

Effect of irrigation regimes and low tunnel heights on microclimatic parameters in the growing of sweet pepper

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ABSTRACT: Field experiment was conducted in the Department of Soil and Water Engineering, PAU, Ludhiana in 2008-09 to study the effects of low tunnel environment in growing of sweet pepper (*Capsicum annuum* L. var. *grossum*). The experiment was laid out in split plot design keeping five irrigation treatments (drip irrigation with IW/CPE ratio of 0.60 (I1), 0.75 (I2), 0.90 (I3), furrow irrigation with paired row planting (I4) and single row planting (I5)), in main plots and three different low tunnel heights (45cm (H1), 60cm (H2) and 75cm (H3)) in sub plots and replicated three times. The air temperature, soil temperature, Relative humidity, solar radiations were observed. For the combinations I2H2 treatment gave higher air and soil temperature than other treatments combinations and I3H3 gave higher mean relative humidity at 7:30 am but at 2:30 pm combination I2H2 treatment gave higher relative humidity than other treatment combinations.

KEYWORDS: Air temperature, Soil temperature, Relative Humidity, Microclimate, Low Tunnels, Sweet pepper.

I. INTRODUCTION

Capsicum (*Capsicum annuum* L. var. *grossum*) or sweet pepper is one of the most popular and high value vegetable crops grown for its immature fruits around the world. High demand of fresh vegetables generated in domestic and export market throughout the year. But due to unfavourable climatic conditions there is a flood of vegetables in the season and very high priced vegetables in off-season. Vegetables can be cultivated in off-season, with the induction of artificial techniques like green houses, low and high poly tunnels technology, in which temperature and moisture are controlled for specific growth of vegetables. The production of vegetables all around the year enables the growers to fully utilize their resources and supplement income from vegetable growing as compared to other normal agricultural crops.

For sweet pepper the optimum night temperature for quality fruits production 16-18°C. When the temperature falls below 16°C for extended periods, growth and yields usually decreases. It can tolerate day temperature above 30°C. Sweet pepper are generally raised in open during main season thus causing glut in the market, which lead to price crash in the season. Punjab has extreme low temperature during winter and high temperature during summer, therefore, availability of these vegetable is for a short span. This situation suggests us to modify microclimate, which will not only increase the availability span of vegetables but also the yield. Low tunnel technology can help sweet pepper in off-season during early summer. With this technology, the farmers can capture the market in the early season and may get good return of their produce.

Low tunnels or row covers are plastic film covered shelters with small frames, producing greenhouse like effect. For low tunnels the sheet of the film is placed over the plants in a single or double row with an arch-shaped frame for support. The shape of the frame can vary but the farmer cannot work inside the low tunnels. These tunnels facilitate the entrapment of carbon dioxide, thereby enhancing the photosynthetic activity of the plants and hence the yield. These structures also protect the plants from the high winds, rain, frost and snow. Besides being inexpensive they are easy to construct and dismantle. Low tunnels are being used for producing high quality high valued nurseries and crops such as tomatoes, cucumber, radish, beans and capsicum.

Libik and Siwek (1994) studied the changes in soil temperature affected by the application of plastic covers in field production of lettuce and watermelon. It was reported that at 8.00 h soil temperature was 3°C higher than in the open ground and by 14.00 h the air temperature under the cover was 10-15°C higher than the ambient temperature. Lamarrel *et al* (1996) was found that the use of low tunnel has been beneficial during winter when the crop has to be protected from frost and low temperature for higher productivity.

II. MATERIALS AND METHODS

Field experiment was conducted at the Research Farm of the Department of Soil and Water Engineering, PAU, Ludhiana from October, 2008 to June, 2009. Ludhiana is situated at latitude of 30° 54' N and longitude of 75° 48' E and at a mean height of 247 meters above sea level. Average minimum and maximum temperature in the region varies from 3°C to 43°C respectively.

