Greenhouse Cultivation in a Hot Arid Area

G. Sharan[1] **Kamalesh Jethava**[2] **Anand Shamante**[3]

Abstract

A facility for controlled environment agriculture is under investigation at Kothara (Kutch), a hot and extremely arid region. It consists of a greenhouse of 120 m^2 floor area coupled in closed-loop mode to an earth-tube-heat-exchanger (ETHE) buried directly below. The ETHE provides conditioned air at 20 air changes per hour when needed. A 7.5 hp blower moves the air. Greenhouse is furnished with two continuous roll-up side vents, close-able continuous ridge vents and a retractable top cover made of shade net. Greenhouse has a fertigation system and an array of overhead foggers to supplement humidity and cooling.
The ETHE was able to heat the house easily from 9^{o}C to 22-23^{o}C in half hour in the cold winter nights. Static ventilation from side and ridge vents along with shading was effective for day time control till early March. Subsequently ETHE was operated. It limits the greenhouse temperature gain keeping the inside near 36^{o}C while shaded on top and when crop is inside. ETHE holds promise as an effective environmental control device in hot arid areas. A higher air change rate appears desirable to lower the temperature further.
Two rounds of cropping has been done, the third is in progress. The results of growing tomato were presented else where. In this paper we present the results of growing capsicum.

Keywords: greenhouse, arid environment, earth-tube-heat-exchanger

Introduction

Kutch region of Gujarat is characterized by low and erratic rainfall, high ambient temperatures, salt-affected soils and poor quality water. Open-field cultivation is low yielding and risk-prone. Vast areas of land remain uncultivated. Techniques that can raise the productivity of (scarce) water such as greenhouse need to be introduced. Mears (1990) drew attention to this possibility:

> "while a greenhouse is generally regarded as necessary to provide a warm environment in cold climates, it has also been shown that with properly designed cooling system, it is possible to improve plant growing conditions under extensively hot conditions. Adaptation of modern cooling technologies to Indian conditions will undoubtedly lead to increased opportunities for production of high value plants and materials in areas where the environment is extremely harsh. Protected cultivation also has the potential benefit of substantially increasing plant productivity per unit water consumption, which is important in many areas where good quality water is severely limited."

[1] Professor, 2 & 3 Research Engineers, Cummins -IIMA Laboratory for Environment Technology in Arid Areas, Indian Institute of Management, Vastrapur, Ahmedabad 380 015.

The most common method of cooling greenhouses is through evaporative procedures - fan and pad systems and foggers. Computations had shown that under the conditions prevailing in Kutch, a greenhouse of - 360 m^3- volumes would require a 7 m^2 pad and use up nearly 400 liters of water in a 5 hour operation which will be required for most part of the year. It was unclear if the combined requirement – plant use and cooling- would be a significant improvement over open-field. The idea of depending entirely on evaporative cooling procedures was given up. It was decided instead to explore the use of ETHE as a means of environmental control.

Santamouris *et al* (1995) published a review of 18 projects using ETHE in greenhouses. Most of these projects are from cold countries and ETHE was deployed to supplement heating. ETHE kept the greenhouse air several degrees above the ambient. In some cases, especially those that had thermal storage, significant part of annual heating requirement was met. They reported one instance where cooling was also accomplished successfully by similar systems. heir own greenhouse in Agrinion (38.5^o N lat) had 1000 m^2 floor was furnished with high inertia north wall as well as 4 plastic pipes of 30 m length, 25 cm diameter carrying air at 8 m/s. They reported that the operation of the system in summer (June) reduced greenhouse temperature by several degrees compared to the ambient.

Feuilloley et al (1990) discussed the problem of high summer temperatures in greenhouses in the Mediterranean region. They investigated the desirability of providing sufficient static ventilation. They studied the effect of vent area, vent location, wind speed and height of vegetation in a small experimental Quonset shape tunnel. Tietel and Tanny (1999) carried out experiments as well as developed transient mathematical model relating temperature and humidity ratio to the opening of roof windows, wind speed and solar radiation. The results are useful for design of vents and understanding of ventilation process.

