Cropping in Arid Area Greenhouse

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Abstract

In hot, arid regions, yields are usually low and unstable. Greenhouse technology can stabilize and improve yields. But its adoption is impeded by the requirement of large amounts of water for cooling. Evaporative cooling is the most common method. Arid Area Greenhouse (AAG) is being developed for hot arid regions, particularly to reduce or eliminate the water needed for cooling. To achieve this, AAG employs earth-tube-heat-exchanger (ETHE) and static vents for environmental control. A prototype was installed in 2002 in an arid region, at village Kothara (φ 23° 14 N, λ 68° 45 E, at 21 m a.s.l.) for study.

The single span saw-tooth greenhouse is 20 X 6 X 3.5 m. The ETHE is buried 3m deep directly below and coupled to it in closed-loop mode. ETHE is made of a bundle of eight mild steel pipes arranged in two tiers. Each pipe is 23 m long and 20 cm diameter. ETHE provides 20 air changes per hour. Initial cost of ETHE (material, fabrication, transport and installation) was $ 5000, nearly equal to that of greenhouse excluding instrumentation. There are three continuous closable vents - two along the base of long sides and one along the ridge. A retractable shading cover is provided over the roof.

The aim was to determine (a) the extent to which ETHE and natural ventilation meet the need for environmental control and the associated costs (b) the extent to which productivity is increased, cropping season extended. By summer of 2007 five rounds of cropping have been done. ETHE was able to heat the greenhouse easily from 9°C to 22-23°C in half hour in the cold winter nights. Static ventilation along with shading was effective for day time control till February keeping the temperature about 34°C inside. Subsequently, ETHE was operated. It limited the greenhouse temperature to 36-37°C with top shaded and crop inside. If grid supply is steady it is operated for five-six hours in the day. House is closed in May-June. Yield of tomato has been close to 2 times that of the open-fields in the province. Water used was 44% of that used in open-field. The water used was mostly for plants, only a small part was for supplementary cooling using foggers. ETHE and static vents hold promise as environmental control device for greenhouses in hot arid regions. There is need to reduce installation cost by substituting plastic pipes for metal. It is also necessary to develop a more easily scalable design than the present one.

Keywords: greenhouse, earth-tube-heat-exchanger

INTRODUCTION

Kutch region of north-west India is a vast arid area, characterized by low rainfall, high ambient temperatures, salt-affected soils and poor quality water. Greenhouse technology, suitably adapted, could help make this area more productive. Two major impediments are - lack of cost-effective desalination technology and lack of alternatives to evaporative cooling that consumes large amounts of scarce water. Our work aims at exploring the use of earth-tube-heat-exchanger (ETHE) and natural ventilation to reduce dependence on evaporative procedures.

SURVEY OF LITERATURE

Santamouris *et al* (1995) reviewed a set of eighteen greenhouse installations drawn from different countries using ETHE, mostly to reduce heating costs. The cover it provided to total heating requirement varied from 28% to 60 %. Actual use in cooling mode, if any , was not mentioned. But using (TRYNSIS) simulated results for a facility in Athens (37.5° N lat) they stated that ETHE would be an equally attractive supplement for cooling. Air temperature of the greenhouse in summer was predicted and compared with measurements from their 1000 m^2 glass-covered greenhouse coupled to a set of four underground parallel pipes made of plastic. The air change rates were not indicated. Simulations showed that continuous ventilation of greenhouse with air from the buried pipes will keep the inside air temperature below 40°C. Unventilated greenhouse commonly goes up to 45°C, they stated. In Kothara (23° 14 N Lat) cooling periods will be prolonged and loads higher.

Several in Mediterranean region have been working on natural ventilation. Kittas et al (1996) observed that "development of the greenhouse area in Mediterranean and arid regions calls for efficient greenhouse summer acclimatization. Natural ventilation is the most common system used for greenhouse cooling." It would be appropriate in Kutch region also because, on one hand it is windier , on the other electricity is expensive and supply unreliable.

OBJECTIVE

Work reported in this paper was carried out with following objectives.

1. To determine the extent to which environmental control is achieved with the use of static vents and ETHE; and determine associated costs.
2. To carry out cropping trials to determine the extent to which greenhouse with ETHE and natural ventilation (but no fan-pad) can improve productivity extend cropping season compared to open field practices in the area.