A field plot measuring approximately 550.8 m² (54m x 10.2m) was prepared and the experiment was laid out in split plot design keeping five irrigation treatments in main plots and three different heights of low tunnel in sub plots and replicated three times. The irrigation treatments were taken as main plots as they require bigger plot size. The three treatments of different heights of low tunnel made with tunnel frame height of 45cm (H1), 60cm (H2) and 75cm (H3) were used in the experiment. Low tunnels were made with the 6mm thick steel (iron) rods. The shape of the low tunnel frame was made parabolic with the given base and desired height. A length of 15cm at the base was kept for inserting frame into the soil and inside loops was provided on both side of frame for the support in addition to low tunnel height.

Nursery raising of sweet pepper of "Bharath" variety was done in polyhouse on 13th of October, 2008 and transplanting was done in the field on 17th of November, 2008. In paired sowing 60 cm wide beds were raised, row to row space between paired rows was 45 cm and row space between pairs was 75 cm but plant to plant space was kept as 30 cm. Irrigation was applied as per the treatments. In the single furrow the row to row spacing was 60 cm and plant to plant spacing was 30 cm. As per the recommendations of PAU Ludhiana "Package of Practices for Vegetable Crops" (Anonymous, 2008) full package of plant protection measures were adopted during the growth period of crop so as to have a disease free and weed free crop.



Fig.1 Low tunnels of different heights in experimental field

After transplanting of crop, the crop was covered with polysheet of 50 micron thickness with width of 150cm, 185cm and 240cm over the low tunnel frame heights of 45cm, 60cm and 75cm respectively, to protect crop from frost and other injury (Fig.1). The low tunnel frames were kept at beginning and at end of paired row and distance between successive frames was kept as 2.50m. The crop was completely covered with low tunnel till 4th February, 2009 and after that low tunnels were removed.

To observe the effect of low tunnels on soil temperature, soil temperature thermometers were installed at a depth of 10 cm in the field in 45 sub-plots under low tunnel and outside in adjoining open field. Daily data of minimum and maximum soil temperature was recorded till the tunnel cover was removed from the crop. The minimum temperature was recorded at 7.30 AM in the morning and maximum temperature was recorded at 2.30 PM in the afternoon.

Maximum and minimum air temperature was recorded by placing thermometer at middle in each sub-plot and outside in adjoining open field. This observation was also recorded daily at 7.30 AM and 2.30 PM respectively till the tunnel cover was removed from the crop.

Relative humidity was recorded by placing hygrometer at middle in each sub-plot and outside in adjoining open field. These observations were also recorded daily at 7:30 AM and 2:30 PM till the tunnel cover was removed from the crop.

Maximum solar radiation inside the tunnel and outside in adjoining field was taken out by using digital Lux meter (TES 1332) daily at 2.30 PM till the tunnel cover was removed from the crop.

III. RESULTS AND DISCUSSION

To observe the effect of different treatments on microclimate inside the low tunnels air temperature, soil temperature, relative humidity and solar radiation were recorded daily from the time when the crop was covered with low tunnels till the low tunnels were removed (i.e. 27th Nov,2008 to 4th Feb,2009). Mean of seven days was calculated and used for analysis.

3.1 Air Temperature

The measurement of recorded temperature showed that the thermal condition depends on the tunnel height and the type of irrigation applied as presented in Table 1. At 7:30 am the air temperature in low tunnel which varied from 8.75°C to 13.42°C was higher by 3.25°C to 3.71°C in comparison with open field whose temperature varied from 5.50°C to 9.71°C during the low tunnel coverage period. Among the tunnel height treatments, in H2 treatment the air temperature was highest which varied from 9.33°C to 13.42°C and was higher by 0.57°C to 0.58°C in comparison with H1 treatment whose temperature was lowest which varied from 8.75°C to 12.85°C. Among the irrigation treatments, in I2 treatment the air temperature was highest which varied from 9.61°C to 13.42°C and was higher by 0.76°C to 0.86°C in comparison with I5 treatment whose temperature was lowest which varied from 8.75°C to 12.66°C. For the treatment combination in I2H2 treatment the air temperature was highest which varied from 9.75°C to 13.42°C and was higher by 1°C in comparison with I5H1 treatment whose temperature was lowest which varied from 8.75°C to 12.42°C.

