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RESEARCH ARTICLE

Comparative evaluation of actual evapotranspiration of capsicum inside and outside of naturally ventilated polyhouse

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ABSTRACT: This study was conducted to study the relationship between capsicum crop evapotranspiration inside (ET_{Cin}) and crop evapotranspiration outside (ET_{Cout}) the naturally ventilated polyhouse (NVPH) using meteorological parameters. Polyhouse has a straightway impact on air temperature and relative humidity while it indirectly influences soil temperature and soil moisture inside the structure. Under this study, crop evapotranspiration was estimated by conventional method *i.e.*, obtaining reference evapotranspiration from weather data recorded inside the polyhouse and multiplying it with crop coefficient values of capsicum crop. Reference crop evapotranspiration inside and outside the polyhouse found as 745.19 mm and 590.22 mm, respectively whereas capsicum crop evapotranspiration inside and outside the polyhouse was 868.40 mm and 694.16 mm, respectively. The results of the study revealed that the relationship between weekly ET_{Cin} and ET_{Cout} can be expressed mathematically as $ET_{Cin} = 0.84\ ET_{Cout}$. This implies that, there was approximately 15 % lower crop evapotranspiration requirement for the capsicum crop inside the naturally ventilated polyhouse as compared to outside the polyhouse.

1. INTRODUCTION

Crop evapotranspiration (ETc) is the quantity of water required by the crop to meet its evaporation and transpiration rate. Precise information on crop water requirement is essential for better yield, higher system efficiency and to save precious water sources. Crop evapotranspiration is influenced by various properties of different parameters such as soil, crop, meteorological, season and irrigation methods. Meteorological parameters are varying spatially and temporarily. Thus, irrigation engineers must understand every controllable and modifiable component which influences crop evapotranspiration for developing an efficient irrigation system.

Cultivation of crop inside polyhouse is highly profitable due to effective management of all resources and this results in higher production and better quality of produce round the year (Neelam and Rajput, 2010). It also enables the cultivator to take non-season/off-season crops so that one may fetch a higher price for the produce. Capsicum yields in open field cultivation ranges between 20-40 t ha^{-1}, whereas in a greenhouse the yield range is from 100-120 t/ha which is particularly because of environment inside greenhouse is modified as per the crop requirement *i.e.*, inductive microclimate for crop growth (Thangam *et al*., 2013).

In India, Capsicum (*Capsicum annuum*) is also known as *Shimla Mirch* in the states of Northern India. It is considered as a luxury vegetable due to the nutritional value of it. It is a rich source of vitamin A and C along with many minerals like Calcium, Magnesium, Phosphorus, Potassium, in different proportions. It is generally grown in a winter climate, but with the availability of recent advance techniques such as protected structures can be grown around the year. Protected cultivation techniques regulate temperature and humidity inside the structure and help in the development of favourable crop growth condition. Capsicum crop gives better crop yield and

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quality fruits if day temperature is not higher than 25-30˚C and night temperature in the range of 18-20˚C with R_h of approximately 50- 60%. Setting of fruit affected if the temperature more than 35˚C or drop below 12˚C and result in yield loss (Shankara *et al*., 2011). Lettuce grown in winter season in region of sub-humid is mortal because of drop in temperature below optimum level which has caused results in deficient growth (Santosh *et al*., 2017). Santosh *et al.*, 2017 recommended that under various cropping systems trials under protected condition ETc inside the protected cultivation structures is to be adjusted according to different kinds of protected structures as well as under different climatic regions.

Rajasthan state produces 17530 tonnes of Capsicum from 17720 ha area covered by the crop with average productivity of 0.99 tonnes per hectare (Vanitha *et al.,* 2013). Capsicum yield is on higher side inside greenhouse production system which ranges between 100-120 t/ha as compared to open field cultivation system which yields is drastically low and generally varies between 20-40 t/ha. This difference in the yield is due to fact that inducive microclimate inside greenhouse which is more favourable for yield and growth parameter of crop and thus vigorous growth (Thangam *et al.,* 2013). Over the decades, several evapotranspiration models have been developed and being utilized to compute evapotranspiration, but these models are suitable under specific conditions *i.e.*, regional or area specific and requires certain set of meteorological parameters for evapotranspiration estimation. Evapotranspiration estimation for a given specific place or region could vary depending upon the input parameters (meteorological) are considered and model/methodology adopted for estimation. Sagar *et al.,* 2019 evaluated different models viz., FAO-PM (benchmark), FAO Penman, Hargreaves, Stanghellini, Priestley-Taylor and FAO Radiation to estimate ET_0 inside polyhouse and open condition. ET_0 estimated significantly varied under different models under polyhouse inside and open condition. Lesser ET_c values were reported for green chilli inside the polyhouse as compared to open field condition during all growth stages (Aiswarya *et al.*, 2019). Decreased evaporation component of crop evapotranspiration has caused reduced crop water requirement inside polyhouse which emphasize that evaporation is higher in open field condition.

