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Influence of different protected cultivation structures on water requirements of winter vegetables

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Abstract

Protected cultivation structures provide favourable environment for crop growth thereby achieving greater yield and high quality produce. Green house, polyhouse, shade net house & low tunnels are different types of protected cultivation structures, which are commonly adopted for crop cultivation. During extreme cold in winter season (November-February) vegetables can be grown under green house structure. Accurate irrigation scheduling in protected cultivation structures is one of the important factors in achieving high yields and avoiding loss of quality. The objective of this work was to evaluate the effect of protected cultivation structures (Poly house, shade net house and shadow hall) on temperature, relative humidity and water requirement of vegetable crops (Tomato, Cucumber, Capsicum, Cauliflower, Cabbage, Broccoli & Brinjal) with drip irrigation system grown during winter season (November-February). FAO-56 Penman Monteith approach was used to estimate the reference crop evapotranspiration under different kind of protected cultivation structures with different vegetable crops. Study shows that vegetable production in winter for sub humid region reduces due to fall in temperature below optimum level. Green house structure offers a solar energy saver and enhances temperature inside the structures. Daily average reference crop evapotranspiration value was found to be minimum for shadow hall (1.2-2.9 mm day^{-1}) followed by polyhouse (1.3-3.2 mm day^{-1}), shadenet house (1.4-3.7 mm day^{-1}) and open field (2.0-4.9 mm day^{-1}) condition. The total water requirement of drip irrigated vegetable crops in protected cultivation structure is reduced by about 35.6 %, 35.2 % and 25.5 % respectively under shadow hall, poly house and shade net house in comparison to open field cultivation.

Highlights

- Comparing temperature, relative humidity and crop reference evapotranspiration of different protected cultivation structures with open cultivation condition
- Estimation of water requirement of vegetables using FAO 56 Penman Monteith equation for Polyhouse, Shadenethouse, Shadow hall and outside condition.

Keywords: Temperature, Polyhouse, Shadenet house, Reference crop evapotranspiration

Vegetables are an important source of food and nutrition. India is the second largest producer of vegetable crops in the world. However, its vegetable production is much less than the requirement if balanced diet is provided to every individual. The present production of 125.74 million tones (NHB 2014) is to be raised to 250 million tones by 2024-2025. There are different ways and means to achieve this target, e.g., bringing additional area under vegetable crops, using hybrid seeds, use of improved agro-techniques. Another potential approach is perfection and promotion of protected cultivation of vegetables (Sanwal *et al.* 2004). During winters in north Indian plains and hills, the temperature and solar radiations are sub-optimal for growing off-season vegetables – tomato, capsicum, brinjal, cucurbits, okra, cowpea, amaranth and chilli. Hence, during extreme conditions of winter season (November-February) these vegetables can be well cultivated under protected cultivation structures.

Research results have shown that by adopting protected cultivation, productivity of vegetable crops can be increased by 3 to 5 times as compared to open environment. Green house, polyhouse, shade net house & low tunnels are the different types of protected cultivation structures commonly adopted by the Indian farmers. Poly house is a framed structure having 200 micron (800 gauges) UV stabilized transparent or translucent low density polyethylene which creates greenhouse effect making microclimate favorable for plant growth and development. Structure is large enough to permit a person to work inside. Shadenet house is a framed structure made of materials such as GI pipes, angle iron, wood or bamboo. It is covered with plastics net which are made of 100% Polyethylene thread with specialized UV treatment having different shade percentages. It provides partially controlled atmosphere and environment by reducing light intensity and effective heat during day time to crops grown under it. Hence round the year seasonal and off-season cultivation is possible. Shading nets are used in tropical and subtropical countries for vegetable production (Castellano *et al.* 2008; Ilic *et al.* 2012; Kittas *et al.* 2012).

Shading also reduces water requirements and increases irrigation water use efficiency in vegetable crops (Moller and Assouline, 2007). Shadow hall is hybrid concept of shadenet house and polyhouse. In well framed structure made up of GI pipes covered with nets of different shades. Poly film layer placed beneath shade net (around 1m below shadenet) which increases the temperature during winter & reduces during the summer season. This structure also aims at protect crop from devastating rains.