At 2:30 pm the air temperature in low tunnel which varied from 23.8°C to 36.8°C was higher by 6.38°C to 9.3°C in comparison with open field whose temperature varied from 17.42°C to 27.5°C during the low tunnel coverage period. Among the tunnel height treatments, in H2 treatment the air temperature was highest which varied from 24.42°C to 36.8°C and was higher by 0.14°C to 0.62°C in comparison with H1 treatment whose temperature was lowest which varied from 23.8°C to 36.66°C. Among the irrigation treatments, in I2 treatment the air temperature was highest which varied from 25.94°C to 36.8°C and was higher by 1.1°C to 2.14°C in comparison with I5 treatment whose temperature was lowest which varied from 23.8°C to 35.7°C. For the treatment combination in I2H2 treatment the air temperature was highest which varied from 26.61°C to 36.8°C and was higher by 2.81°C to 3.23°C in comparison with I5H1 treatment whose temperature was lowest which varied from 23.8°C to 33.57°C. Differences in temperature between low tunnels treatments may be due to many factors including: initial air and soil temperature; soil moisture, air volume in tunnel, convective and conductive heat exchange characteristics of the material and transmissibility to long wave radiation.

The above mentioned results were in close proximity with those of Wolfe *et al* (1989) who reported 5°C to 20°C daytime air temperature rise under row covers as compared with open field.

Table 1 Variation of air temperature in different heights of low tunnel with various irrigation treatments

Week after covering of crop	Mean Air Temp. (°C) (Open Field)		Mean Air Temperature (°C)						
			Low Tunnel Heights						
	7:30 am	2:30 pm	45cm		60cm		75cm		
				7:30 am	2:30 pm	7:30 am	2:30 pm	7:30 am	2:30 pm
IW/ CPE= 0.60 (I1)									
1. (27 Nov -3 Dec)	7.85	24.71	10.90	32.47	11.37	33.42	11.14	33.09	
2. (04 - 10 Dec)	9.71	23.14	12.66	30.52	13.04	31.28	12.80	30.85	
3. (11 -17 Dec)	7.85	22.42	11.09	31.37	11.42	32.90	11.18	32.37	
4. (18- 24 Dec)	9.28	20.85	12.33	27.90	12.61	28.94	12.56	28.66	
5. (25- 31 Dec)	7.42	17.42	10.71	24.94	11.33	25.80	10.99	25.28	
6. (01 -7 Jan)	6.16	18.00	9.33	26.28	9.56	27.09	9.51	26.95	
7. (08 - 14 Jan)	5.50	23.42	9.04	30.04	9.52	31.24	9.28	30.61	
8. (15 -21Jan)	8.28	22.57	11.42	30.85	11.61	31.71	11.52	31.14	
9. (22 -28 Jan)	8.66	23.50	11.85	30.18	11.99	31.56	11.95	31.28	
10. (29 Jan - 4 Feb)	7.00	27.50	10.18	35.56	10.33	36.56	10.23	36.14	
IW/CPE= 0.75 (I2)									
1. (27 Nov -3 Dec)	7.85	24.71	11.33	33.38	11.90	33.99	11.47	33.94	