Work was carried out at the Development and Outreach Station, Kothara (Kutch) where a facility termed Arid Area Greenhouse (AAG) has been constructed. It consists of a greenhouse coupled to ETHE in closed-loop mode, with side and roof vents and retractable shade nets on top. The facility has been described in detail elsewhere by Sharan et al (2003). Here a brief description is given followed by presentation of results and discussion.

EXPERIMENTAL FACILITY

Greenhouse

The greenhouse is a saw-tooth structure with frames made of square closed- structurals of galvanized iron. It has 6 m span, 20 m length and 3.5 m height at the ridge; with floor area of 120 m^2 and enclosed volume 360 m^3. The gutter is east-west oriented. Cladding is 200 micron UV stabilised PE film.

Vents – Location, Configuration, Air Flow Rate and Size of Openings

Placing the openings on opposite sides with some vertical distance between them facilitates air flow caused by thermal gradient (ASHRAE Fundamentals 1985). Feuilloley et al (1990) reported "the best ventilation system has top and bottom openings and bottom opening area greater than top opening area. The optimal total opening area for this system (quonset tunnel) is 32% (15% top , 17% bottom)." Ted Short (1998) made measurement of temperature and air-change rate in a naturally ventilated Quonset house - four and a half span, gutter connected, double poly clad in

Wooster, Ohio. The house had side vent on the west (windward) side and leeward opening roof vents. " For westerly winds , the volumetric air exchange was found to be 0.9 air-changes per minute; inside temperature never exceeding outside by more than 5°F. In most cases the inside temperature was within 2°F of the outside ." Short suggested that the roof vent opening should be 15-20 % of the floor area and open leeward to the wind. Side opening should be windward and equal at least one roof vent in size. The Kothara greenhouse has three continuous openings - one each at the base of the two long sides, one on the roof.

The standard for greenhouses in the north American region is one or more air change per minute. There are no recommended standards in India. Nor have there been reports of empirical work in hot arid zones. On a typical day in December (winter) in Kothara , mean solar radiation (between 10 am to 4 pm.) would be 600 W and temperature 28°C ; in June (peak summer) 850 W and upwards of 36°C. For a few days it goes over 40°C. Equation 1 relates air flow (ventilation) rate, sensible heat to be removed from the ventilated space and the average inside –outside air temperature difference.

$$Q = \frac{H}{(cf_2)(T_i - T_0)} \quad \text{----------} \quad (1)$$

Where Q is air flow rate (m^3/h) , H heat to be removed form the space (W), cf2 a computational coefficient (0.34), Ti and To the temperatures inside and outside the space (K). The Kothara facility is normally shaded on top from about 10 am to 4 pm with shade net of 50% shading (Sharan and Chitlange 2004). Further, with crop inside the floor is covered reducing absorptivity, and ET effects some cooling. This is accounted for by use of a empirical factor - evaporation coefficient - with values between 0 -1 depending upon several factors some related to crop. Indian standards relating to greenhouse heating and cooling (IS 14485:1998) indicates that in absence of fan-pad evaporative system (as at Kothara) values in higher range, 0.5 and above, could be reasonable. Taking the shading and evaporation coefficient of 0.5 to estimate, H , for June and using equation (1) the air change rate needed to keep the inside temperature within two degrees of outside was computed and found to be close to one per minute. This suggests that ASAE standard of one or more may be useful in these parts as well. Air change rate of one at Kothara facility works out to air flow rate of - 6 m^3 /s.

The wind speeds in the middle of days in June are 8 to 10 m/s; an average of 4 m/s. At such speeds wind –induced flow is dominant, buoyancy effects negligible (Papadakis et al 1996). They carried out experiments in a two-span polyethylene covered greenhouse equipped with continuous roof and side ventilators, apparently without screens and determined the wind -coefficients for - side only (0.142), roof only (0.246), side and roof (0.21). Length of openings at Kothara facility was taken as 20 m, equal to the long side. Using the coefficients for side and roof configuration the height needed was determined - 53 cm. Since the coefficients used were for vents without screen , it was anticipated that a larger area would be needed to compensate for screen resistance. Accordingly, an additional opening on the side was added. Thus , the facility has three continuous openings of equal size - 20 m X 0.5 m. Total (unscreened) vent area amounts to 25% of the floor area - 17% on the sides, 8% ridge. Vents were initially not screened to permit study of empty greenhouse in relation to temperature gain etc. Later these were screened with commercially available stainless steel wire mesh - 15 strands per inch in each direction and whole size less than a 1 mm.