Irrigation system is one of the most important components affecting the yield and quality of agricultural produce from protected cultivation system. The use of drip irrigation and fertigation saves water and fertilizer and gives better plant yield and quality (Singh and Singh, 2011). A correct determination of irrigation scheduling is one of the main factors in achieving high yields and avoiding loss of quality in protected cultivation (Pereira *et al.* 2002; Ramirez and Harmsen, 2011). To do this, it is fundamental to know the crop water requirements, which depends on specific interactions among soil, crop and atmospheric conditions. For protected cultivation structures crop evapotranspiration ETo have been estimated by measuring water evaporation with a pan evaporimeter (Yuan *et al.* 2001). Also, the Modified Penman-Monteith model, which has solid physical principles, could be used to estimate the water requirements for greenhouses and shade net houses. This model requires as input atmospheric condition measurements inside the structures.

To date, there is not much work available on protected cultivation of vegetables. There is an urgent need to assess the cultivation and suitability of different vegetables under protected cultivation structures to meet the growing demand of the vegetables. Thus, the investigation was aimed to determine the efficacy of protected cultivation compared to open field on temperature and water requirement of vegetables during winter season. In this research paper an attempt is made to estimate the crop water requirement of winter vegetable grown in sub-humid and sub-tropical climate of Kharagpur under different protected cultivation structures.

Materials and methods

The study area is located at Precision Farming Development Centre, experimental farm of Agricultural and Food Engineering Department, IIT Kharagpur, India. It is situated at 22° 20' N latitude and 87° 20' E longitude and at an altitude of 48 m above the mean sea level. The climate of the region is sub-humid, with an average annual rainfall of about 1400 mm. The minimum temperature varies from 9.6 °C to 27 °C and maximum temperature ranges from 27.2 °C to 41.8 °C during winter and summer seasons respectively. The maximum and minimum relative humidity varies respectively from 79 to 99 % and 19 to 78 % throughout the year.

Three types (polyhouse, shadenet house with 75% shade and shadow hall or modified shadenet house with 75% shade and 200 micron UV stabilized film) of protected structures considered for the study (Fig. 1a, b, c). The width of all structures was 5 m, the length was 17 m. Height was 3m, 4m & 4m for polyhouse, shadenet house and modified shadenet house respectively. Evapotranspiration was estimated by using climatic data recorded under different protected structures. Major winter vegetables are considered for this present study which includes Tomato, Capsicum, Brinjal, Cucumber, Cabbage, Cauliflower and Broccoli.

Fig. 1a, b & c. Poly house, Shadenet house and Shadow hall situated at PFDC experimental field IIT Kharagpur

The daily irrigation water requirement for the vegetable crops were estimated by using the following relationship:

$$WR = ETo \times Kc \times Wp \times A$$

Where,

WR = Crop water requirement (L d^{-1})

ETo = Reference evapotranspiration (mm d^{-1})

Kc = Crop coefficient (Table 1 lists typical values for Kc ini, Kc mid, and Kc end for various winter vegetable crops)

Wp = Wetting fraction (taken as 1 for close growing crops)

A = Plant area, m^2 (i.e. spacing between rows, m x spacing between plants, m)

The daily meteorological data recorded during the year 2014 and 2015 were used to compute reference evapotranspiration (ETo). The modified Penman-Monteith method suggested by Allen *et al.* (1998) was used to compute reference evapotranspiration (ET_O).

Results and discussion

The presence of cover, characteristics of protected cultivation structures, causes changes in the climatic conditions compared to those outside during winter crop season. Radiation and air velocity are reduced, temperature and water vapour pressure of the air increases. Each of these changes has its own impact on the growth, production and quality of the crop inside the protected cultivation structures (Singh and Sirohi, 2006).

Effect of different structures on climatic data

Temperature is the major regulator of development processes in crops. Each kind of crop grows and develops most rapidly at a favorable range of air temperatures. This is called the optimum air temperature range. For most crops the optimum functional efficiency occurs mostly between (12 and 24°C). Most crops (and especially vegetables) can be classified according to the temperature requirements of their optimum air temperature range. However they are generally grouped into whether they require low or high air temperatures for growth. Temperature requirements are usually based on night temperature. Those that grow and develop below 18°C are the cool season crops, and those that perform above 18ºC are the warm season crops. Optimum temperature for winter vegetable crop is 21-29°C during day and 15-20°C during night. Optimum temperature for colour development of fruit is 21-24°C. Seed germination and pollen germination are adversely effected below 10°C. It observed from the recorded temperature data that average minimal temperature recorded below 15°C for the whole winter season in open field condition which adversely affects the growth of vegetable crop. Lower temperatures have more adverse influence on net photosynthesis which leads to decreased production of photosynthates below a certain temperature (Silva *et al.* 2004).

