The Andhra Agric. J 60(2):415-428, 2013

Design and Evaluation of Greenhouse for Gerbera (*Gerbera Jamesonii L.*) Cultivation in Humid Subtropics

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ABSTRACT

Greenhouse floriculture in humid subtropics suffers from high summer temperatures and humidity due to the lack of suitable design and cost-effective environmental control strategies. The present study aimed at in-depth investigation of microclimate variation in two different shapes of greenhouses (Quonset and Sawtooth) and cladding materials (UV stabilized and diffused films) of greenhouses suitable for gerbera production with low-cost cooling techniques. The biometric growth and flower yield performance of gerbera (*Gerbera Jamesonii L.*) was evaluated during winter and summer months of 2008. The shape and height of a greenhouse had significant influence on the internal air temperature as Sawtooth shape maintained 3°C lesser temperature variation than the Quonset shape against ambient condition at 12:30 PM during summer months. The relative humidity variation was less (13%) in the Quonset shape at 8:30 AM during summer and the solar radiation was 5 to 10% greater than that of Sawtooth shape throughout the year. The reduction of greenhouse temperature in the diffused film was greater in winter (3°C) than in summer (1.5°C) with 50% perforated shade net placed on the inner side of greenhouse. Among the two shapes of greenhouses, biometric performance of gerbera was superior in Sawtooth shape than Quonset shape in terms of plant height, leaf area index and flower yield. The cultivation of gerbera in the Sawtooth greenhouse of 84 m^2 floor area was economically viable with a net profit of Rs. 38708.00, benefit-cost ratio of 1.8 and a payback period of 3.1 years.

Key words : Benefit-cost ratio,Diffused film, Gerbera, Microclimate variation, Quonset shape, Sawtooth shape

Crop quality and predictability can be achieved with an efficient and cost-effective structure such as a well-designed greenhouse. Greenhouse design requires substantial modification right from its geometry to environmental control to make them more suitable to local agro-climatic conditions (Kumar *et al*., 2009). In addition, the sustained growth of greenhouse industry on a wider scale is possible when the design is economically viable for both cultural and biological demands of remunerative crops. Hence, a careful thought will resolve the specific details of greenhouse design including a balance of investment costs, available resources, and the potential crop production capacity.

Climatic conditions of humid subtropics are adverse and capricious in nature. The quality and production of greenhouse floriculture in this region suffers due to high summer temperatures and humidity (Pek and Hayles, 2004). Moreover, suitable greenhouse design with an affordable cooling system is lacking to overcome the effects of excessive temperature and humidity. In this contest, the selection of a suitable cladding material is crucial for attainment of an optimal controlled environment, particularly relating to the solar radiation intensity and wavelengths without losing photosynthetically active radiation (PAR) component (Hoffman and Waaijenberg, 2002).

Studies on the effects of greenhouse geometry and their functional characteristics influence on the microclimate relating to floricultural crop growth in particular is a research endeavor as the earlier studies have been limited to few vegetable crops (Boulard and Draoui, 1995; Kittas *et al*., 1995). Moreover, the studies pertaining to tropical and subtropical regions were more of thermal in nature and not related with crop growth. Tiwari *et al*., (2002) evaluated the comparative performance of different configurations of the greenhouse with equal floor area and central height for Indian climate and inferred that greenhouse with modified arch shape performed better where cooling is required and an uneven shape of greenhouse with north wall is suitable for cold places. The effect of greenhouse height on the microclimate was investigated by Connellan (2002) and mentioned that the height of greenhouse up to gutter should be in the range of 2.5 to 4.5 m instead of traditional range of 1.5 to 2 m with height up ridge as 3 m or above to obtain favorable microclimate in high temperature regions. Garcia (2001) and Hoffman and Waaijenberg (2002) reported that new cladding films having special radiation properties as greenhouse covers maintained favorable microclimate for crop growth in tropical regions. Hemming *et al.* (2006) derived a special design equipped with high ventilation capacity in combination with nettings and special polythene film that blocks NIR (Near Infrared Radiation) was suitable for tropical climates. Sethi (2009) evaluated the performance of different greenhouse shapes in composite climate of India and concluded that air temperature rise in the greenhouse depends on its shape. The variation from uneven span shape to Quonset shape is 4.6°C (maximum) and 3.5°C (daily average). In a recent study, the author of the present investigation presented a critical review on the design and cooling methodology options for greenhouse in tropical and subtropical regions and inferred that the ventilation area equal to 15–30% of floor area provided at ridge and sides covered with insect-proof net size of 20 to 40 mm with cladding material properties of near-infrared radiation (NIR) reflection during the day and far-infrared radiation (FIR) reflection during night was suitable for crop production throughout year in tropical and subtropical regions (Kumar *et al.*, 2009).

An overview of the above literature indicates that limited research is available on the mode of greenhouse design and its functional characteristics influence on the microclimate in subtropical regions with humidity being the dominating factor responsible for incidence of pests and diseases. Moreover, no reports are available on the design aspects of greenhouse for maintaining favorable microclimate suited to local agro-climatic conditions for floricultural crops. Therefore, there is a need to carry out an in-depth investigation concerning design of naturally ventilated greenhouse and its functional characteristics that helps in natural cooling at affordable costs. Hence, in the present study, an in-depth investigation of microclimate variation in different shapes and covers of greenhouse during different seasons of a year was carried out using sensors and dataloggers. In addition, suitable cost-effective cooling methods for controlling high temperature in the greenhouse have also been evolved for different shapes and covers of greenhouse for Gerbera cultivation.

MATERIALS AND METHODS

Design and construction of experimental greenhouses

Quonset and Sawtooth shapes of greenhouses of size 11 m $\times$ 4 m $\times$ 2.5 m and 14 m $\times$ 6 m $\times$ 4.5 m were designed and constructed in the Field Water Management Laboratory of Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, West Bengal, India to assess the microclimate variation due to the design geometry and type of ventilation provisions. The design consideration of the Quonset and Sawtooth shape greenhouses meets the requirements of International Building Code (IBC) in general and American Society of Civil Engineers Code (ASCE 7) in particular. Allowable stress design approach was used as a design methodology for greenhouses by considering both structure and cladding material weights in the calculation of dead loads. The roof load of 0.005 kg cm^{-2} was considered in the design by omitting the snow load as it was not a major concern for humid subtropics of India. A thermal factor of '1.2' and a roof slope factor (C_s) of '0.6' were considered in the design as per the recommendation of NGMA (National Greenhouse Manufacturers' Association) standards (NGMA Design Manual, 2002). However, wind factor was taken as '1' by considering subtropical Indian climate under non-hurricane zones (NGMA, 2006).