Earth tube heat exchanger

ETHE (Figure **1**) is made of eight parallel thin walled (3 mm) ms pipes arranged in two tiers. First tier of four parallel pipes is placed at 3 m depth, the second 1 m above. Each pipe is 23 m long and 20 cm diameter. Pipes of each tier are at same level, 1.5 m apart laterally. All pipes are connected to common headers at both ends. Air is drawn from the greenhouse via a single duct, cycled through the buried bundle of pipes and returned to the greenhouse again via a single duct. ETHE provides 20 air changes per hour. Computations had shown that a higher rate was required, but system was becoming unwieldy and expensive. Total cost of the ETHE (material, fabrication, transport, installation) was $ 5000, nearly equal to the rest of the greenhouse. Air is moved by a centrifugal blower powered by a 4 KW, 1440 rpm motor. An array of overhead foggers (39 foggers with rated discharge of 7 lph) was provided. There is a fertigation unit and dripper lines for watering and application of fertilizers.

Instrumentation

An eight-channel data logger powered by chargeable 12 V batteries is installed. Air temperature and relative humidity, wind speed (three cups anemometer at 5m above the ground) were measured and recorded on site every hour by a data logger (Weather Technologies India). Temperature measurements accuracy is ± 0.2°C (resolution ± 0.1°C), relative humidity accuracy is ± 3 % (resolution ± 0.1 %), wind speed accuracy is better than ± 0.5 m/s with a stalling speed of 0.3 m/s. Three weather shielded temperature sensors are placed 1 m above ground at three locations on the centre line - ends and middle. Relative humidity sensor is placed over the centre line at the middle 1 m above ground. Data logger has LCD display, real time clock calendar, and serial output port for connecting it to PC with parallel interface to printer or memory module.

RESULTS AND DISCUSSION

Environmental control

Table 1 shows the temperature gain by empty and un-shaded greenhouse. With all vents closed, gain by mid day is 13.5°C in February , 17° C in April and 20.5°C in June. With all three vents open , these reduce to 4.4°C, 5.9°C and 4.2°C respectively. Actual measurements of air change rate have not been possible at the facility. But an indirect estimate can be made - by means of equation (1) whose right hand side factors are known – given that the house is empty and not shaded. Doing that suggested that in February and April the rates may have been close to 2 Ac/min and in June 3.5 Ac/min. This is good as it is higher than one. It is also plausible. Kacira et al (1998) showed by CFD simulations that in empty condition in a two span house with external wind of 2 m/s , the air change rate was 3.7 Ac/min with the windward side vent open along with only one (of the two) roof vents, apparently without screen. The side vent in simulation was 9 % of the floor area, each of the two roof vents 12%.

Openings are now screened. With crop inside (tomato 1.9 m high trellis supported) and top-shaded a closed greenhouse in June (2005) showed a peak gain of 9.8°C, which reduced to 3.1°C when all vents were opened. As anticipated the gains are markedly lower in these conditions. When ETHE system is operated, all vents are closed. ETHE alone is able to limit the gain to 2.5°C. It was not entirely expected since the ETHE provided only 1/3 Ac/min. One reason could be that the outlet air from the ETHE in

June is cooler than the ambient air. Also it is plausible that tomato trailed to nearly 2.5 m height hindered flow from vents more than that from the ETHE. Vegetation does reduce flow in natural ventilation significantly (Feuilloley et al op cit).

If grid supply is steady ETHE is operated for about five to six hours in the middle part of day. When along with the ETHE system , fogging is also done (2 minute bursts every half hour) the gain is reduced further to just 1.2°C. Amount of water used was 18 liters per hour. Increasing the frequency of fogging further did not help appreciably. Five to six hours of ETHE operations did not degrade its performance noticeably. It costs 50 cents /hr to operate or $ 3 for five to six hours usually needed.