Table 1: Crop coefficients, Kc (Allen *et al.* 1998), and plant area, m^2 of different vegetables

Sl No.	Crop	Kc ini	Kc mid	Kc end	Plant area, m^2
1	Tomato	0.6	1.15	0.80	0.5 × 0.5 = 0.25
2	Capsicum	0.6	1.05	0.90	0.45 × 0. 5 = 0.23
3	Brinjal	0.6	1.05	0.90	0.5 × 0.5 = 0.25
4	Cucumber	0.6	1.00	0.75	0.5 × 0.25 = 0.13
5	Cabbage	0.7	1.05	0.95	0.6 × 0.45 = 0.27
6	Broccoli	0.7	1.05	0.95	0.6 × 0.45 = 0.27
7	Cauliflower	0.7	1.05	1.00	0.6 × 0.45 = 0.27

Daily variation of maximum and minimum temperature in different protected cultivation structures namely poly house, shade net house and shadow hall were recorded from November to February for consecutive two years. Temperature of these structures showed that the use of different covering materials for structure exerted an influence on temperature. Air temperatures tended to be lower under the shade net comparing with other covers, due to the interception of radiation which is greater than the gain of temperature caused by the use of shadenet. Interception of air within the structure daily maximum and minimum temperature tended to be higher in case of Poly house.

Average monthly maximal and minimal air temperatures during the winter season in different structures are shown in Fig. 2 & 3. Fig. 2 show that Polyhouse and shadow hall recorded the highest value (18 °C) for minimal air temperatures for the month of November followed by shade net house and open condition. The same trend continues for other three months. Monthly average of daily maximal temperature for the winter season (Fig. 3) shows that highest value of maximal temperature recorded in polyhouse for the month of November (40°C) and December (36°C) followed by shadenet house, shadow hall & open condition. In the month of January all structures were recorded almost same value of minimal and maximal temperature. We can also observe from Fig. 3 that in month of January and February highest value of temperature recorded for shadow hall fallowed by the polyhouse and shade net house.

Polyhouse recorded highest mean monthly average temperature for the month of November and December and lowest mean monthly average temperature recorded for open condition for the same months. It also observed that significant increase in mean temperature in polyhouse (8%), shadenet house (2%) and shadow hall (5%) compare to the open condition. Poly film increases the temperature by accumulation of solar radiation inside structures and shade reduces temperatures inside a structure by reducing the amount of solar energy that enters structures. Shade nets are often deployed over crops to reduce heat stress however, in enclosed shade net houses, temperatures during the day are typically higher than outside in winter (Pérez *et al.* 2006) and may be lower at night, at least during radiation freezes. Shade nets also reduce wind speeds and wind run, which can affect temperatures.

Fig. 4 shows that the average relative humidity increased in poly house by 3–7% as compared with open field which is followed by shadow hall (2-6%) and shadenet house (1-5%). These results were in line with those reported by Igle-sias and Alegre (2006), indicating a 3–9% increase in humidity associated with the use of shade nets. These authors also reported a decrease in evaporation associated with the use of cladding materials and a significant reduction in wind speed.

Reference evapotranspiration

Application of FAO-56 Modified Penman–Monteith (PM) equation was used for estimating vegetables water requirement, the microclimate data plays an important role for irrigation planning. With the appropriate climatic data measured in the