A rectangular area of 11 m 4 m was marked at the site orienting its longer dimension in East-West direction. The markers were put at every two meters along the sides of the rectangular area. Pit holes of 20 cm 15 cm were dug at each marked location with the help of a bucket auger and crowbar. A 12.5 mm wide and 3 mm thick aluminum strip was reinforced to the hoops to hold the poly-grip assembly. Foundation pipes were placed in the pit holes and grouted with cement concrete mix (1:3:6) up to a depth of 15 to 20 cm, and cured for 72 hours. After curing, the remaining depth of the pit was filled with soil up to the ground level. Both the end frames were installed vertically in the dug holes. The hoops were inserted into the foundation pipes in such a way that they rest on the aluminum strip attached to the foundation and bolts were used for fixing the poly grip channel. An ultraviolet (UV) stabilized polythene sheet was spread from one end to other without any wrinkles keeping the edges together. The film was placed between the ploy-grip channels, stretched gently and fixed with 12.5 mm inch bolts along the parallel sides and on the roof. On the other hand, Sawtooth shape greenhouse was constructed by placing the markers at every 2.3 m length along the sides of the rectangular area. Pit holes of 1 m 0.15 m were dug at each marked corner location. Four Galvanized Iron pipes of 5 cm diameter and 1.5 m length were fixed in the pit holes and covered with cement concrete mix (1:3:6) up to a depth of 0.5 m and cured for 72 hours. After curing, the remaining depth of the pit was filled with soil up to the ground level. Columns of 50 mm diameter Class A galvanized iron pipe was inserted into the foundation pipe and tightened by 12.7 mm diameter bolts and nuts. An ultraviolet stabilized polythene sheet was spread from one end to other without any wrinkles keeping the edges together. The film was placed between the Aluminum 'C' channels and locked with the help of G.I. lock spring mechanism. An insect-proof net of 20 mm size and 1500 mm width was fixed along the sides of the greenhouse by lock springs. The isometric views of the Quonset and Sawtooth greenhouses are shown in Fig.1.

Both the greenhouses were provided with larger ventilation openings (60% of the floor area) at roof and sides to eliminate the risk of high temperatures during peak summer (Harmanto *et al.*, 2006). Shade nets having 75% shading intensity were placed from the interior side of the greenhouse extending 50% and 100% of greenhouse ridge area during winter and summer seasons followed by occasional fogging for half an hour during peak summer hours to reduce the scorching effect on the crop (Fig. 2). However, in the rainy season, shade nets from the interior side were not placed in order to allow more photosynthetically active radiation levels. The effects of shape, height, and type of ventilation provision on the microclimate of the greenhouses were assessed by monitoring inside air temperature, relative humidity and solar radiation three times a day (8:30 AM, 12:30 PM and 4:00 PM) throughout the year 2008. The temperature variation in vertical direction of the greenhouses was also monitored by placing infrared thermometers at a distance of 0.5, 1.0, 1.5 and 2.5 m along the ridge. Apart from this, effects of two cladding materials (UV stabilized and Diffused films) of the Sawtooth greenhouse differing in their cover properties have been evaluated during winter and summer seasons of the year 2009 to investigate the extent of reduction in temperatures during summer.

Monitoring of greenhouse microclimate

An automatic weather station of M/S Campbell Scientific, Canada comprising a datalogger and sensors for measuring air temperature, relative humidity, global radiation, photosynthetically active radiation (PAR), soil moisture and soil temperature were installed inside the greenhouses to monitor the microclimate. The temperature and humidity inside the greenhouse were measured by a combined sensor of model HMP 45 C installed at 1.25 m above the ground level. Incoming radiation in the greenhouse (global) and photosynthetically active radiation (PAR) were measured by the two pyranometers SPLITE and PARLITE of Kipp and Zonen with quantum sensor sensitivity of 5.42 μv/μ m by installing them at the diagonal centre of the greenhouse at a height of 1.5 m above the floor. The soil temperature and moisture sensors of models 107 BL and CS616 L were installed at 15 cm and 30 cm depths below the ground level. All the sensors were connected to CR1000 datalogger and logging was done at a 30 minutes interval. Outside climate was recorded from the local meteorological observatory located at 50 m away from the greenhouses.

Crop cultivation and irrigation system

For potential gerbera growth, the soil should be highly porous and well drained to have better root growth and penetration (NCPAH, 2000). In the experiment, soil, farmyard manure, rice husk and fine sand were mixed in the proportion of 3:3:3:1 to improve soil aeration and better drainage. Optimum soil pH ranging from 5.5 to 6.5 was maintained to get a maximum efficiency in the absorption of nutrients. Lime at a rate of 2 kg m^{-2} was added to bring the soil pH to neutral. Single super phosphate (0:20:0) @ 2.5 kg per 100 ft^2 was added for better root establishment. $MgSO_4$ @ 0.5 kg per 100 ft^2 was added to take care of the magnesium deficiency. Disinfection of the soil was done by spraying Formalin at a rate of 450 ml per square meter and the soil was covered with a plastic film for 6 to 8 weeks to get rid of the fungus Phytophthora, which is a menace to the gerbera culture. Plenty of organic matter in the form of well rotted farmyard manure was added to improve soil's physical health. Raised beds of size 60 cm wide 45 cm height were prepared in the greenhouses and two rows of Gerbera were planted in the greenhouse with spacing of 37.5 cm 30 cm and plant density of 8 to 10 plants per square meter. A pathway of 30 cm was maintained in between the beds to facilitate easy movement for cultural operations. Initial irrigation for crop establishment was applied using overhead micro sprinklers for four weeks to ensure uniform root development. Later, irrigation water was quantified as per the requirement of the crop and supplied through inline drippers of 2 lph capacity. The irrigation requirement was varied according to

Fig. 1. Isometric views of experimental greenhouse designs.