Above works suggest that in hot arid areas like Kutch it would be useful to make use of both - ETHE as well as static ventilation - as conjunctive means of environmental control. Most of the greenhouse research in India has been for colder areas. There is need to deploy this new technology to improve the productivity of agriculture in general and water in particular in hot arid areas which are a substantial part of the country. The facility at Kothara has been built to pursue this aim. Measurements of deep soil temperature in this region (Sharan and Jadhav 2002), study of performance of a single pass ETHE (Sharan and Jadhav 2003 a; Sharan and Madhavan 2003 b) and performance of a ETHE based system in the zoo at Ahmedabad (Sharan, Sahu and Jadhav 2001) provided the necessary local database and some experience to build a 7000 m3/hr ETHE for a greenhouse at Kothara.

A detailed description of the experimental facility can be seen in Sharan et al (2003 c). A brief description is given also in this paper. Performance of the system and results of growing capsicum is discussed.

Experimental Details

A schematic diagram of experimental set-up at Kothara is shown in figure 1. Greenhouse stands above an ETHE which is buried at 3m depth (figure 2). The two are coupled in closed-loop mode. The greenhouse has a fertigation system, overhead foggers and environmental sensors.

Greenhouse

Greenhouse is of 6 m span, 20 m length and 3.5 m height at the ridge. Its floor is 120 m^2 and volume 360 m^3. The saw-tooth structure east-west oriented. Frames are made of square, closed-structural of galvanized iron. The bay size is 2 m. It is designed for winds of 180 km/hr, besides the usual other live and dead loads. Cladding is 200 micron UV stabilised polyethylene sheet. At the base of both the long sides there are roll-up curtains. Third vent is at the ridge. This is also closeable and is made of polycarbonate louvers. It can be operated manually from the floor. All three vents (side and ridge) are of 0.5 m height when fully open. Total vent area is 30 m^2 which is 25% of the greenhouse floor area. Side vents account for 17% and ridge 8%. Side vents are covered with insect screen.

There is provision for retractable shading screen, which can be spread over the roof above and vertically on the south face, if needed. Shading screen is made of agronets of 50% shading. There are 39 foggers (discharge 7 lph). Drippers have discharge of 3 lph..

Earth Tube Heat Exchanger

ETHE is made of eight pipes arranged in two tiers. The first tier has four pipes placed at 3 m depth, the second also has four pipes and is placed 1 m above the first. Each pipe is 23 m long and 20 cm in nominal diameter. Thickness of pipe wall is 3 mm. Pipes are made of mild steel, and placed 1.5 m apart. There is a common header at both ends of each tier. Headers in turn are connected to specially fabricated ducting that rises above the ground to form inlet and outlet. Hot air is drawn from the greenhouse, cycled through the buried pipes and returned to the greenhouse. Inlet and suction louvers spanning the greenhouse on both ends can be seen in figure 3.

ETHE moves air equivalent to 20 air changes in the greenhouse per hour (7200 m^3/hr). Computations had shown that a higher change rate is desirable, but the system was tending to become unwieldy, and expensive. Air velocity of 8 m/s was set for each pipe. Pressure drop in the ETHE calculated using Longest Path method, worked out to 200 mm water gauge. Blower is powered by a 7.5 hp, 1440 rpm motor. It is rated to deliver 4000 m^3/hr to 7000 m^3/hr of air in its optimum working range of 200 mm to 225 mm water pressure gauge.

Instrumentation

An eight-channel data logger powered by chargeable 12 V battery is installed. Sensors include temperature, solar radiation, wind speed, humidity, soil temperature. Three weather shielded temperature sensors are placed 1 m above ground at three locations on the centre line - ends and middle. Of the two soil temperature sensors, one is placed at 30 cm depth and the other just below the surface. 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, serial output port for connecting it to PC with parallel interface to printer or memory module. Data logger is placed just outside the greenhouse in weather proof enclosure.