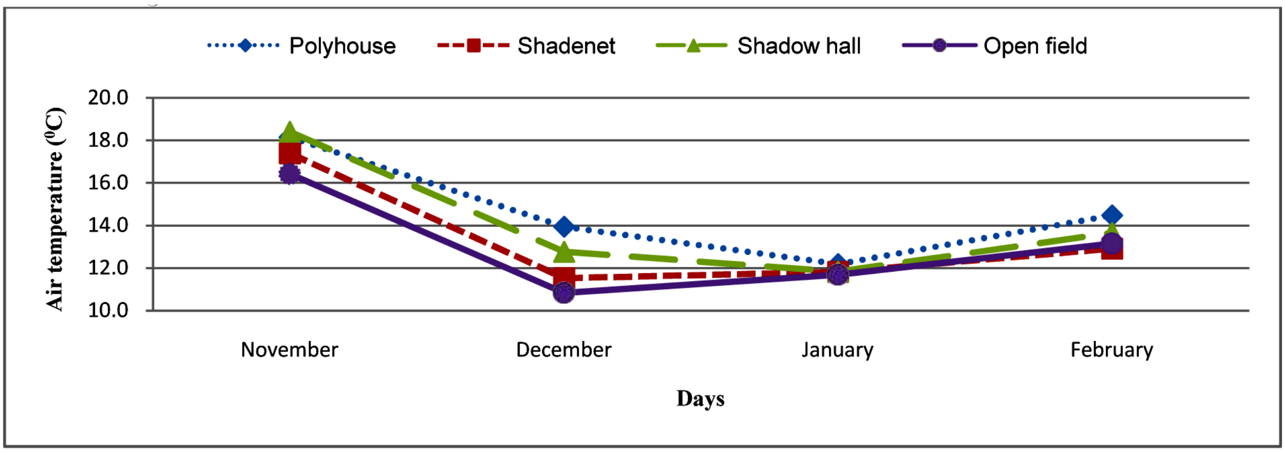

Fig. 2: Average monthly minimum temperature recorded in different protected cultivation structures for winter season

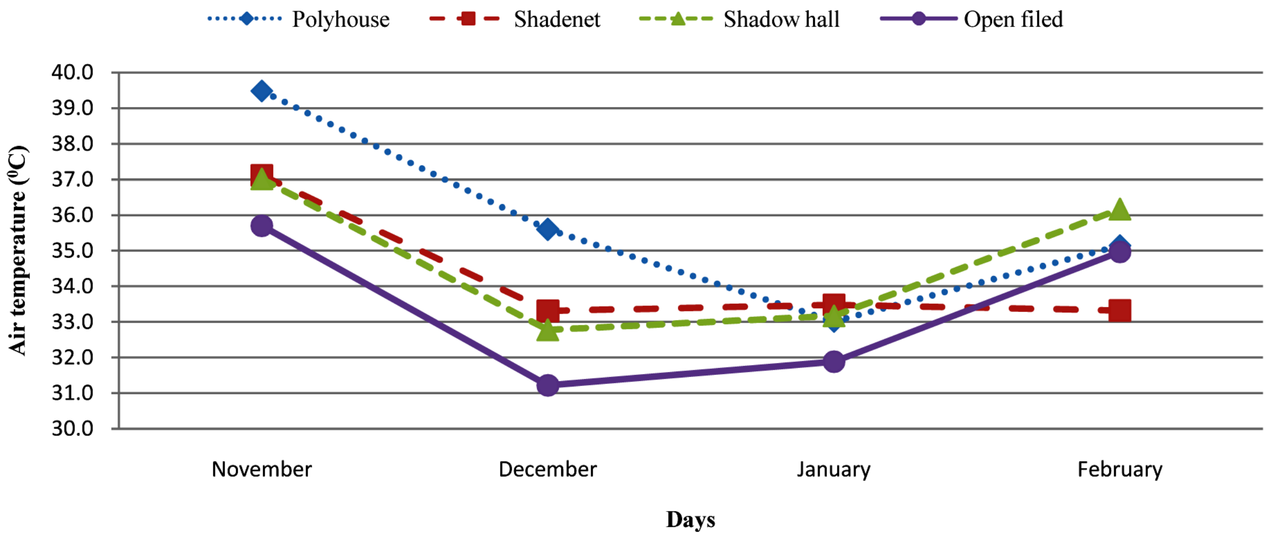

Fig. 3: Average monthly maximum temperature recorded in different protected cultivation structures for winter season