2. (04 - 10 Dec)	9.71	23.14	12.85	31.61	13.42	32.56	13.19	32.04
3. (11 -17 Dec)	7.85	22.42	11.28	32.37	11.76	33.04	11.61	32.90
4. (18- 24 Dec)	9.28	20.85	12.61	29.33	12.90	29.80	12.80	29.61
5. (25- 31 Dec)	7.42	17.42	11.23	25.94	11.66	26.61	11.42	26.18
6. (01 -7 Jan)	6.16	18.00	9.71	27.28	9.95	27.99	9.85	27.47
7. (08 - 14 Jan)	5.50	23.42	9.61	30.80	9.75	31.66	9.71	31.61
8. (15 -21Jan)	8.28	22.57	11.71	31.56	11.95	31.95	11.80	31.80
9. (22 -28 Jan)	8.66	23.50	12.09	31.71	12.52	31.99	12.23	31.85
10. (29 Jan - 4 Feb)	7.00	27.50	10.37	36.66	10.61	36.80	10.47	36.95
IW/CPE= 0.90 (I3)								
1. (27 Nov -3 Dec)	7.85	24.71	11.04	32.90	11.76	33.75	11.33	33.61
2. (04 - 10 Dec)	9.71	23.14	12.76	30.99	13.23	32.23	13.04	31.04
3. (11 -17 Dec)	7.85	22.42	11.18	31.8	11.61	32.76	11.33	32.75
4. (18- 24 Dec)	9.28	20.85	12.47	28.75	12.71	29.42	12.66	28.94
5. (25- 31 Dec)	7.42	17.42	11.14	25.33	11.52	26.37	11.28	25.90
6. (01 -7 Jan)	6.16	18.00	9.56	26.99	9.71	27.47	9.61	27.23
7. (08 - 14 Jan)	5.50	23.42	9.18	30.23	9.56	31.61	9.47	31.18
8. (15 -21Jan)	8.28	22.57	11.52	31.18	11.85	31.66	11.66	31.33
9. (22 -28 Jan)	8.66	23.50	12.04	31.66	12.33	31.71	12.13	31.61
10. (29 Jan - 4 Feb)	7.00	27.50	10.23	36.42	10.47	36.75	10.37	36.52
Paired Row Planting (I4)								
1. (27 Nov -3 Dec)	7.85	24.71	11.04	32.90	11.76	33.75	11.33	33.61
2. (04 - 10 Dec)	9.71	23.14	12.76	30.99	13.23	32.23	13.04	31.04
3. (11 -17 Dec)	7.85	22.42	11.18	31.8	11.61	32.76	11.33	32.75
4. (18- 24 Dec)	9.28	20.85	12.47	28.75	12.71	29.42	12.66	28.94
5. (25- 31 Dec)	7.42	17.42	11.14	25.33	11.52	26.37	11.28	25.90
6. (01 -7 Jan)	6.16	18.00	9.56	26.99	9.71	27.47	9.61	27.23
7. (08 - 14 Jan)	5.50	23.42	9.18	30.23	9.56	31.61	9.47	31.18
8. (15 -21Jan)	8.28	22.57	11.52	31.18	11.85	31.66	11.66	31.33
9. (22 -28 Jan)	8.66	23.50	12.04	31.66	12.33	31.71	12.13	31.61
10. (29 Jan - 4 Feb)	7.00	27.50	10.23	36.42	10.47	36.75	10.37	36.52
Single Row Planting (I5)								
1. (27 Nov -3 Dec)	7.85	24.71	10.47	31.23	10.95	32.18	10.61	31.33
2. (04 - 10 Dec)	9.71	23.14	12.42	29.28	12.66	30.09	12.57	29.85
3. (11 -17 Dec)	7.85	22.42	10.85	30.18	11.09	31.90	10.94	31.33
4. (18- 24 Dec)	9.28	20.85	11.90	27.32	12.33	27.66	12.14	27.56
5. (25- 31 Dec)	7.42	17.42	10.42	23.80	10.99	24.42	10.71	24.18
6. (01 -7 Jan)	6.16	18.00	8.85	24.42	9.33	25.04	9.04	24.90
7. (08 - 14 Jan)	5.50	23.42	8.75	27.90	9.37	29.04	8.90	29.23
8. (15 -21Jan)	8.28	22.57	11.23	30.28	11.47	30.94	11.33	30.47
9. (22 -28 Jan)	8.66	23.50	11.56	28.99	11.76	30.42	11.66	29.94
10. (29 Jan - 4 Feb)	7.00	27.50	10.04	33.57	10.18	35.70	10.09	34.61