Our computations had shown that had this house been fitted with a fan-pad system it would have a pad area of 7 m^2, two fans of total 2.1 KW power and consume about 350- 500 liters of water in a day depending on the number of hours used.

Night temperature in Kothara generally begins to drop below 18°C in December. January nights are colder with temperature going down to 8°C to 9°C. Heating is therefore needed from December 15 to about February 15. As reported elsewhere (Sharan et al 2003) heating is very effectively done with ETHE.

Let us recapitulate. In colder months - November, December and January and part of February - simply opening the vents for two hours around noon is adequate. Heating is needed at night which can be easily done by ETHE. Beginning February, top is shaded and vents are opened for four hours around noon. This procedure keeps the inside temperature below 34°C. Some days into March , ETHE is operated in the middle part of day and on occasions fogging is also used. This procedure keeps the inside temperature about 36-37° C. In the initial years cropping was done through May and part of June. But now it is done till the end of April. Greenhouse is closed from May to June 30.

Cropping

A crop of hybrid tomato (Avinash F2 of Sygenta) was raised - planted October 28, 2004, last picking May 15, 2005. Although the vines continued to yield fruits for 2-3 weeks more, size became too small to sell. Flowering began 30 days after planting, first picking in 100 days. Fruits measured between 5.5 to 6 cm major and minor axes. occurred Plant heights exceeded 1.9 m, Total irrigation water applied was 211 mm (**Table 2)**. This is only about half of that used in the open-field cultivation. Total yield was an equivalent of 56.3 t/ha. In immediate neighborhood in this district itself the best yield in open-fields reported by growers is just 15 t/ha. In other parts of this province however, which are humid, the best yield reported by growers is 30 t/ha. Thus the AAG yield is nearly two times that of the best open -field yields in humid areas of the province**.** Being able to carry out cropping well into summer is a very important achievement in this area where generally it is limited to rainy season – June to November.

CONCLUSION

Earth-tube-heat-exchanger and static ventilation hold promise as environmental control devices for greenhouses in hot arid areas like Kutch where water is in short supply and public grids unreliable. Following conclusions have emerged.

1. In colder months - November, December and January and part of February - simply opening the vents for two hours around noon is adequate. Heating is needed at night which is easily done by ETHE. Beginning February, top is shaded and vents are opened for four hours around noon. This procedure keeps the inside temperature below 34°C. From early March, ETHE is operated in the middle part of day for 5 to 6 hours if the grid supply is not interrupted. On particularly hot days fogging is also used along with ETHE. This procedure keeps the inside temperature about 36-37°C. Cropping could be done till the end of April, an important achievement in this area where commonly there is no standing crop beyond October – November in general. Greenhouse is closed in May and June.
2. Water required to raise a crop of hybrid tomato was nearly half of that required in the open field in Gujarat. Yield was nearly two times that of the open field.
3. Present ETHE is made of metal pipes and is expensive . This will need to be made cheaper by use of plastic pipes. That will also lead to reduced pumping power. A More important aspect that calls for further work is the layout and configuration which can be easier to scale-up than the present design.

Table 1. Temperature gain - greenhouse empty un-shaded
Vents without screen – Kothara

Observed in	All vents closed (C)	side vents open ridge vent closed (C)	All three vents open (C)	Ambient conditions
February 2002	13.5	5.1	4.4	776 w/m^2, 32.4°C
April 2002	17	5.9	5.9	914 w/ m^2, 37.7°C
June 2002	20.5	6.8	4.2	962 w/ m^2, 36°C
Values relate to 1 pm, taken from data logger, greenhouse temperature is mean of three locations.				

Table 2. Temperature gain - greenhouse with crop inside top shaded
Vents screened - Kothara (June 2005)

Status of vents And cooling system	Gain 2 pm (°C)	Water used if foggers on (liter/hr)
All vents closed	9.8	off
All vents open	3.1	off
All vents closed ETHE turned on at 10 AM turned off 4 PM	2.5	off
All vents closed ETHE on from 10 AM to 4 PM Fogger 30 min off, 2 min on	1.2	18
Note: tests done from June 16 to 22, 2005; mean radiation levels between 10am and 4 pm was 883 w/m^2 and mean wind speeds 8 m/s.		

Figure 1. Earth tube heat exchanger
Before backfill

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