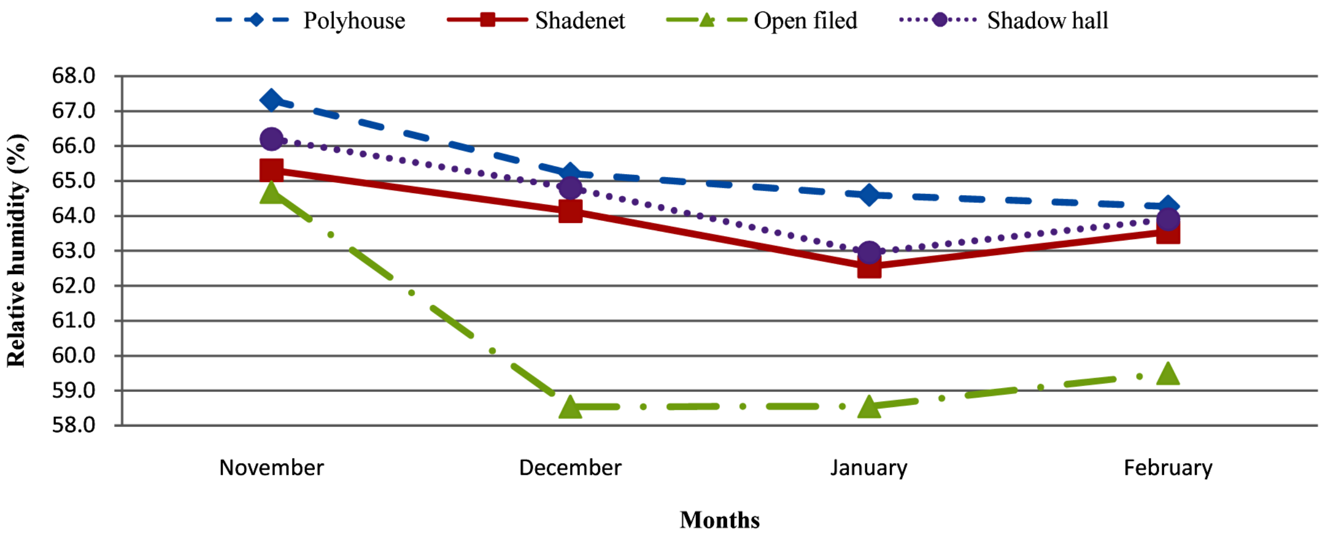

Fig. 4: Average monthly mean relative humidity (%) recorded in different protected cultivation structure during winter season

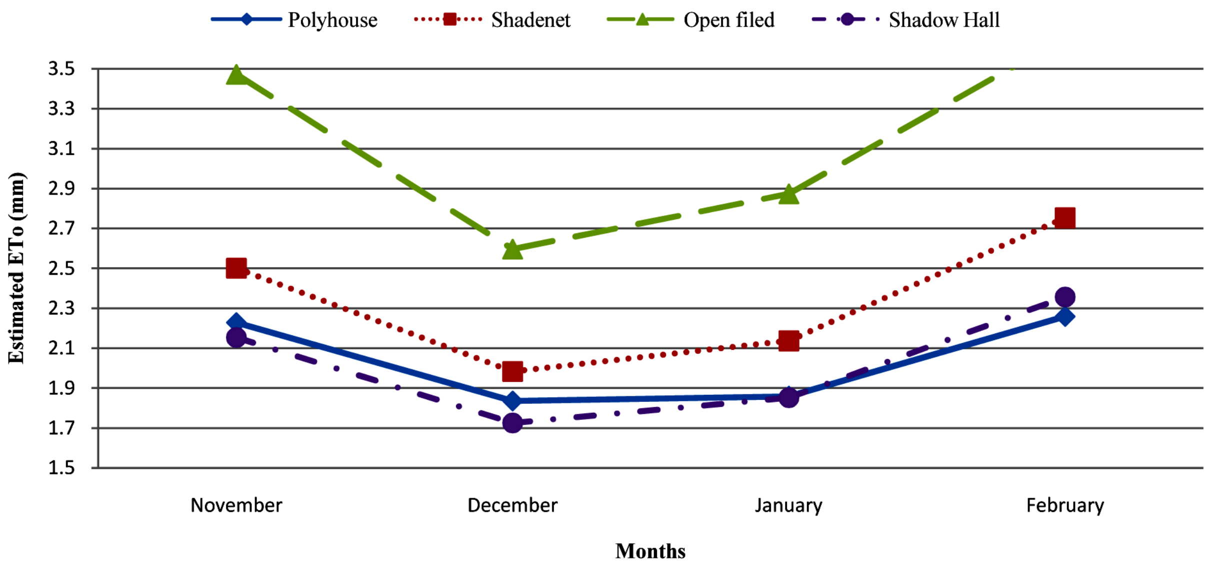

Fig. 5: Average monthly estimated reference evapotranspiration in different protected cultivation structures

greenhouse, crop water requirement could be predicted using the evapotranspiration equation from PM model (Boulard and Wang, 2000). Baille (2004) claimed that the PM model is believed to be the best adapted to estimate crop water requirements, but requires more sensors for measuring microclimatic parameters i.e. air temperature, relative humidity, wind speed, global solar radiation, soil temperature as well as specific crop parameter such as the aerodynamic, stomata conductance and leaf temperature. At present, the most irrigation of greenhouse crops is mainly controlled on the basis of solar radiation due to unavailability of sensing devices and cost consideration. The cladding materials covering on protected cultivation structures, 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).