Bhakar and Singh (2003) estimated reference evapotranspiration for Udaipur region in Rajasthan state. They evaluated 10 most reliable and commonly used reference evapotranspiration models in terms of their applicability and validity under climatic conditions of Udaipur region. Tested models were: a) Penman FAO-24 model, b) Penman-Monteith FAO-56 model, c) Kimberly-Penman model, d) Priestly-Taylor model, e) Jensen – Haise Alfalfa reference model, Out of these 10 models only 3 models viz. Penman- Monteith FAO-56 model, Jensen-Haise Alfalfa reference model and FAO-24 Blanny Criddle models accurately predicted ET_0 under the climatic conditions of the region which implies that selection of given model is important for a specific reason\ climate to reliable measurement of evapotranspiration. Abbas *et al.,* 2018 recommended use of lysimeter and piche tube over class A pan for precise estimation of reference evapotranspiration (ETo) inside the greenhouse.

Usually, evapotranspiration rate for given climatic condition inside a greenhouse is approximately 60 to 80% as compared to open field condition (Montero *et al.,* 1985; Rosenberg *et al.,* 1989). Farias *et al.* (1994) in their experimental findings mentioned that the reference evapotranspiration (ETo) inside greenhouses was always lesser and ranged between 45 to 77% of that verified outside. Braga and Klar (2000) reported that 5% less evapotranspiration occurred when orientation of greenhouse was east/west compared to north/south orientation and inside reference evapotranspiration was approximately 82.5% of reference evapotranspiration verified outside for greenhouses.

From several previous studies, it was observed that crop evapotranspiration either inside the polyhouse or outside the polyhouse were estimated but only a few studies have correlated both in a single experiment. So, there is lack of information about evapotranspiration inside and outside the polyhouse. The objective of this experiment is to develop relationship between capsicum evapotranspiration inside and outside of the polyhouse. The implication of this study could assist to determine crop evapotranspiration of capsicum grown under a similar climatic condition for better management of irrigation water and enhancement of yield.

2. MATERIAL AND METHODS

2.1. Study Area and Trial Details

Naturally Ventilated Polyhouse (NVPH) is situated at Plasticulture Research Farm, College of Technology and Engineering (CTAE), Maharana Pratap University of Agriculture and Technology (MPUAT), Udaipur, Rajasthan. The experimental site is at elevation of 582.17 m above the mean sea level (AMSL) and having geographical coordinates as Latitude: 24º 35’31.5” to 24º 35’38.5” N and Longitude: 73º 44’18.2” to 73º 44’21.1” E. Maximum temperature reaches up to 46 °C during summer season and minimum temperature dips to 5 °C during winter season. Atmospheric humidity is generally high between June and October months.

Research trials were carried out during March, 2017 to August, 2017 and experimental treatments were allotted by applying randomized block design (RBD) with four replications under the NVPH. Experimental plots of size 8 m × 1 m were used under this study. The total area of the experimental field size was 192 m^2. Deficit irrigation levels were used are as follows:

In this study, meteorological parameters inside and outside the naturally ventilated polyhouse were observed, recorded and analysed for the whole crop season to establish the relationship of capsicum crop evapotranspiration in outside and inside the polyhouse condition. As crop evapotranspiration is varies with climatic parameters, but under same experimental condition of meteorological parameters inside the polyhouse, the crop evapotranspiration will remain same. So, in this study the prime focus is to develop relationship between crop evapotranspiration inside and outside the polyhouse.

