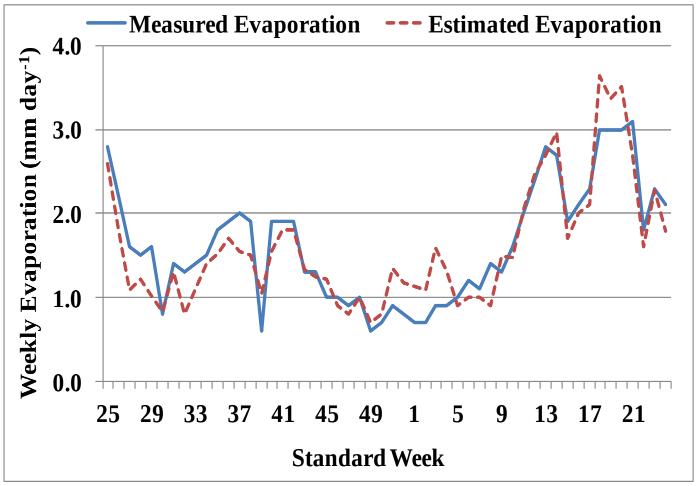
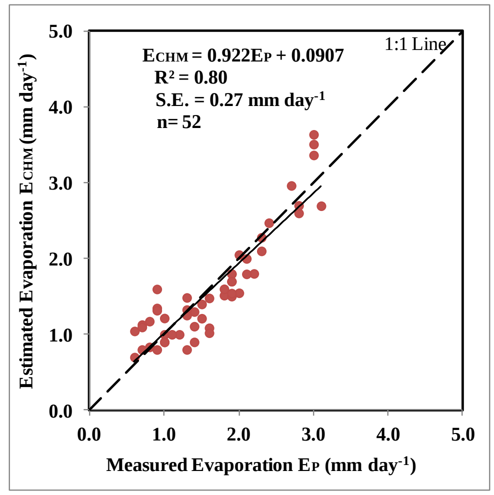


Fig.18 Relationship between estimated evaporation by modified Christiansen model (E_{CH}) and measured evaporation (Ep) inside



The model however has shown a considerable variation with observed pan evaporation. It was observed that for inside polyhouse climatic data Dalton model give good results, hence for inside climatic condition Dalton model may be used for estimation of evaporation.

A significant correlation coefficient 0.64 was obtained at 1 % level. The standard error of predicted evaporation was 0.24 mm day^{-1}. Computational of the Dalton estimate is comparatively simpler and it requires air temperature, relative humidity and wind speed data. Dalton model may be used for estimation of evaporation in this region if only air temperature, relative humidity and wind speed data are available.

Penman Combination model

Fig.12. shows that the variation of evaporation estimated by combination model and measured evaporation. It is evident from Fig.13. the maximum variation between estimated rate of evaporation and measure rate of pan evaporation was found to occur during the summer season, while this variation was found to be least during the winter season. This variation is probably due to the fact that, the original combination model contains considerable empiricism. The difference occurring between the estimated rate of evaporation and that of the measured rate of evaporation may also be due to radiation term. It appears that the model is unable to adequately consider the adjective condition prevalent in increasing the rate of evaporation during summer season.

The relationship between evaporation estimated by combination model and measured evaporation is shown in Fig. 13. It is evident from Table 2. Combination model underestimates the evaporation. The correlation coefficient and standard error were found to be 0.76 and 0.31 mm day^{-1} respectively.

The correlation coefficient was found to be significant at 1 per cent level. The combination model may give good estimates of evaporation inside polyhouse.

Christiansen model

The estimated values of evaporation computed by Christiansen model (Equation. 5) on weekly basis are given in Table 2. The results are also shown in Fig.14. from the analysis made with the help of the Christiansen Model, it is found that estimated values of evaporation re more than that of actual rate of evaporation occurring during experimental period. Fig.15. shows that the variation of evaporation estimated by Christiansen model and measured evaporation. The correlation coefficient and standard error were found to be 0.80, which is significant at 1 per cent level. The standard error is 0.26 mm day^{-1}. It was observed that the model overestimate the evaporation throughout the year. There could be basically two main reasons for the model failing to predict the rate of evaporation with higher degree of accuracy.

Secondly, the value of the period coefficient, Cm as found by Christiansen varies between 0.90 to 1.10. This is basic on his analysis of monthly data was observed at Logon, U.S.A., with climatic condition different from what exists over this region. In reality, the value of Cm varies from climate to climate and from latitude to latitude. In present study the average value of Cm = 1.0 was assumed and this contributed to the variations occurring in estimates. However, studies carried out elsewhere reveals that significant variations are likely to occur in computation, unless the range of Cm modified according to local climate and latitude.

On the basis of above finding, an attempt was made to modify the range of values of coefficients. Weekly values of Cm were determined by dividing weekly measured values with respect to time are shown in Fig. 16. It was found that the weekly value of Cm varies from 0.3 to 1.1. The mean weekly value of coefficient, Cm was taken 0.7.

The variations occurring between the estimated and measured rate of evaporation are well within the acceptable range indicating that the modified Christiansen model can very well be employed for prediction of weekly rate of evaporation. However, minor variation occurring in the new set of results may be attributed to the fact that there is further scope of modifying the model. The estimated evaporation values by modified Christiansen model are shown in Fig.17. Fig.18. and Table 2. shows the relationship between evaporation estimated by modified Christiansen model (E_{CHM}) and measured evaporation. The correlation coefficient and standard error of the linear regression equation are 0.80 and 0.27 mm day^{-1} respectively. The correlation coefficient was found to highly significant a 1 per cent level. The average value of E_{CHM} was found to be almost equal to average value of Ep.

Therefore, for this region inside polyhouse, the Christiansen model with the new set of values for Cm may be used to give sufficiently accurate prediction of evaporation rate on weekly basis.

The estimated evaporation inside polyhouse computed by most commonly used models for estimation of evaporation (i) Dalton model, (ii) Penman Combination model and (iii) modified Christiansen model were compared with measured evaporation. The modified Christiansen model was found better than other models for this region inside polyhouse.

The average annual evaporation rate was found to be 1.6 mm day^{-1}, average annual temperature was found to be 24.9 ^{o}C and average annual relative was found to be 72 %. It was favorable and very good condition for growing high value vegetables crops like capsicum, tomato and cucumber inside Polyhouse.

The average annual vale of wind speed at 2 m height was found to be 0.32 m s^{-1}. It was observed that the wind speed record ranging between 0.6 to 2.4 km/hr. From this result it can be concluded that wind moves with a non significantly to that surrounding inside polyhouse.

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