3.2 Soil temperature

The measurement of recorded soil temperature also depends on the tunnel height and the type of irrigation applied as presented in Table 2. At 7:30 am the soil temperature in low tunnel which varied from 8.71°C to 16.61°C was higher by 1.29°C to 4.76°C in comparison with open field whose soil temperature varied from 7.42°C to 11.85°C during the low tunnel coverage period. Among the tunnel height treatments, in H2 treatment the soil temperature was highest which varied from 9.23°C to 16.61°C and was higher by 0.52°C to 1°C in comparison with H1 treatment whose soil temperature was lowest which varied from 8.71°C to 15.61°C. Among the irrigation treatments, in I2 treatment the soil temperature was highest which varied from 10.57°C to 16.61°C and was higher by 0.95°C to 1.86°C in comparison with I5 treatment whose soil temperature was lowest which varied from 8.71°C to 15.66°C. For the treatment combination in I2H2 treatment the soil temperature was highest which varied from 11.13°C to 16.61°C and was higher by 2.42°C to 2.62°C

in comparison with I5H1 treatment whose soil temperature was lowest which varied from 8.71°C to 13.99°C. At 2:30 pm the soil temperature in low tunnel which varied from 20.52°C to 27.95°C was higher by 3.52°C to 6.38°C in comparison with open field whose temperature varied from 17°C to 21.57°C during the low tunnel coverage period. Among the tunnel height treatments, in H2 treatment the soil temperature was highest which varied from 21.76°C to 27.95°C and was higher by 0.48°C to 1.24°C in comparison with H1 treatment whose temperature was lowest which varied from 20.52°C to 27.47°C. Among the irrigation treatments, in I2 treatment the soil temperature was highest which varied from 23°C to 27.95°C and was higher by 1.43°C to 2.48°C in comparison with I5 treatment whose soil temperature was lowest which varied from 20.52°C to 26.52°C. For the treatment combination in I2H2 treatment the soil temperature was highest which varied from 23.76°C to 27.95°C and was higher by 1.43°C to 2°C in comparison with I5H1 treatment whose temperature was lowest which varied from 21.76°C to 26.52°C. Differences in soil temperature between low tunnels treatments may be due to many factors including: initial air and soil temperature; soil moisture, air volume in tunnel, convective and conductive heat exchange characteristics of the material, surface area of the tunnel to volume ratio and transmissibility to long wave radiation.

The above mentioned results were in close proximity with those of Hemphill (1986) who reported that row covers increased daily mean soil temperature by 1 to 4°C over bare ground. The results are also in line with those of Gaye and Maurer (1991) who reported that row cover elevated mean soil temperature 1 to 6°C and promoted plant growth compared with bare soil.

Table 2 Variation of soil temperature in different heights of low tunnel with various irrigation treatments