2.2. Climatological Data

The weather data were recorded daily from the meteorological observatory station located at CTAE, Udaipur. The meteorological data for a period of 5 years (2012-2016) were collected, analysed, and used in this study for irrigation scheduling of capsicum crop. The meteorological data include daily parameters (*i.e.* maximum temperature (^{0}C), minimum temperature (^{0}C), Average relative humidity (%) (RHavg), wind speed at the height of 3 m, pan evaporation, and sunshine hours). Dry and wet bulb thermometers located inside the polyhouse was used to determine relative humidity values inside the polyhouse. Reference evapotranspiration of previous five years (2012-2016) at the experimental farm are shown in the Table 1.

2.3. Estimation of Reference Evapotranspiration (ETo)

For pre-scheduling of crop water requirement, the daily reference evapotranspiration outside the polyhouse

Table 1.
Reference evapotranspiration in previous five years (2012-2016)

Standard meteorological weeks	Reference Evapotranspiration (ET_0), mm/day					
	2012	2013	2014	2015	2016	Mean
11	4.65	3.60	4.31	3.57	4.08	4.04
12	4.42	3.92	4.09	3.96	4.58	4.19
13	5.36	3.97	4.33	4.57	4.13	4.47
14	5.04	4.59	4.67	5.28	5.24	4.96
15	6.27	4.64	4.64	4.91	5.17	5.12
16	6.00	5.17	4.96	5.48	5.34	5.39
17	5.81	5.25	5.47	5.67	5.20	5.48
18	6.14	6.00	6.03	5.86	5.77	5.96
19	6.18	6.12	6.26	6.14	5.79	6.10
20	6.45	6.56	6.23	6.06	5.75	6.21
21	6.36	7.25	6.10	6.99	6.67	6.67
22	6.40	6.21	6.67	6.88	5.85	6.40
23	3.90	5.52	6.65	6.05	6.50	5.72
24	3.67	4.89	7.04	5.27	5.65	5.30
25	4.78	4.96	6.65	5.31	4.29	5.20
26	4.52	4.89	6.93	5.92	4.56	5.36
27	3.04	3.42	5.20	4.81	3.75	4.05
28	2.83	3.29	4.28	3.15	2.83	3.28
29	2.80	3.00	2.90	2.70	2.80	2.84
30	2.66	3.06	3.15	2.25	3.53	2.93
31	2.28	2.60	3.51	4.20	2.56	3.03
32	2.40	2.54	3.07	4.53	2.52	3.01
33	2.10	3.07	4.39	4.43	4.16	3.63
34	2.31	4.10	4.37	4.63	2.78	3.64
35	1.88	2.81	3.58	4.58	2.28	3.03
ET_o (mm)	725.18	745.96	838.64	819.54	755.44	776.95

form last 5-year data have been determined by using the standard method *i.e.* Penman-Monteith (Allen *et al.*, 1998) for the present study.

2.4. Crop Evapotranspiration

Crop evapotranspiration was calculated from following formula:

$$ET_c = ET_0 \text{ x } K_c \quad ...(1)$$

Where, K_c is the crop coefficient value of crop refereed from FAO-56. The crop coefficient (Kc) values for capsicum during initial stage, mid-season stage and late season stages were taken as 0.53, 0.94 and 0.60, respectively. Kumar *et al*. (2011) precisely quantified ET_c by utilizing standard formula as shown in equation 1.

To develop relationship between the weekly ET_{cin} and ET_{cout} of the polyhouse, crop evapotranspiration inside and outside the polyhouse was calculated by utilizing measured meteorological parameters and using capsicum crop coefficient values. A simple linear regression analysis was done.

The air temperature data inside the polyhouse were measured by the maximum and minimum thermometers placed inside the polyhouse. Dry and wet bulb thermometers located inside the polyhouse was used to measure relative humidity values inside the polyhouse. The most convenient method of determining the humidity of the air for metrological purpose is using wet and dry thermometers. The wind speed inside the polyhouse was taken as zero and sunshine hour was taken as per outside sunshine hours. (Neelam and Rajput, 2010).

From the weathers data recorded inside and outside the polyhouse reference evapotranspiration have been worked out using FAO-56 Penman-Monteith Method model. The crop evapotranspiration has been calculated by Equation 1.