Evapotranspiration under all structures tended to be lower than open field because of the greenhouse effect and the low radiation under these covers. Polyethylene sheet cover obtained the highest air temperatures and open field recorded the highest evapotranspiration during the whole season, which agreed with the results reported by Abdrabbo (2001). The difference between internal and external evapotranspiration varies according to meteorological conditions. Seasonal ET_o of greenhouse is quite low when compared to that of irrigated crops outdoors during winter. The values of ETo for the month of November (2.5, 2.3 & 2.2 mm day^{-1}), December (2, 1.8 & 1.7 mm day^{-1}) & January (2.1, 1.8 & 1.8 mm day^{-1}) were estimated lower for the shadenet house, poly house and shadow hall respectively compares to open condition. For poly house and Shadow hall, values of estimated ETo are close in range throughout the season but lesser values compare to shadenet house. For the month of November, December & January estimated ETo values of shadow hall condition are lowest comparing to other structures.

However, the trend is reversed for the month of February in which estimated ETo values for shadow hall little bit increased compare to the polyhouse. Many authors have also observed that evapotranspiration inside a greenhouse is around 60 to 80% of that verified outside (Fernandes *et al.* 2003). (Fernandez *et al.* 2010) observed that the reference evapotranspiration (ET_o) inside greenhouses was always lower, ranging on 45 to 77% of that verified outside. Braga & Klar (2000) observed that the values of reference evapotranspiration were 85 and 80% of the reference evapotranspiratoin verified outside for greenhouses oriented east/west and north/south, respectively. These results can be explained by the influence of the main factors of evaporative demand of the atmosphere, such as lower wind speed values, higher relative humidity and lower incidence of direct solar radiation inside greenhouses.

Solanaceous crops (Tomato, Brinjal & Capsiccum) constituted about 60% greenhouse areas. Among Solanaceae, the most researched crop is tomato. Tomato (*Lycopersicon esculentum*) is the largest vegetable crop in the world in terms of acreage, and it is mainly cultivated in the greenhouse during winter and spring seasons (Yuan *et al.* 2001). Prevailing low temperature and frost injury during winter season are limiting factor for successful cultivation of tomato under the agro-climatic region of Eastern plateau and Hills. It is difficult to grow this vegetable under open conditions during November – February because of adverse effects of low temperature on overall morphological growth and fruit setting. The temperature conditions did not affect the vegetative growth of tomato, but the lower minimum temperatures reduced or delayed the fruit settings. Higher relative humidity in protected cultivation structures promotes pollen germination and also improves pollen adhesion to the flower stigmatic surface. Tomatoes require a high water potential for optimal vegetative and reproductive development. Total water requirement of Tomato crop estimated as 65.12 L plant^{-1} (257.4 mm) for Sahdenet house which is followed by 56.6 L plant^{-1} (226.6 mm) for polyhouse and 56.3 l plant^{-1} (225.1 mm) for shadow hall. Not only do microclimate parameters affect the crop water requirement, but also it depends very much upon crop variety, season and the method of tomato cultivation.

Capsicum (*Capsicum annum L.*) is an important crop in many parts of the world given their economic importance, ranking second in world production. Temperature affects the vital functions of plants such as germination, transpiration, respiration, photosynthesis, growth and flowering (Goto and Tivelli, 1998). Therefore, planting in a protected environment may reduce the effects of temperature to the plant (Santos *et al.* 2009). The optimum temperature favourable for growth of Capsicum ranges between 20 and 25°C. When temperature falls below 15°C or exceeds 32°C, growth is usually retarded and yield decreases. High air humidity improved fruit set, but also enhanced flower abscission during the early production period. Seasonal water requirement of Capsicum crop under PCS estimated as 56.92 L plant^{-1} (252.9 mm) for shade net which is followed by poly house with 49.20 L plant^{-1}(218.7 mm) and shadow hall with 49.11 L plant^{-1} (218.28 mm). Open field condition estimated higher water requirement with 76.45 L plant^{-1} (339.76mm) comparing to other structure. In general, under PCS soil water content was higher compared to open field. Covering material reduces the demand for crop evapotranspiration, causing reduction of transpiration, resulting in decreased soil water uptake in Capsicum (Díaz-Pérez, 2013).