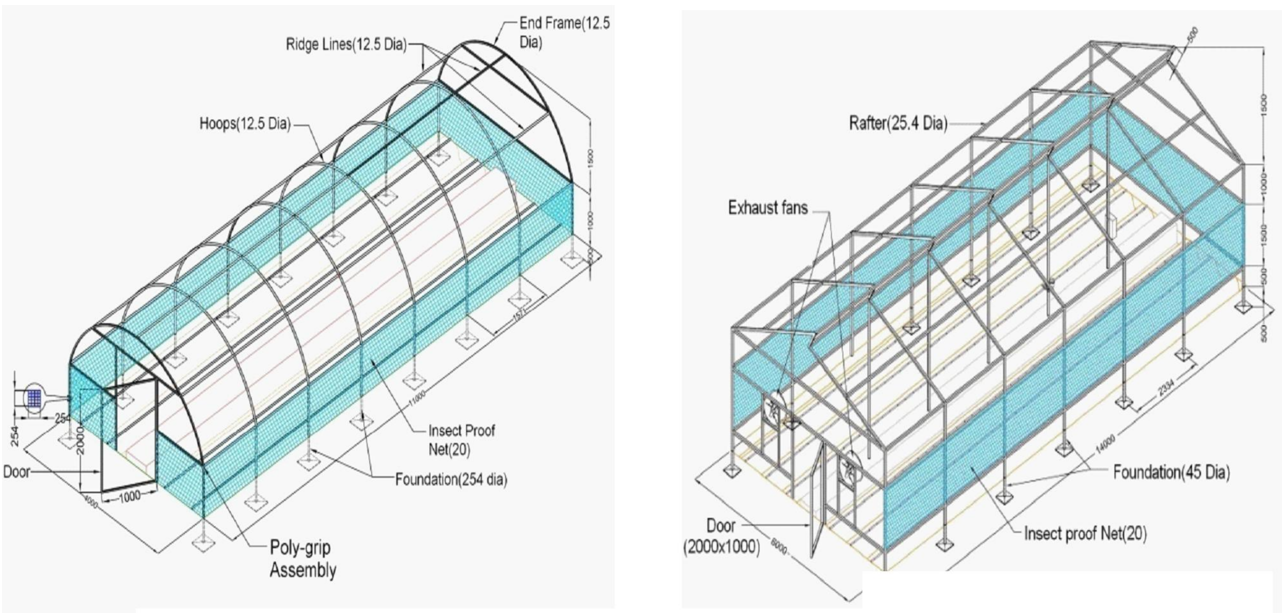
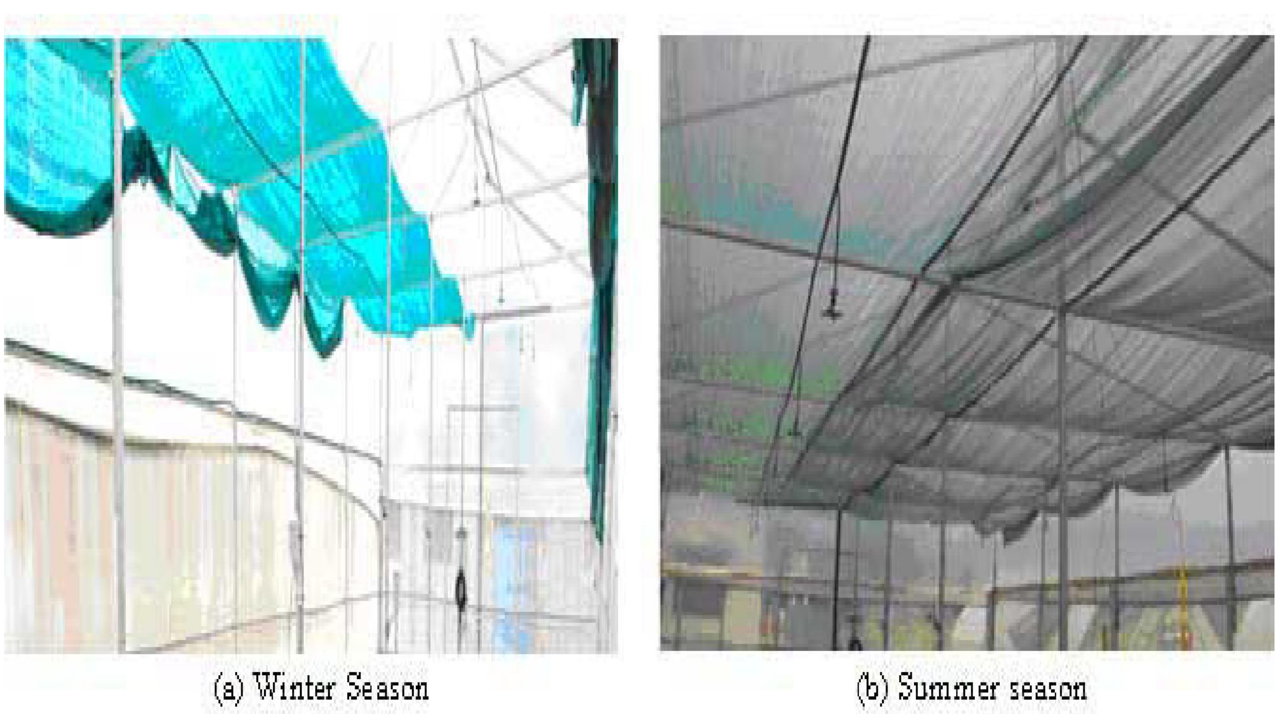


Fig. 2. Extent of shade net placement in the greenhouse during winter and summer seasons.



the plant growth stage. Plant height, number of leaves, leaf area index (LAI), stalk length, flower diameter and yield per meter square area were used to describe the crop biometric performance. Measurements were recorded at the same time in each greenhouse at a 15-days interval. However, stalk length, flower yield and flower diameter was recorded at every 15 days interval after two months of transplantation.

RESULTS AND DISCUSSION

Effect of greenhouse shape and size on microclimate

Temperature

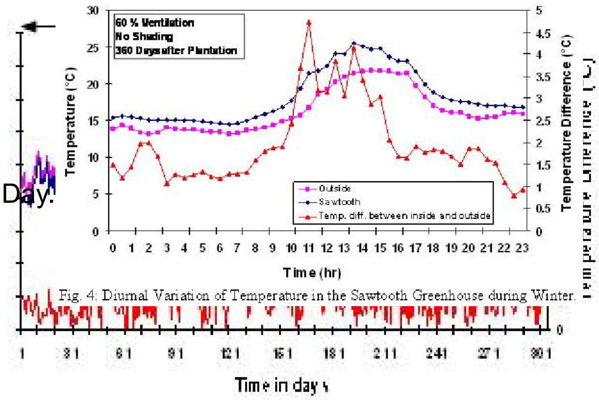
Daily variation of air temperature in Quonset and Sawtooth shapes during different times of the day i.e., 8:30 AM, 12:30 PM and 4:00 PM are shown in Figs. 3 (a), 3 (b) and 3 (c). It is evident from the figures that air temperature was always less in Sawtooth shape than the Quonset shape during winter, summer and rainy seasons of the year. Among temperature variation during different timings, the variation at 12:30 PM between the greenhouse shapes is prominent as compared to others. The effect of greenhouse shape and size on the temperature differences against ambient condition for the Quonset and Sawtooth shape designs throughout the year 2008 are shown in Tables 1(a) and 1(b). It is evident from these tables that the air temperature difference against ambient condition between the shapes at 8:30 AM did not vary significantly. Moreover, it is interesting to note that sometimes the temperature difference between Sawtooth shape to the ambient condition at 8:30 AM is less by 2°C in winter due to placing shade net from the interior side. However, the same is not true during other times of the day. On an average, the Sawtooth shape maintained 1°C less temperature than the Quonset shape in winter and summer seasons, and 2°C during rainy season at 8:30 AM. On the contrary at 12:30 PM, the effect was much pronounced during summer (3°C) than that of winter and rainy seasons (1°C). However, the temperature variation at 4:00 PM is almost on par with that of 8:30 AM as Sawtooth shape maintained 1°C less temperature than the Quonset shape in all seasons of the year.

The diurnal variation of air temperature in the Sawtooth shape greenhouse during winter and summer for typical days on 20.12.2008 and 12.04.2008 are shown in Fig. 4(a) and 4(b). The diurnal variation of air temperature in the Sawtooth shape varied between 15 and 25, and 23 to 34°C respectively during winter and summer seasons. The maximum diurnal temperature difference (day to night) in the greenhouse was more prominent during summer than winter season. In summer, the diurnal temperature difference was more (13°C) while it was marginal (6°C) in winter season. However, the average diurnal temperature differences between the greenhouse and the ambient condition were observed as 2°C and 1.5°C during winter and summer seasons, respectively. The obtained results were slightly more than the specified diurnal temperature requirement for ornamental crops (Hannan, 1969). However, to reduce temperature in the greenhouse suitable for gerbera, the effect of fogging on the internal temperature of greenhouse was investigated for a typical summer day (Fig 5). It is evident from the figure that during peak summer hours, fogging reduced the peak summer temperature to 3 to 4°C for consecutive three days in a typical summer month (April 2008) without affecting the incoming PAR (Photosynthetically Active Radiation) in the greenhouse and thereby recommended temperature for gerbera growth in the peak summer was maintained.