3. RESULTS AND DISCUSSION

Meteorological data were observed and analysed during the whole experimental period. It was found that the weekly maximum temperature (T_{max}) and minimum temperature (T_{min}) were 29.01 ^{0}C and 13.07 ^{0}C, respectively. The weather data recorded during experiment period are represented below in Figure 1.

The maximum temperature during the experiment varied between 38.01 ºC to 27.57 ºC with mean value 32.18 ºC whereas minimum temperature varied between 26.69 ºC to 17.24 ºC with mean value 20.97 ºC. The average maximum relative humidity of different weeks varied from 92.67 to 38.37% with mean value 61.08 while, weekly average minimum relative humidity of different weeks varied from 73.17 to 12.90% with mean value 36.23. The average values of reference evapotranspiration ranged from 7.14 to 3 mm/day with mean value 4.68 mm/day, whereas average sunshine values varied from 11.46 to 1.31 hours/day with mean value 9.46 hours/day, maximum wind velocity during crop period was 6.23 km/hr and minimum was recorded 0.20 km/hr with mean value 2.62 km/hr.

It was observed that dry bulb temperature ranges from 38.34 ºC to 25.36 ºC with mean value of 33.79 ºC. Wet bulb temperature ranges from 35.46 ºC to 18.99 ºC with mean value of 29.33 ºC. The maximum temperature up

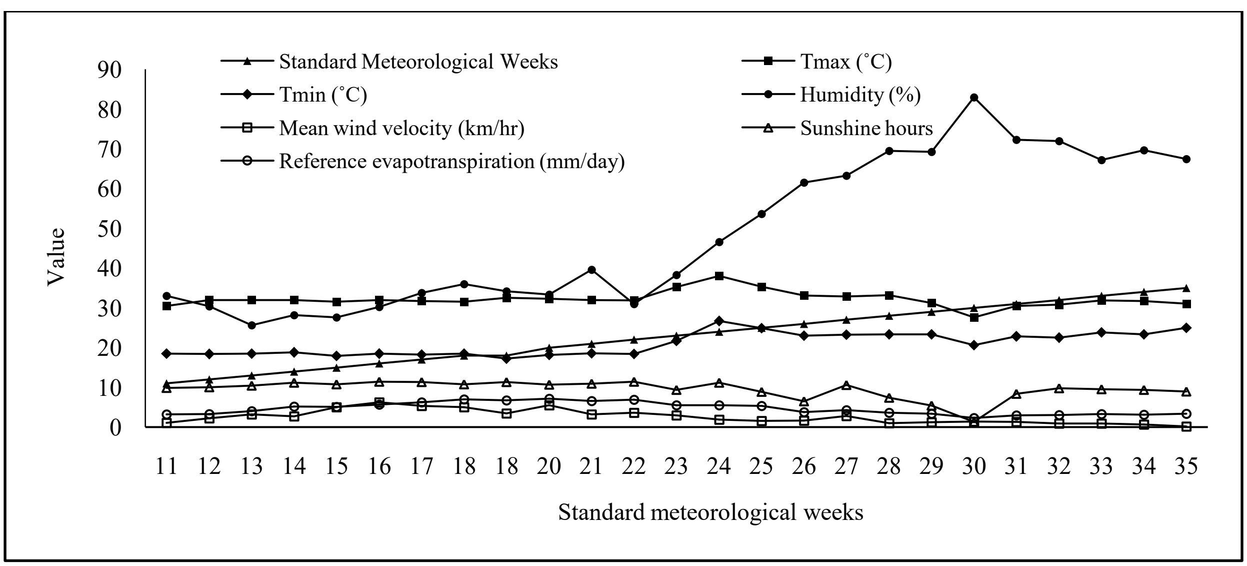


Fig. 1. Weekly meteorological observations recorded outside the polyhouse during the year 2017