Environmental Control Operations

Environmental control involves heating in winter nights, cooling in hot days. Heating is achieved by the ETHE alone. Cooling is achieved as much as possible by each of the following procedures. Opening the roll-up side vents is done first. Ridge vents are also opened if needed. Shading the top by a retractable net is done next. Finally cooling is done by operating the ETHE. Foggers are used occasionally to help cooling but more to improve humidity levels.

Heating

Night temperature in Kothara generally begin to drop below 18°C in December. January nights are colder with temperature going down to 8°C to 9°C. Night temperature rise above 18°C by about middle of February. Night temperatures in closed greenhouse at night were observed to be virtually the same as the ambient. Heating is therefore needed from December 15 to about February 15.

When temperature in greenhouse fell below 15°C, ETHE is turned on. It was observed that operation of ETHE at night raised the temperature to 22-23°C within about 30 minutes. Keeping the ETHE on continuously was difficult because of wide fluctuations in voltage and consequent tripping of motor. An on/off schedule was adopted. ETHE would be turned on when temperature reached about 15°C, turned off when it reached 22°C. It usually took 70 to 80 minutes for temperature to fall back again below 15°C. Figure 4 shows the temperatures inside greenhouse and the ambient on one of the nights (January 14-15). ETHE was able to meet the heating need easily, entirely and at only a small cost.

Cooling

In the coolest part of the year, December-January day temperature vary from 25°C to 32°C. In hottest months, May-June, day temperature vary from 34°C to 45°C. There are a few days when the maximum could be as high as 46°C. This greenhouse gains as much as 15°C in winter over the ambient when closed and 20-21°C in summer months. In an air tight greenhouse cooling will be needed practically all through the year during the day.

Opening the two side vents reduces the temperature gain significantly (Table-1). Opening the ridge vent together with side vents reduced it further. Fogging for 60 seconds every half hour was able to reduce the temperature by a further two degrees. It also increased the humidity levels. ETHE operation (all vents closed, top shaded and crops inside) restricted the greenhouse temperature to nearly 36 oC. Higher air change rate perhaps 30 per hour may be desirable. More than about two hours of continuous operation of ETHE was usually not possible due to voltage fluctuations and power interruptions. But when possible and needed it was operated for four hours from 11 am to 3 pm.

Till January 15, opening the three vents from 11 A.M. to 4 P.M. was adequate to maintain the greenhouse temperature below 34oC. From middle of January to end of February, foggers needed to be operated as well. This was adequate to keep the temperatures below 34°C till the end of February. Beginning with March, the greenhouse was shaded from top. Fogging interval was reduced to half hour. This procedure kept the greenhouse at the ambient temperature, in fact on many occasions cooler by two to three degrees. Beginning April ETHE was operated.

Cropping Trials

Sharan et al (2003 c) presented a detailed account of the first trial in which tomato was grown. The cultivar used was not a hybrid but a variety (Mahyco PKM-1) used because of the preference of local community. Tomato yield was 2.7 times the open-field yield in the area and water used for irrigation 34% less than in open field. Capsicum is not grown in Kutch. It is brought from other parts for sale here. It is a relatively higher value commodity than other vegetables. It was therefore decided to grow this on the second round (Figure 5).

Seedlings were raised in the greenhouse in 98 cell trays using cocopeat as root media. Seedlings were ready for transplanting in about 20 days with six true leaves and height of 6 to 8 cm. The media in the greenhouse was a mixture of natural soil, well composted cattle manure and cocopeat. Initially water was applied manually. After two weeks drip system was used. Watering was by a schedule that was related to the stages of growth (Table 2). Watering in the control bed was by observation and occasional measurement of soil moisture with a portable moisture meter. Fertilizer was applied in split doses as per the recommendations of the seed provider.