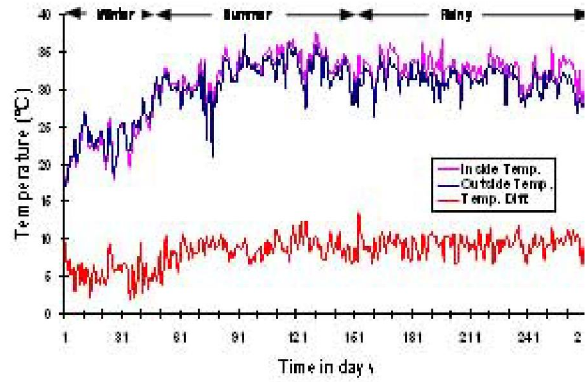
Relative humidity

Daily variation of relative humidity in Quonset and Sawtooth shapes during different times of the day i.e., 8:30 AM, 12:30 PM and 4:00 PM are shown in Figs. 6 (a), 6 (b) and 6(c). It is evident from the figures that relative humidity was always more in Sawtooth shape than the Quonset shape during winter, summer and rainy seasons of the year. Among relative humidity variation during different timings, the variations at 12:30 PM in winter and 8:30 AM in summer are less in Sawtooth shape than Quonset shape due to the presence of less internal temperatures and healthy crop canopy. The effect of greenhouse shape and size on the humidity differences against ambient condition for the Quonset and Sawtooth shape designs throughout the year 2008 are shown in Tables 1(a) and 1(b). It is evident from these tables that the relative humidity difference against ambient condition between the shapes at 8:30 AM and 12:30 PM vary significantly in both winter and summer seasons (7-13%). However, the same is not true at 4:00 PM and the trend is at par. In rainy season, variations between the shapes during different times of the day are marginal (5-6%) due the presence of clouds and occasional showers in the year 2008. On an average, the relative humidity levels maintained in both shapes of greenhouse are within the limits specified for floricultural crops in general and Gerbera in particular (NCPAH, 2000).

Fig 3. Daily variation of temperature during different times of the Day.

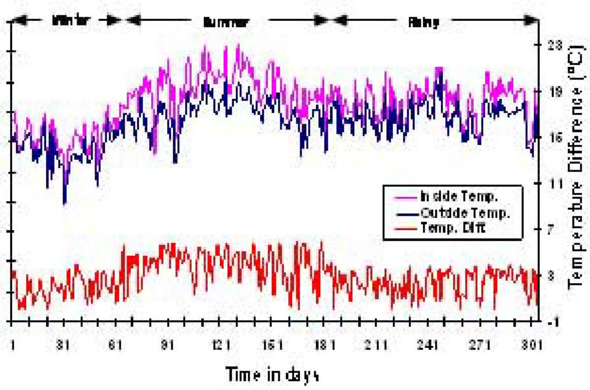


Quonset Shape

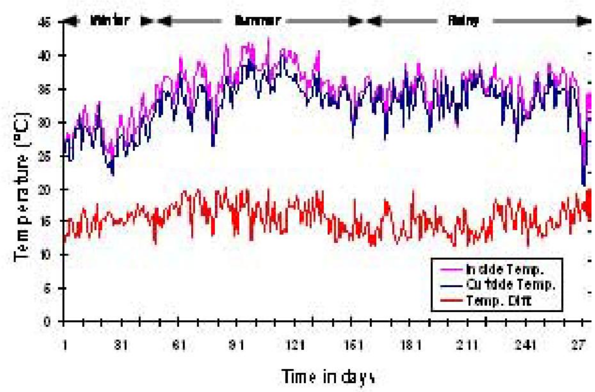


Sawtooth Shape

3(a):

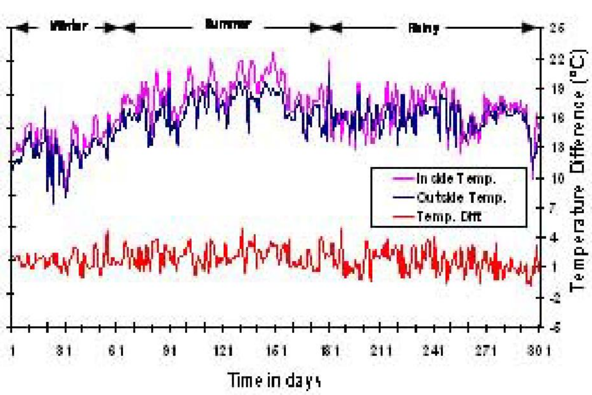


Quonset Shape

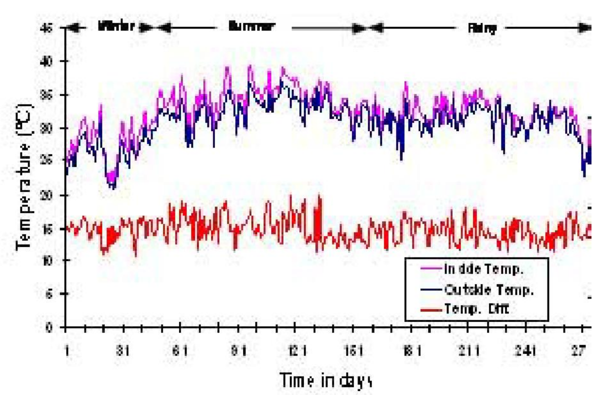


Sawtooth Shape

3(b):



Quonset Shape



Sawtooth Shape

3(c):

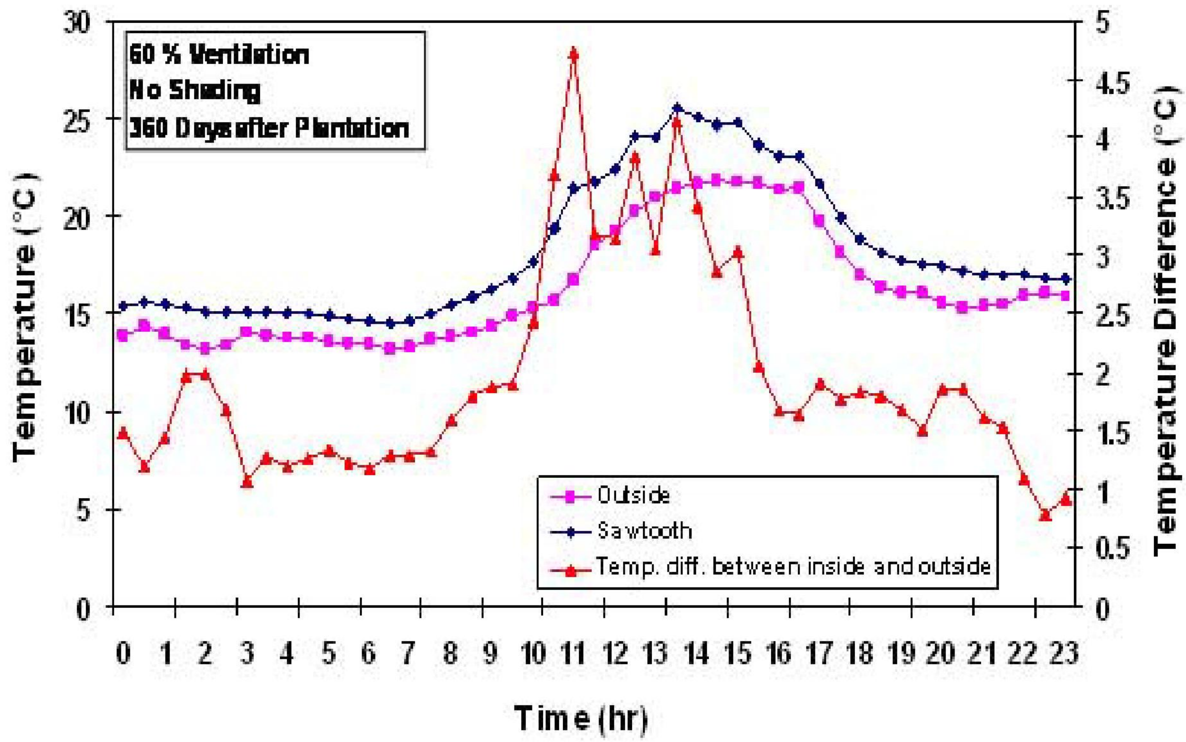


Fig. 4: Diurnal Variation of Temperature in the Sawtooth Greenhouse during Winter.