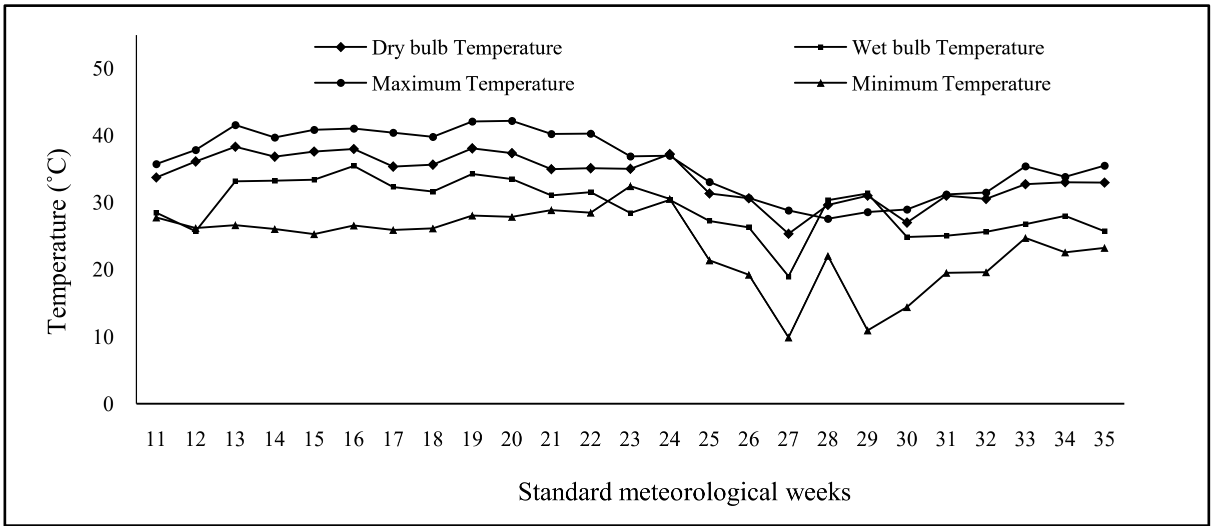


Fig. 2. Weekly meteorological observations recorded inside the polyhouse during the year 2017

to 42.21 ºC and minimum temperature was recorded as 9.89 ºC. The air temperature is favourable for the growth of the capsicum except for few hours when maximum temperature was gone up to 42.21 ºC.

Overall, $ET_{oinside}$ is 14.96 % less as compared to the ET_{0out} reference evapotranspiration as evident from Fig.3. Similarly, (Shukla, 2013) observed that the reference evapotranspiration (ETo) inside structure-4 (polyhouse) was 15.58% lower in comparison to the outside reference evapotranspiration. The results of weekly ETo are presented in Fig. 3 for inside and outside of the NVPH. It has been found that the ETo inside the NVPH is less than the outside of the NVPH. The ETo inside the NVPH is obtained 745.19 mm which ranged from 2.24 mm/day to 5.79 mm/day. Likewise, ETo outside the NVPH obtained as 868.40 mm which varied between 2.60 mm/day to 7.27 mm/day.

The climatic parameters *i.e.* temperature, R_h, wind speed and bright sunshine hours have significant influence on the magnitude of the ETo. Goyal, (2004) studied the effect of meteorological parameters on evapotranspiration rate and reported that wind velocity, relative humidity in conjunction with temperature causes a significant variation in magnitude of evapotranspiration. He found that individual as well as combination of various meteorological parameters influences estimation of reference evapotranspiration in various proportions.

Evapotranspiration plays a crucial role in the calculations of water requirement of crops. Therefore, it proves