There was no attack of pest or pathogens. But a neem biocide (trade name GRONIM) was sprayed every four days. This was done to prevent or eliminate small infestation of white flies which is seen more in tomato, much less in capsicum. Results of cropping are summarized in Table 3.

Conclusion

Open-field agriculture in hot arid areas is low yielding and risk prone. Adoption of greenhouse technology can improve yield and productivity of scarce water. Adoption of this technology will be facilitated if new cooling procedure is used that do not consume as much water as the evaporative methods. Investigations have shown that providing static ventilation and earth-tube-heat-exchanger of suitable capacity, environmental control can be achieved to permit cropping till the end of April or for ten months in a year. Based on the experience at Kothara, following conclusions can be drawn.

1. Earth-tube-heat-exchanger and static ventilation appear to make greenhouse cultivation feasible in hot, arid conditions. Cropping could be done till the end of April. In the month of May fruit size reduced and premature ripening increased.
2. Heating requirement is limited to two months. Heating was easily done by ETHE.
3. This house had static vent area of 25% of the floor. Side vents accounted for 17% and the ridge vent for 8%. Opening the vents from 11 A.M. to 4 P.M. was adequate to keep the house below 34^{o}C till the middle of January. Subsequently, fogging and still later shading from top was added to this practice. April onwards, ETHE needed to be operated during noon hours. ETHE operation limited the temperature gain and kept the inside near 36^{o}C. Further increase in air change rate may be desirable.
4. Capsicum in greenhouse crop continued to fruit for nine months. Crop in the control bed lasted only five months. Plants withered away due to sun outside after the middle of January. Yield was equivalent of 16 t/ha in the greenhouse, 1.4 times that of the control bed outside. The proportion of healthy fruits in the greenhouse was 90%. It was 60% in the control bed.

Table 1. Difference between empty greenhouse temperature and the ambient

Details	February 2002 (^oC)	April 2002 (^oC)	June 2002 (^oC)
All vents closed	15.4	20.0	21.3
Only the side vents open	5.5	6.7	7.9
Side and ridge vents open	4.9	-	2.6

Table 2. Watering schedule (greenhouse capsicum)

Schedule	Duration (days)	Time (minutes)	Water required (liter)
After planting	1 to 7	Manually	175
Up to 15 days	8 to 15	2	234
Up to flowering stage	16 to 35	3	350
At flowering stage	36 to 56	4	466
At fruit setting stage	57 to end	5	584

Table 3. Summary of cultivation (greenhouse capsicum)

Sr. No.	Details	Greenhouse	Control bed
1	Variety	Bejo Sheetal BSS 89	Bejo Sheetal BSS 89
2	Plant spacing	40 x 30 cm	40 x 30 cm
3	Planting date	02 August 2004	02 August 2004
4	Planted area	28 m^2	4 m^2
5	First flowered	35 day after planting	35 day after planting
6	First fruit picked	69 day after planting	60 day after planting
7	Fruit size	Long axis 85-90 mm Max dia 65-47.5 mm Min dia 65-44.5 mm Avg weight 40-50 gm	Comparable
	Proportion of Undeveloped fruits (%)	10	40
8	Plant height	72.6 cm (max)	70 cm
9	Total yield	16 t / ha (équivalent)	11 t / ha (équivalent)
10	Last picking	30 May 2004 (9 months)	10 January 2004 (5 months)
11	Total irrigation water applied	18395 liter (678 mm)	Approx. 550 mm
12	Total fogger water applied	8287 liter	--