Week after covering of crop	Mean Soil Temp. (°C) (Open Field)		Mean Soil Temperature (°C)					
			Low Tunnel Heights					
			45cm		60cm		75cm	
	7:30 am	2:30 pm	7:30 am	2:30 pm	7:30 am	2:30 pm	7:30 am	2:30 pm
IW/ CPE= 0.60 (I1)								
1. (27 Nov -3 Dec)	11.00	19.14	13.28	23.14	13.75	24.19	13.61	23.85
2. (04 - 10 Dec)	11.85	20.57	13.95	25.23	14.66	26.14	14.28	25.71
3. (11 -17 Dec)	9.71	17.42	12.37	22.47	12.90	22.95	12.66	22.66
4. (18- 24 Dec)	11.14	20.85	13.47	25.38	14.09	26.85	13.76	25.9
5. (25- 31 Dec)	11.28	18.14	13.71	22.52	14.04	23.38	13.99	23.00
6. (01 -7 Jan)	10.66	19.14	13.28	23.95	13.94	25.04	13.61	24.47
7. (08 - 14 Jan)	7.42	17.00	10.18	22.33	10.80	23.19	10.42	22.61
8. (15 -21Jan)	10.42	19.57	15.04	23.61	16.00	24.47	15.56	24.14
9. (22 -28 Jan)	9.71	19.71	12.38	23.19	12.75	24.04	12.61	23.57
10. (29 Jan - 4 Feb)	10.50	21.57	13.85	26.28	14.04	27.28	13.99	26.61
IW/CPE= 0.75 (I2)								
1. (27 Nov -3 Dec)	11.00	19.14	13.80	24.23	14.28	25.18	14.14	24.62
2. (04 - 10 Dec)	11.85	20.57	14.37	26.38	15.09	26.85	14.71	26.52
3. (11 -17 Dec)	9.71	17.42	12.95	23.00	13.37	23.76	13.18	23.28
4. (18- 24 Dec)	11.14	20.85	13.94	26.85	14.71	27.52	14.47	27.09
5. (25- 31 Dec)	11.28	18.14	14.23	23.42	15.09	24.33	14.47	23.71
6. (01 -7 Jan)	10.66	19.14	13.99	25.04	14.37	25.66	14.13	25.23
7. (08 - 14 Jan)	7.42	17.00	10.57	23.00	11.13	23.76	10.76	23.23
8. (15 -21Jan)	10.42	19.57	15.61	24.71	16.61	26.09	15.85	25.61
9. (22 -28 Jan)	9.71	19.71	12.90	24.19	13.23	25.33	13.00	24.95
10. (29 Jan - 4 Feb)	10.50	21.57	14.04	27.47	14.61	27.95	14.37	27.66
IW/CPE= 0.90 (I3)								
1. (27 Nov -3 Dec)	11.00	19.14	13.42	24.09	13.95	24.85	13.71	24.57
2. (04 - 10 Dec)	11.85	20.57	14.23	26.00	14.80	26.62	14.56	26.43
3. (11 -17 Dec)	9.71	17.42	12.75	22.71	13.18	23.38	12.99	23.14
4. (18- 24 Dec)	11.14	20.85	13.85	26.14	14.42	27.04	14.18	26.9

5. (25- 31 Dec)	11.28	18.14	13.99	23.14	14.61	23.95	14.33	23.57
6. (01 -7 Jan)	10.66	19.14	13.75	24.76	14.14	25.33	13.95	24.99
7. (08 - 14 Jan)	7.42	17.00	10.33	22.66	10.94	23.52	10.52	22.95
8. (15 -21Jan)	10.42	19.57	15.37	24.33	16.13	24.80	15.71	24.76
9. (22 -28 Jan)	9.71	19.71	12.61	23.99	13.04	24.95	12.90	24.52
10. (29 Jan - 4 Feb)	10.50	21.57	13.94	26.99	14.37	27.52	14.14	27.14
Paired Row Planting (I4)								
1. (27 Nov -3 Dec)	11.00	19.14	13.09	22.57	13.61	23.81	13.47	23.28
2. (04 - 10 Dec)	11.85	20.57	13.80	24.42	14.47	25.71	14.14	25.09
3. (11 -17 Dec)	9.71	17.42	12.09	21.19	12.70	22.76	12.37	22.33
4. (18- 24 Dec)	11.14	20.85	13.28	24.95	13.85	25.95	13.71	25.57
5. (25- 31 Dec)	11.28	18.14	13.51	21.71	13.85	23.09	13.71	22.19
6. (01 -7 Jan)	10.66	19.14	13.04	23.05	13.71	24.61	13.37	24.19
7. (08 - 14 Jan)	7.42	17.00	9.94	21.38	10.33	22.23	10.04	21.90
8. (15 -21Jan)	10.42	19.57	14.95	23.43	15.75	24.00	15.37	23.76
9. (22 -28 Jan)	9.71	19.71	12.23	22.76	12.52	23.62	12.37	23.04
10. (29 Jan - 4 Feb)	10.50	21.57	13.66	25.90	13.85	26.81	13.76	26.52
Single Row Planting (I5)								
1. (27 Nov -3 Dec)	11.00	19.14	12.95	22.09	13.33	23.47	13.18	22.62
2. (04 - 10 Dec)	11.85	20.57	13.28	24.75	14.13	25.38	13.80	24.19
3. (11 -17 Dec)	9.71	17.42	11.89	20.52	12.33	21.76	12.09	21.57
4. (18- 24 Dec)	11.14	20.85	13.04	23.76	13.56	25.61	13.33	24.90
5. (25- 31 Dec)	11.28	18.14	13.37	21.33	13.71	22.42	13.47	21.90
6. (01 -7 Jan)	10.66	19.14	12.90	22.28	13.42	24.38	13.04	23.42
7. (08 - 14 Jan)	7.42	17.00	8.71	21.09	9.23	22.14	8.95	21.42
8. (15 -21Jan)	10.42	19.57	13.99	22.81	15.66	23.62	14.56	23.19
9. (22 -28 Jan)	9.71	19.71	11.61	22.24	12.23	22.80	11.99	22.47
10. (29 Jan - 4 Feb)	10.50	21.57	13.04	25.42	13.56	26.52	13.23	26.14