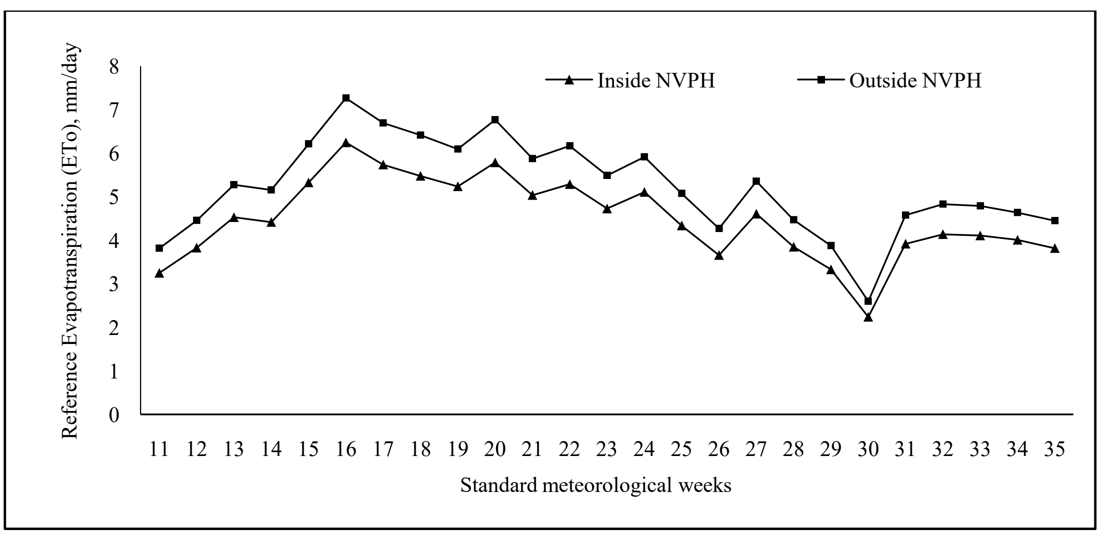


Fig. 3. Estimated weekly reference evapotranspiration (ETo), mm/day from climatologically data for the year 2017 inside and outside naturally ventilated polyhouse at Udaipur.

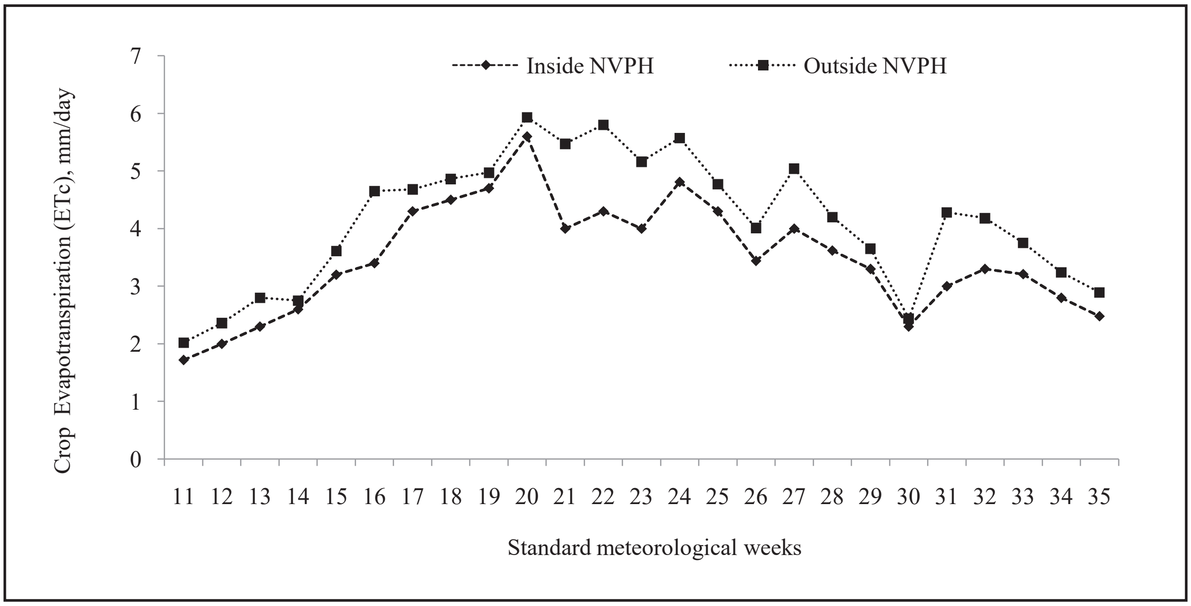
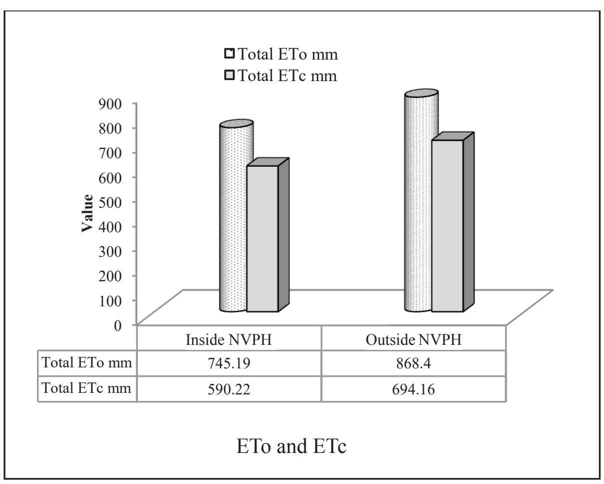