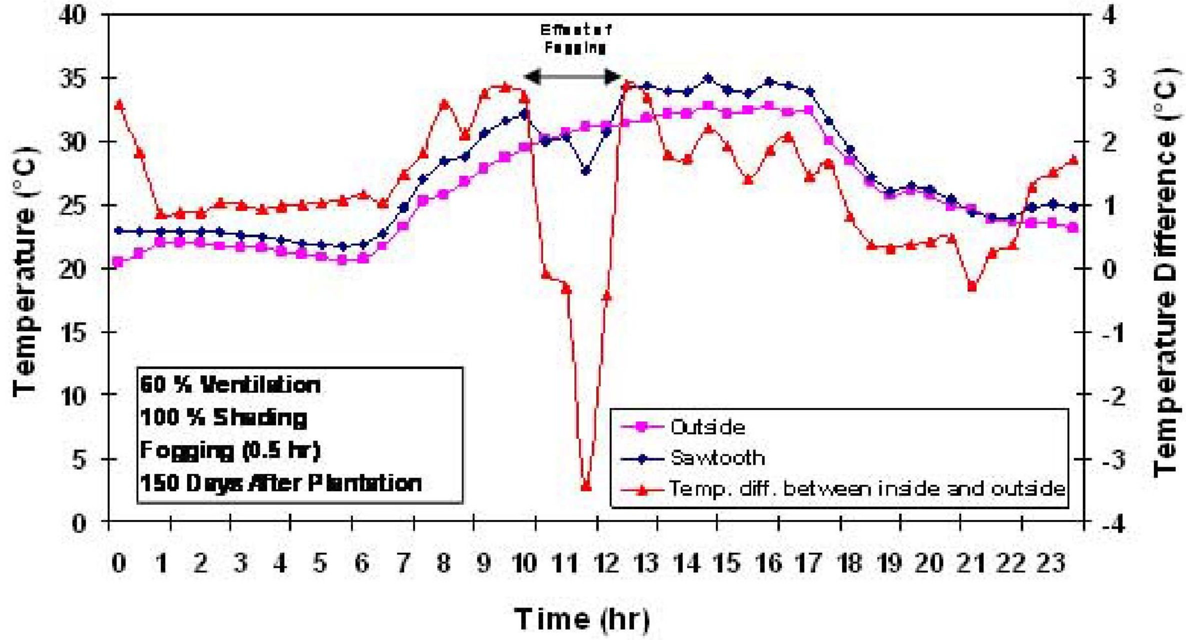
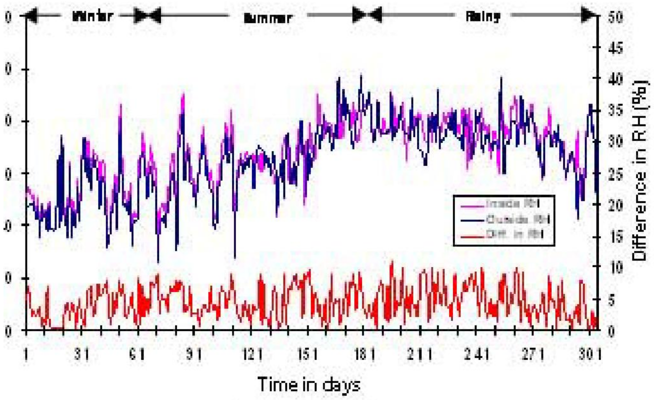
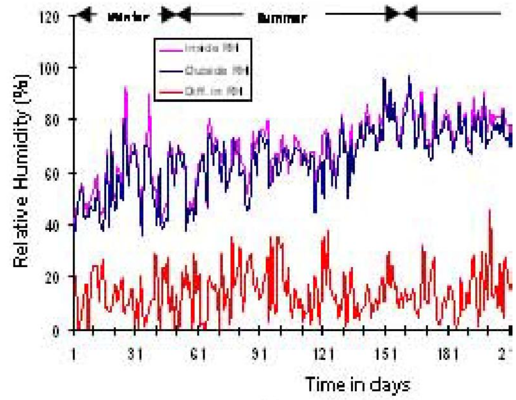


Fig. 5: Effect of fogging on the greenhouse microclimate.

Fig. 6. Relative humidity variation in the greenhouses.

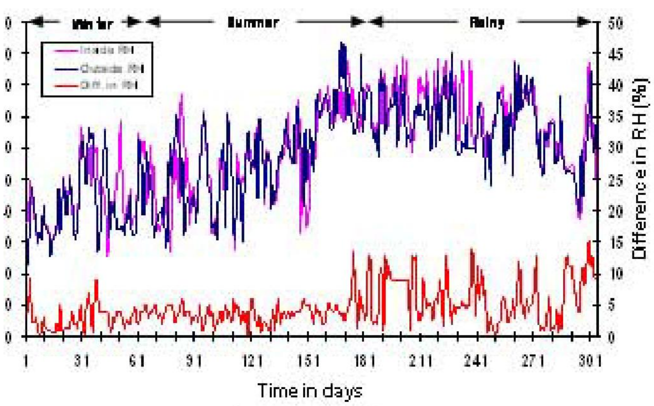


Quonset Shape

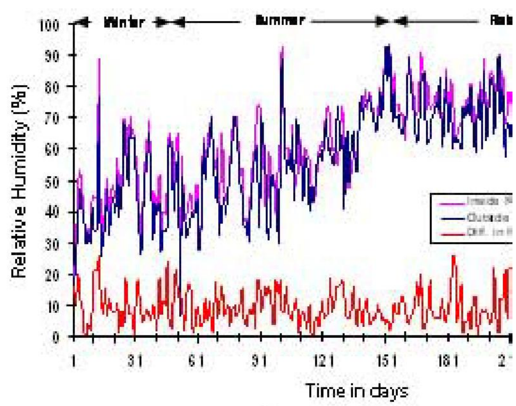


Sawtooth Shape

Fig. 6(a):

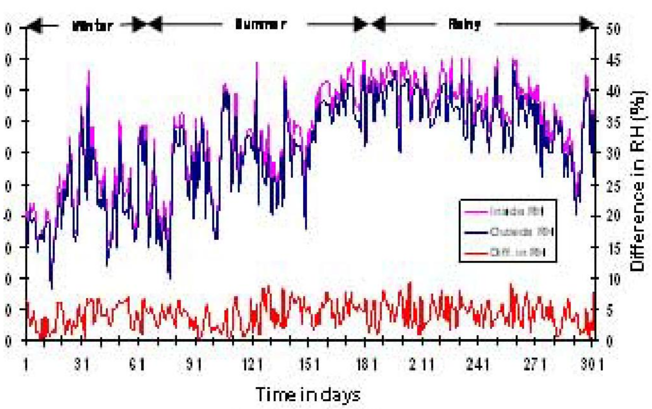


Quonset Shape

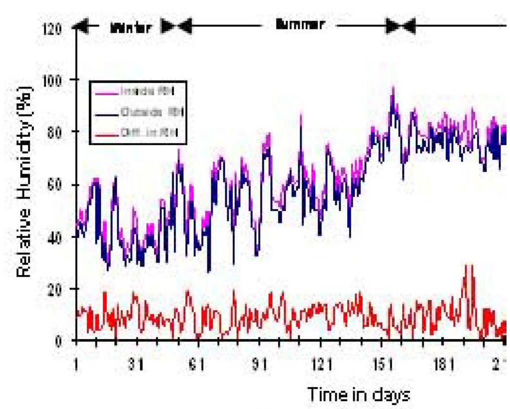


Sawtooth Shape

Fig. 6(b):



Quonset Shape



Sawtooth Shape

Fig. 6(c):

The diurnal variation of relative humidity for a typical day in April 2008 in the Sawtooth greenhouse is shown in Fig. 7. It is obvious that the relative humidity was more or less same (40 to 60%) throughout the day in summer. However, there was no significant difference in relative humidity at night time during winter and summer months and varied between 85 and 92%. In the afternoon, humidity level in the greenhouse was comparatively less than outside by 5% which was quite under the specified limits for gerbera cultivation (Henan *et al*., 1969; NCPAH, 2000).