Brinjal (*Solanum melongena L.*) is a popular greenhouse crop due to the high yield potential, rapid growth, and improved quality possible over a longer season. In addition to the field production, the reasons why greenhouse production of the brinjal gains importance, is because of more profit and greenhouse producers want to get rid of their dependence on the tomato production. Plantation area of brinjal in greenhouses increases year by year with application of improving agricultural technologies, and the brinjal is the fourth in rank within the green-house products, after tomato, pepper and cucumber. Brinjal is a thermophilic plant, of high water requirements, especially in the period of setting buds and fruits growth (Aujla *et al.* 2007).

In brinjal plant both vegetative and fruit growth was negatively affected by the lower minimum temperatures (Uzun, 2006). Optimum temperature for brinjal growth is within the range of 22–30ºC, while temperature fall to 17°C results in inhibition of plant development. Therefore, the highest production of this species originates from the area of a very hot climate of the country (Lawande and Chavan 1998). Cemek *et al.* (2005) reported that plant height was greater in brinjal plants grown in polyhouse, which had a higher temperature than in shade net and open field condition. It was also found that an increase in temperature from 10 to 32°C led to increase in plant height. As it can be concluded from the Fig. 2 & 3, thermal conditions are favorable for brinjal plant growth. Total irrigation requirement of Brinjal crop estimated as 83.50 L plant^{-1} (334 mm) for open cultivation which is followed by Sahdenet house (62.17 L plant^{-1}), poly house (53.98 L plant^{-1}) and shadow hall (53.69 L plant^{-1}). Open field condition estimated less water

Table 2: Crop water requirement of winter vegetable under different protected cultivation structures

Month	Crop water requirement ETc (mm)				Water requirement (L day^{-1} $Plant^{-1}$)			
	Poly house	Shadenet house	Open	Shadow Hall	Poly house	Shadenet house	Open	Shadow Hall
				Tomato				
Nov	1.63	1.83	2.54	1.56	0.41	0.45	0.63	0.39
Dec	1.86	2.03	2.65	1.76	0.46	0.51	0.66	0.44
Jan	2.06	2.44	3.28	2.11	0.52	0.61	0.82	0.53
Feb	1.80	2.05	2.91	1.88	0.45	0.55	0.73	0.47
Total	226.58	257.37	349.79	225.06	56.64	65.12	87.45	56.27
				Capsicum				
Nov	1.65	1.85	2.57	1.59	0.37	0.42	0.58	0.36
Dec	1.52	1.65	2.16	1.44	0.34	0.37	0.49	0.32
Jan	1.69	2.00	2.69	1.73	0.38	0.45	0.61	0.39
Feb	2.31	2.81	3.74	2.41	0.52	0.63	0.84	0.54
Total	218.66	252.99	339.76	218.28	49.20	56.92	76.45	49.11
				Brinjal				
Nov	1.58	1.76	2.45	1.51	0.39	0.44	0.61	0.38
Dec	1.73	1.88	2.47	1.64	0.43	0.47	0.62	0.41
Jan	1.78	2.11	2.84	1.83	0.45	0.53	0.71	0.46
Feb	1.94	2.37	3.15	2.03	0.49	0.59	0.79	0.51
Total	215.93	248.70	334.01	214.74	53.98	62.17	83.50	53.69
				Cucumber				
Nov	1.48	1.65	2.30	1.42	0.19	0.21	0.29	0.18
Dec	1.45	1.58	2.07	1.37	0.18	0.20	0.26	0.17
Jan	1.68	1.99	2.67	1.72	0.21	0.25	0.33	0.22
Feb	1.97	2.40	3.18	2.05	0.25	0.30	0.40	0.26
Total	201.23	232.36	311.94	200.61	25.16	29.05	38.99	25.08
				Cabbage				
Nov	1.69	1.88	2.62	1.62	0.46	0.51	0.71	0.44
Dec	1.61	1.75	2.29	1.52	0.43	0.47	0.62	0.41
Jan	1.83	2.16	2.91	1.87	0.49	0.58	0.79	0.51
Feb	2.21	2.69	3.57	2.31	0.60	0.73	0.97	0.62
Total	224.22	258.98	347.75	223.54	60.54	69.92	93.89	60.36
				Broccoli				
Nov	1.69	1.89	2.63	1.63	0.46	0.51	0.71	0.44
Dec	1.66	1.81	2.36	1.57	0.45	0.49	0.64	0.42
Jan	1.83	2.17	2.92	1.88	0.49	0.59	0.79	0.51
Feb	2.27	2.76	3.66	2.36	0.61	0.74	0.99	0.64
Total	227.75	263.05	353.17	227.06	61.49	71.02	95.36	61.31
				Cauliflower				
Nov	1.69	1.88	2.62	1.62	0.46	0.51	0.71	0.44
Dec	1.58	1.72	2.25	1.50	0.43	0.46	0.61	0.40
Jan	1.79	2.12	2.85	1.84	0.48	0.57	0.77	0.50
Feb	2.32	2.82	3.75	2.42	0.63	0.76	1.01	0.65
Total	225.12	260.29	349.52	224.62	60.78	70.28	94.37	60.65

requirement with 123 L day^{-1} $plant^{-1}$ comparing to other structure. The obtained values related to the amount of the irrigation water and ET was similar to the findings of Drosos (1995) and Lovelli *et al.* (2007).