Fig. 4. Estimated weekly crop evapotranspiration (ETc), mm/day from climatologically data for the year 2017 inside and outside the naturally ventilated polyhouse at Udaipur.

necessary to study the relationship between inside and outside Evapotranspiration in protected cultivation. Figure 4 shows the variation of crop evapotranspiration inside and outside the polyhouse. The highest crop evapotranspiration rate for capsicum inside and outside the polyhouse was occurred 20th standard meteorological week whereas lowest in the 11th standard meteorological weeks. Figure 5 shows total seasonal reference and crop evapotranspiration inside and outside the polyhouse. Reference crop evapotranspiration inside and outside the polyhouse found as 745.19 mm and 590.22 mm, respectively whereas capsicum crop evapotranspiration inside and outside the polyhouse was 868.40 mm and 694.16 mm, respectively. Regression analysis was done with crop evapotranspiration (ETc) outside and inside the NVPH during the crop period. The graphs were developed with intercept value of 0.272 and shown in Fig. 6. The relation between ET_{cin} and ET_{cout} e the NVPH found to follow straight line equation with intercept as zero. Inside crop evapotranspiration is obtained as 84 per cent of the outside evapotranspiration with coefficient of determination (R^2) as 0.87.



	Inside NVPH	Outside NVPH
Total ETo mm	745.19	868.4
Total ETc mm	590.22	694.16

Fig. 5. Estimated weekly crop evapotranspiration (ETc), mm/day from climatologically data for the year 2017 inside and outside the naturally ventilated polyhouse at Udaipur.

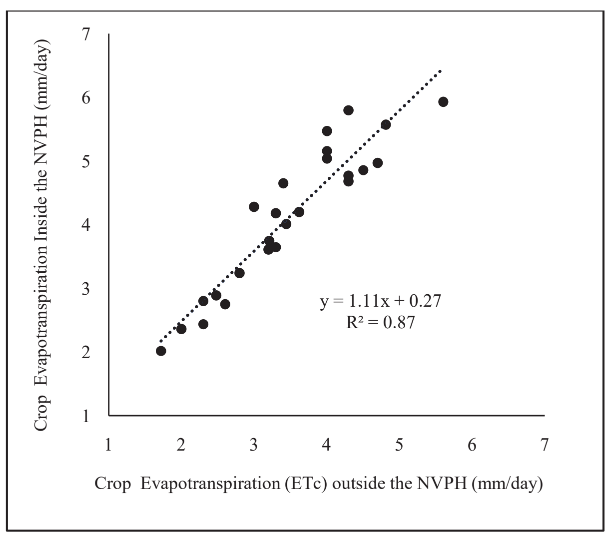


Fig. 6. Relation between weekly ETc inside and weekly ETc outside the NVPH.

The relation between the weekly $ET_{cinside}$ and outside the NVPH was established to be represented by:

$$ETc_{in} = 0.84\ ETc_{out} \quad ...(2)$$

The coefficient of determination (R^2) between ETc inside and outside was obtained as 0.87 during the entire growth period of capsicum crop.

4. CONCLUSIONS

From the findings of the present study, it can be concluded that crop evapotranspiration is greatly influenced by the meteorological weather parameters and therefore higher accuracy should be maintained while working out the crop evapotranspiration for a particular crop grown in protected cultivation structures. The results showed that the reference and actual crop evapotranspiration obtained for inside polyhouse microenvironment was found less as compared to that of outside the polyhouse. Reference crop evapotranspiration inside and outside the polyhouse were estimated to be 745.19 mm and 590.22 mm, respectively whereas capsicum crop evapotranspiration inside and outside the polyhouse was 868.40 mm and 694.16 mm, respectively. The crop evapotranspiration of capsicum inside the NVPH was approximately 84 per cent of the crop evapotranspiration outside. Crop evapotranspiration of capsicum was about 15% less inside the polyhouse condition as compared to open field condition. This difference in magnitude of crop evapotranspiration is highly significant to encourage efficient and effective cultivation techniques to save irrigation water particularly in water-scarce regions.

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