Solar radiation

The effect of design geometry on the incidental radiation at 12:30 PM throughout year is presented in Fig.8. It is evident that, solar energy levels vary significantly between the two shapes of greenhouse. The Quonset shape always maintained larger amount of solar energy than the Sawtooth shape during specified course of time in all the three seasons. The reduction of solar radiation with respect to ambient condition was found to be 40%, 70% and 30% in the Quonset shape and 50%, 80% and 35%, in the Sawtooth shape during winter, summer and rainy seasons, respectively [Tables 1(a) and 1(b)]. Less solar radiation during summer months in both the greenhouses was due to the effect of shade net covering to the full extent of ridge area in both the greenhouses. Almost similar trend of reduction in solar energy in both the shapes during winter was observed owing to the adoption of shade net treatment in the greenhouse covering equal extent of areas in both the shapes. However, the different trend of reduction in solar energy during rainy season was due to the removal of shade nets from interior side of the greenhouse with an intention to increase light level for enhanced photosynthesis process.

Diurnal variation of PAR (Photo synthetically Active Radiation) in the Sawtooth greenhouse ranged from 0 to 165 W m^{-2} against the global radiation (0 to 309 W m^{-2}) during winter. In summer, the variation was observed as 0 to 77 W m^{-2} against incoming radiation (0 to 225 W m^{-2}). The daily average reduction in the PAR against incoming radiation was 40% and 35% during winter and summer seasons, respectively which was quite suitable for gerbera production in the greenhouse (Fig.9). The obtained results are in reasonable agreement with the results reported by Impron *et al*., 2006 for tomato production in the greenhouse under tropical climatic conditions.

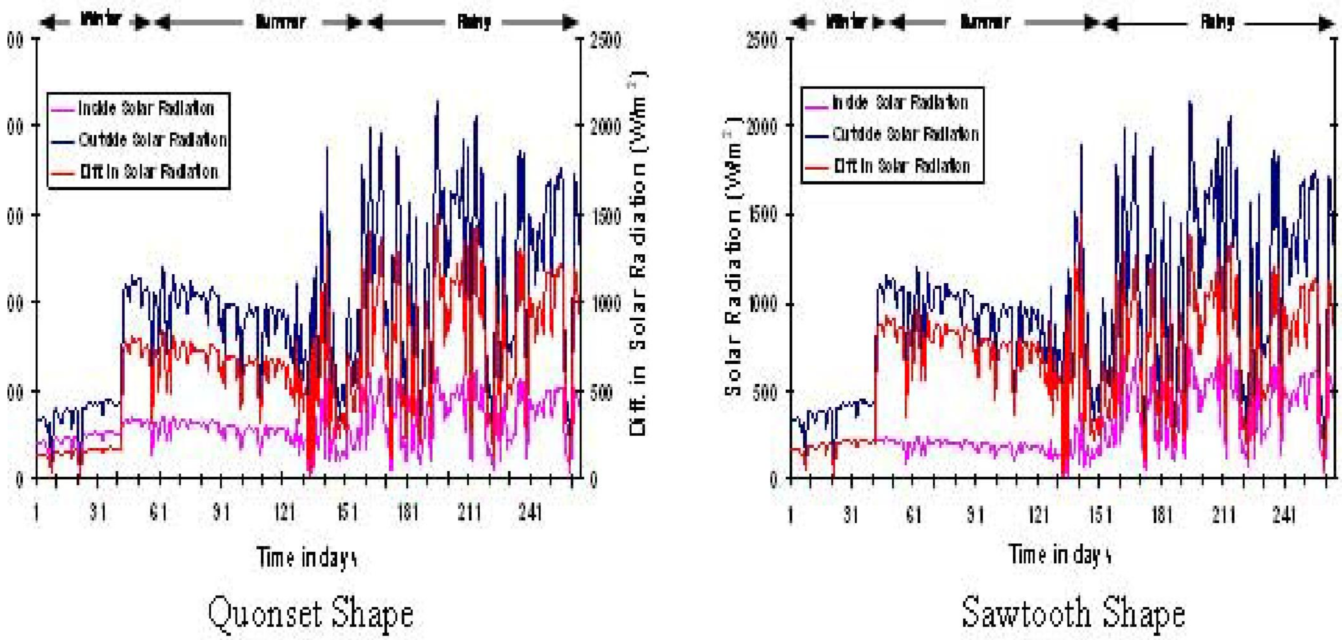
Vapor pressure deficit

The specified time course variation of vapor pressure deficit at 12:30 PM during the entire year was shown in Fig. 10. It is apparent from the figure that the vapor pressure deficit varied marginally among the seasons. However, the variations were found significantly differing at 12:30 PM in all the seasons. The Quonset shape maintained relatively more vapor pressure deficit in all the seasons as compared to the Sawtooth shape because of increased internal temperatures [(Tables1(a, b)]. Apart from this, it is observed that in Sawtooth shape at 12:30 PM, the vapor pressure deficit was less than the ambient value especially during summer season. This could be due to the effect of fogging which was performed to reduce high summer temperature resulted in enhanced humidity levels which in turn decreased vapor pressure deficit significantly. However, the variations of vapor pressure deficit did not influence the gerbera growth in reality being a humid loving crop.

Effect of greenhouse height on temperature

The effect of height on the variation of temperature differences at 1.5 m and 2.5 m with respect to 0.5 m ridge height during different seasons of the year is shown in Fig. 11. It is evident from the figures that the maximum temperature differences in the Quonset shape design between 0.5 m and 1.5 m height were 2°C, 3°C and 2°C during winter, summer and rainy seasons, respectively. On the contrary, in Sawtooth shape design, the variations were 1°C, 1.5°C and 1°C during the three seasons. On an average, the maximum temperature difference in the Quonset design between 0.5 m and 2.5 m heights was 9°C, 10°C and 8°C, during winter, summer and rainy seasons, respectively where as differences were less in the Sawtooth design (3°C, 2°C and 2°C) during the respective seasons. From these results, it can be inferred that vertical temperature profile variation between 0.5 and 1 m height was less in both the greenhouses due to the effect of fogging and crop transpiration. However, a different trend was observed between the bottom and top profile (0.5 to 2.5 m) as the Quonset design maintained higher average temperature difference (10°C) due to internal shading and less ridge height of greenhouse. The Sawtooth shape design maintained less temperature variations throughout the vertical profile due to its increased height coupled with cooling methods adopted to reduce peak summer temperatures.