The cucumber (*Cucumis sativus L.*) is a warm season crop and grows best at a temperature between 18°C and 24°C. It is a sub-tropical vegetable crop that grows successfully under conditions of high light, high humidity, high soil moisture, temperature and fertilizers in green-houses (El-Aidy *et al.* 2007). It prefers dry climate with bright sunshine which is not possible in open field condition during winter season. Chilling injury in cucumber is a physiological disorder that occurs in sensitive plants subjected to low temperatures below 12°C. Symptoms of chilling injury include stunted growth, reduced photosynthetic capacity, necrosis and discoloration, abnormal ripening and increased disease susceptibility.

Increased temperature in protected cultivation structure leads to good yield. Water is an important limiting factor in the production and quality of cucumber, because it has a sparse root system, approximately 85% of the root length is concentrated in the upper 0.3 m top of soil layer. There is no much difference in the crop evapotranspiration rate comparing to other winter vegetables crops however, water requirement per day per plant for the Cucumber is much lower comparing to other crops due to fact that crop area is much lesser than the other crops i.e 0.13 m^2 per plant. Lorenzo *et al.* (2006) found that poly house increased yield of cucumber, moreover it reduced crop transpiration and thus water uptake, and improved water use efficiency by 62% for the Cucumber crop. Crops grown in open fields of sub humid climate were subjected to direct sun-light, high temperatures and wind resulting in high crop evapo-transpiration (ETc.), therefore, demanding large amounts of water. In contrast, protected cultivation structures favors plant growth; since plants are less stressful, direct sunlight was avoided, temperature is lower, humidity is higher, wind speed reduced, and ETc was low.

Weather is one of the most limiting factors in producing cole crops. Cabbage, Broccoli and Cauliflower perform best with cool daytime temperatures (21°-29°C), lots of sun, and moist soil conditions. Growers need to provide the best possible growing conditions during the winter so that plants are the maximum possible vegetative size when head or curd (cauliflower/ Broccoli) development starts, since the size of the plant limits the potential size of the head or curd. Early maturing varieties are more sensitive to low temperature damage than are those that mature later. Temperature below 15°C during growth delays maturity and undersized and unmarketable buttons are formed. During winter season many times temperature fall below 10°C in open field condition. Protected cultivation structures increases the temperature and good quality of yield can be produced. Total water requirement of these crops estimated as 93.8-95.6 L $plant^{-1}$ for open field condition which is followed by shade net house (69.9 -71 L $Plant^{-1}$), Poly house (60.5 -61.4 L $Plant^{-1}$) and shadow hall (60.3 -61.3 L $Plant^{-1}$).

Conclusion

Optimum temperature is favourable for growth of vegetables to get maximized yield. Present study shows that vegetable production in winter for sub humid region is fatal due to fall of temperature below optimum level which results in chilling injuries. Protected cultivation structures offer a great solar energy saver and increased temperature inside structures. Due to increased temperature in protected cultivation structures, reference crop evapotranspiration also vary according to temperature and radiation. ETo estimated outside the PCS shows values lower than those for ETo estimated inside, and these results are in agreement with those of other authors whose researches were carried out in distinct environments.

From the above data we can conclude that, winter vegetable production in open field condition requires higher irrigation water requirement for all the crops comparing to other PCS. It also shows that 35.6 % less water for shadow hall cultivation, 35.2 % less for poly house cultivation and 25.5 % shadenet house cultivation comparing to irrigation water requirement for open field cultivation. Therefore, for cropping systems conducted under protected environments, the recommendation for ETo inside the protected cultivation structures is to be reassured. The optimum temperature accompanied by low relative humidity at initial stage and low temperature and high humidity at later stage with low solar intensity inside PCS provide the most suitable growing environment, so growers are benefited by being able to produce higher and off-season tomato which fetched premium prices in the market.

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