Greenhouse

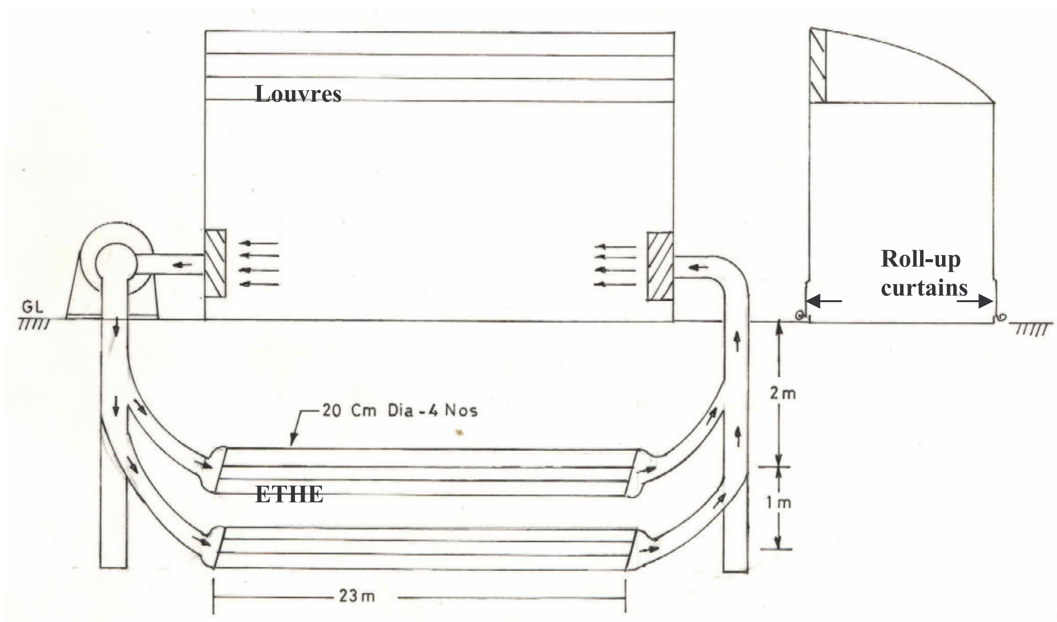

Figure 1: Greenhouse coupled to earth tube heat exchanger (ETHE) at Kothara

Figure 2. ETHE before being covered

Figure 3. Greenhouse Structure

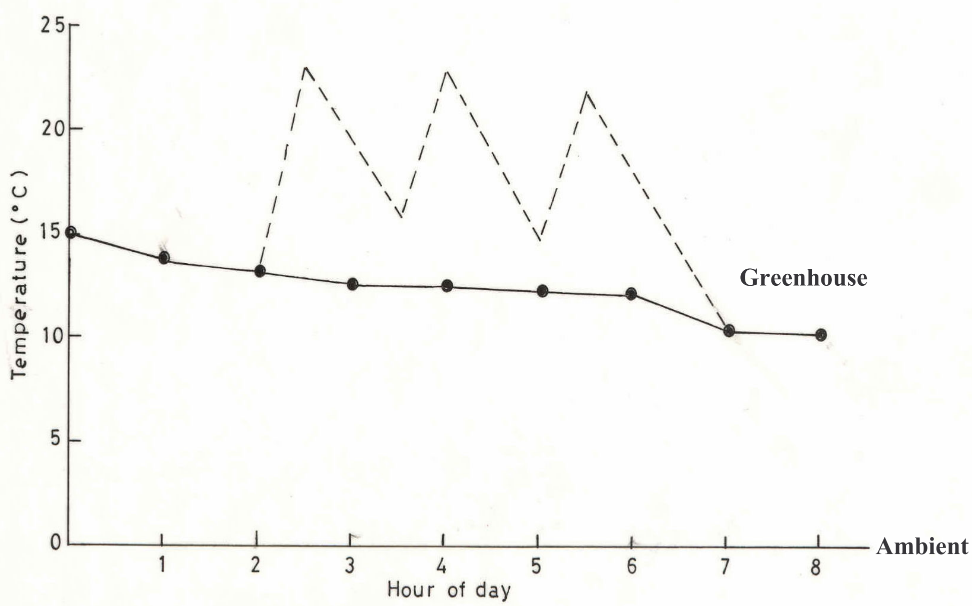

Figure 4. Greenhouse and ambient temperature (14-15Jan)

Figure 5. Capsicum in the Greenhouse

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