Fig. 7: Daily variation of solar radiation in the quonset and sawtooth greenhouses at 12:30PM



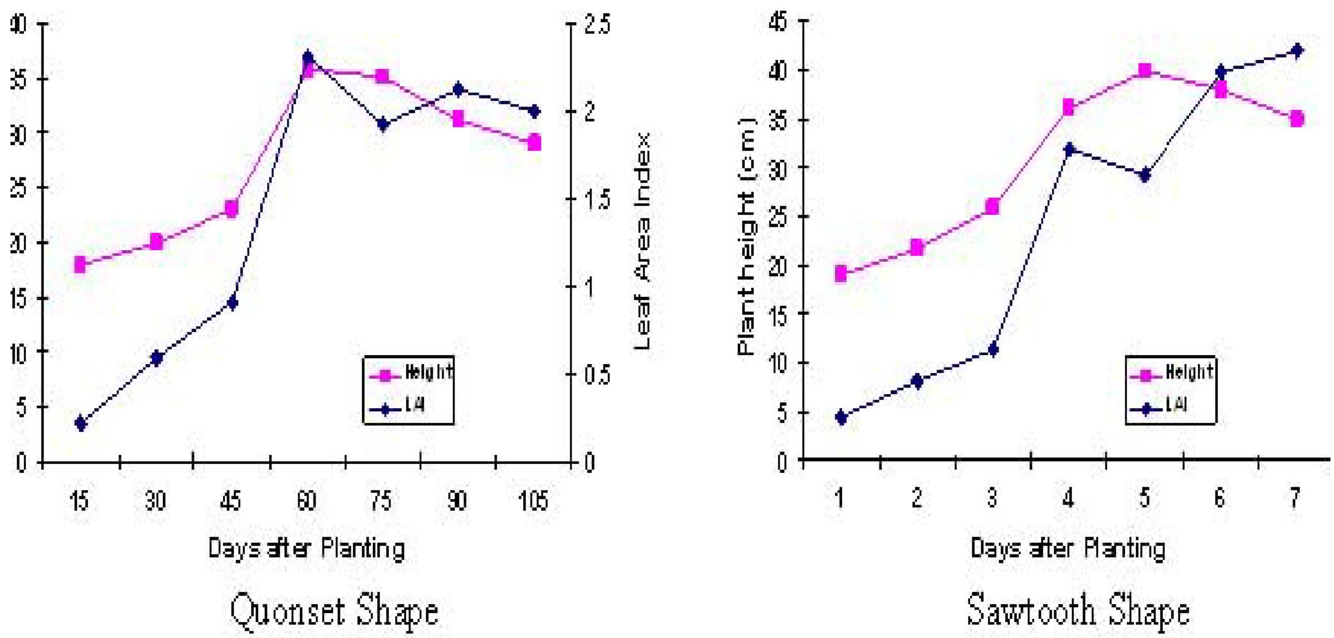


Fig. 13: Biometric crop growth performance of Gerbera.

Effect of new cladding materials of greenhouse

The effect of cladding materials on weekly variation of air temperature in the greenhouse during different times of the day in winter months (January to February, 2009) indicated that air temperature in the greenhouse covered with UV stabilized film at 8:30 AM ranged from 21 to 29°C as compared to diffused film (20 to 29°C) with a marginal difference of 1°C. However, in summer months, the effect of film properties is prominent at 8:30 AM and varied from 30 to 38°C in UV stabilized film against diffused film (30-36°C) with a difference of 2°C. The variation of air temperature at 12:30 PM in both covers of greenhouse during summer is shown in Fig. 12. It is apparent from the figure that during summer season, the weekly variation of temperatures under two cladding materials of greenhouse ranged between 36 to 43°C and 35 to 43°C in the UV stabilized and diffused covers, respectively against the ambient condition (34 to 42°C). The temperature difference between the covers at 12:30 PM during summer months was not much pronounced (1°C). However, from the crop growth point of view, a marginal difference of 1°C influenced in maintaining the Gerbera flower quality during peak summer months. On an average, it can be inferred that the weekly variation of air temperature in the UV stabilized film was more than the diffused film in both the seasons and diffused film maintained 3°C less temperature during winter and 2°C less temperature during summer compared to the UV film with adopted shade net and fogging. Overall, the reduction of solar radiation in the UV stabilized and diffused covers were 60% and 50% respectively in winter, and 80% and 70% in summer during the entire experimental period. Thus, it can be inferred that the use of diffused film as a cover in the greenhouse instead of traditional UV stabilized film is necessary for creating favorable microclimate for summer greenhouse production.

Biometric performance of gerbera plant height and leaf area index

The effect of greenhouse shapes on the gerbera plant height and leaf area index during winter and summer seasons of the year 2008 are shown in Fig. 13. It is evident from the figure that the rate of plant growth in both shapes are almost same at the establishment stage of the crop, and thereafter gradually differs up to the time of flowering i.e., 60 days after planting (DAP). The plant height is better in the Sawtooth shape design than that in the Quonset shape design right from establishment stage to the flowering stage in winter and summer seasons. Moreover, the plants in the Sawtooth greenhouse were relatively healthy (less attack of mites) compared to the Quonset shape greenhouse during summer season due to maintenance of less air temperatures in the greenhouse. Moreover, at the experimental stage, the attack of spider mite was greater in the summer season in the Quonset shape greenhouse, which adversely affected plant growth parameters such as height and leaf area index due to less ventilation and effect of fogging which created a congenial atmosphere for the attack of pests. On the other hand, leaf area index in the Sawtooth greenhouse was more in summer season than in the winter season due to less attack of pests and diseases.

Stalk length and flower diameter

The effect of greenhouse shapes on stalk length and flower diameter indicated that both parameters followed similar trend with greater values in the Sawtooth shape especially flower diameter. The average flower diameter in the Sawtooth shape design reduced from 13 cm to 8 cm, whereas it reduced from 9 to 6 cm in the case of Quonset shape due to the onset of summer season. The less flower diameter in both the greenhouse shapes during summer season could be attributed to fogging operation performed to equalize or to reduce the peak greenhouse summer temperatures.

Flower yield

The monthly flower yield recorded from the experimental greenhouses is shown in Fig.14. Although four cultivars of gerbera were grown under greenhouses, comparison of the yield is presented for one variety, i.e., Popov which was grown in both the greenhouses at a time. In both greenhouse shapes, similar trend of yield commenced after two months of planting, but the flower maturity under Sawtooth greenhouse commenced 10 days earlier than that under Quonset greenhouse. At the starting of flowering season, the yield tremendously increased (11 flowers/m^2) in the Sawtooth shape greenhouse. However, the trend is reverse in the Quonset shape which yielded only 4 flowers/m^2 greenhouse area in the initial flowering stage. After the flowering stage, both the greenhouse covers maintained an increasing trend of flower yield. Thus, the performance of gerbera in Sawtooth greenhouse was superior to the Quonset shape greenhouse as the former maintained favorable microclimate and reduced attack of pests and diseases during summer and winter months.

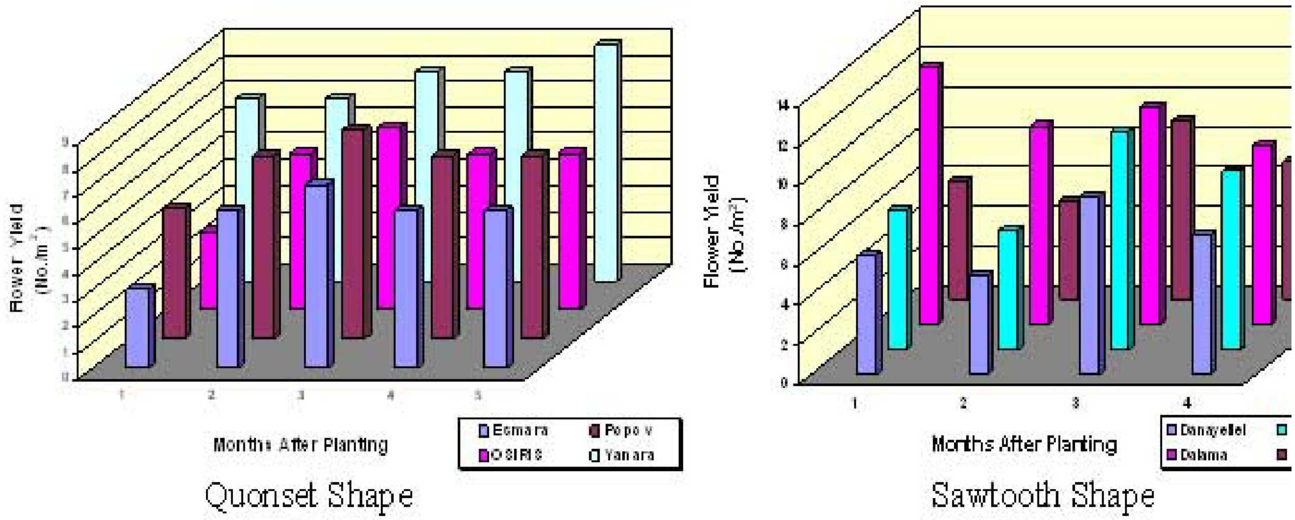


Fig. 14: Flower Yield of Gerbera in the Experimental Greenhouses.

Table 1(a): Temporal Variation of microclimate is the Quonset greehouse during different season.

Microclimate Parameter	Quonset Greenhouse								
	Winter Season			Summer Season			Rainy Season		
	8:30 AM	12:30 PM	4:00 PM	8:30 AM	12:30PM	4:00 PM	8:30 AM	12:30 PM	4:00 PM
Temp. diff. (°C)	0-2	1-3	0-2	0-3	2-5	1-3	0-3	2-3	0-2
Humidity diff. (%)	3-7	0-4	2-6	0-7	2-5	0-4	0-6	9-13	0-9
Solar radiation reduction (%)	40	40	40	70	70	70	30	30	30
VPD diff. (kPa)	0.10-2.10	0.05-0.77	0.14-0.15	0.50-1.35	1.01-2.38	0.50-0.73	0.10-0.30	-0.06-0.84	0.10-2.00

Table 1(b): Temporal Variation of microclimate is the Sawtooth greehouse during different season.

Microclimate Parameter	Sawtooth Greenhouse								
	Winter Season			Summer Season			Rainy Season		
	8:30 AM	12:30 PM	4:00 PM	8:30 AM	12:30PM	4:00 PM	8:30 AM	12:30 PM	4:00 PM
Temp. diff. (°C)	-2-1	0-2	0-1	0-2	1-2	0-2	0-1	1-3	0-1
Humidity diff. (%)	10-16	5-12	3-4	3-20	2-14	0-7	5-12	10-18	5-12
Solar radiation reduction (%)	50	50	50	80	80	80	35	35	35
VPD diff. (kPa)	0.10-2.40	0.12-0.38	0.07-0.50	0.03-0.37	-0.67-0.45	0.03-0.57	0.20-0.90	-0.03-0.60	0.00-0.40

Economic evaluation of gerbera cultivation in greenhouse

Analysis of economic viability for gerbera cultivation in the greenhouse was assessed by considering the life of greenhouse structure as 20 years. The life of cladding material, shade nets and insect proof nets were considered as 3 years and where as the drip irrigation system and prime mover as 7 years. The annual salvage value of Sawtooth greenhouse was assumed as 10% of the initial investment. The selling price of gerbera in the local market was considered as Rs. 5/per flower by taking in to account the average annual yield i.e., 37 flowers/plant/year which was actually obtained from the experiment. The structural cost estimates and the economics of gerbera production in the greenhouse are shown in Tables 2(a) and 2(b). It is evident from the table that the total cost of the experimental greenhouse including the cost of micro-irrigation, shade net and insect proof net was Rs. 99427.00, which can be approximated as Rs.1184.00/m^2 of floor area. The annual cost of the structure was 22650.00. The total operational cost for production of gerbera by considering the cost of land preparation and package of practices is Rs. 45692.00 with annual gross return of Rs.84400.00. The net profit arrived is 38708.00 with benefit-cost ratio of 1:1.8 and a payback period of 3 years 1 month.

Conclusions

The analysis of results of microclimate variation in two experimental greenhouses (Quonset and Sawtooth) inferred that shape and height of greenhouse have a significant effect on the microclimate and crop growth in all the seasons. The Sawtooth greenhouse maintained not only less temperature variation against ambient condition but also maintained 3°C less temperature than the Quonset greenhouse during summer months. Unexpected rise of summer temperatures in the greenhouse can be lowered by fogging to an extent of 4°C during typical summer days. The relative humidity in the greenhouse did not vary considerably throughout year. However, vapor pressure deficits varied significantly in summer months especially in Sawtooth greenhouse which required special attention for controlling the attack of pests and diseases for gerbera. The light intensity required for gerbera was reduced due to placing shade nets from the interior side of the greenhouse in both winter and summer seasons. However, it did not affect the flower yield as the PAR radiation received was within the limits. Sawtooth greenhouse maintained less vertical temperature variations than Quonset greenhouse and hence suitable for using vertical space and compartmental cultivation. Quonset shape greenhouse is not suitable for placing shade nets from interior side of this greenhouse as the temperature variation along the vertical direction increased drastically. The effect of film properties was more prominent in the winter season than in the summer. Diffused film can be recommended as a cover of the subtropical greenhouse for creating favorable microclimate during summer instead of commonly used clear UV stabilized film. Gerbera crop biometric performance factors such as plant height, leaf area index and flower yield in Sawtooth shape greenhouse was superior to Quonset greenhouse. Sawtooth shape greenhouse of 84 m^2 floor area was economically viable with net benefit is Rs. 38708.00, benefit-cost ratio of 1.8 with a payback period of 3.1years.

The following final conclusions can be drawn based on the findings of the present study.

- The Sawtooth design of greenhouse is more suitable than the Quonset design for maintaining favorable microclimate for Gerbera cultivation in subtropics throughout the year. The difference in air temperature variation in the two greenhouses is significant at 12:30 PM in summer (3 °C), however not significant during winter at 8:30 AM.
- The Quonset design of greenhouse maintained less relative humidity variations than the Sawtooth design. The variations in relative humidity were 7, 13 and 6% during winter, summer and rainy seasons, respectively. The solar radiation in the Quonset design was 5 to 10% more than the Sawtooth greenhouse throughout year.
- The combined effect of ventilation, shading and fogging on the microclimate of the greenhouse was considerable. Apart from equalizing the temperature more or less same as the ambient temperature, reduction in the peak summer temperature to an extent of 3 to 4°C was found in the Sawtooth greenhouse keeping other microclimate parameters more or less same.
- The reduction of temperatures in the Diffused cover was more in winter than in summer. The diffused cover maintained 3°C less temperature than the UV film during winter and 1.5 °C less in summer with shade net and fogging.

- The biometric performance of Gerbera in Sawtooth shape greenhouse was superior to Quonset shape in both winter and summer seasons.
- The cultivation of gerbera in the Sawtooth greenhouse is economically viable with a net profit of Rs.38708. 00, benefit cost ratio of 1.8 and a payback period of 3.1 years.
- A naturally ventilated Sawtooth shape greenhouse (60% ventilation area from ridge and sides) with diffused cover and internal shading of 50% and 75% shading intensities covered to an extent of 50% and 100% of ridge area during winter and summer seasons are suitable for Gerbera production in humid subtropics.

Acknowledgements

The authors are thankful to the National Committee on Plasticulture Application in Horticulture (NCPAH), Ministry of Agriculture, Government of India for providing necessary financial support to conduct the experiments.

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(Received on 09.01.2012 and revised on 18.02.2012)