3.3 Relative humidity

The measurement of recorded relative humidity also depends on the tunnel height and the type of irrigation applied as presented in Table 3. At 7:30 am the relative humidity in low tunnel which varied from 87.59% to 94.13% was lower by 4.58% to 6.55% in comparison with open field whose relative humidity varied from 94.14% to 98.71% during the low tunnel coverage period. Among the tunnel height treatments, in H3 treatment the relative humidity was highest which varied from 88.4% to 94.00% and was higher by 0.01% to 0.81% in comparison with H1 treatment whose relative humidity was lowest which varied from 87.59% to 93.99%. Among the irrigation treatments, in I3 treatment the relative humidity was highest which varied from 89.3% to 94.13% and was higher by 1.23% to 1.71% in comparison with I5 treatment whose relative humidity was lowest which varied from 87.59% to 92.9%. For the treatment combination in I3H3 treatment the relative humidity was highest which varied from 89.8% to 93.8% and was higher by 1.19% to 2.23% in comparison with I5H1 treatment whose relative humidity was lowest which varied from 87.57% to 92.61%. The decrease in the relative humidity from the open field may be due to dew effect on the polysheet in the morning.

At 2:30 pm the relative humidity in low tunnel which varied from 59.71% to 91.66% was higher by 11.52% to 17.57% in comparison with open field whose relative humidity varied from 42.14% to 80.14% during the low tunnel coverage period. Among the tunnel height treatments, in H2 treatment the relative humidity was highest which varied from 61.75% to 91.66% and was higher by 1.86% to 2.04% in comparison with H1 treatment whose relative humidity was lowest which varied from 59.71% to 89.8%. Among the irrigation treatments, in I2 treatment the relative humidity was highest which varied from 63.71% to 91.66% and was higher by 2% to 4% in comparison with I5 treatment whose relative humidity was lowest which varied from 59.71% to 89.66%. For the treatment combination in I2H2 treatment the relative humidity was highest which varied from 67.04% to 91.66% and was higher by 3.57% to 7.28% in comparison with I4H3 treatment whose relative humidity was lowest which varied from 59.76% to 88.09%. Differences in relative humidity between low tunnels treatments may be due to many factors including: initial air

and soil temperature; soil moisture, air volume in tunnel, convective and conductive heat exchange characteristics of the material, surface area of the tunnel to volume ratio and transmissibility to long wave radiation. The data also reveals that the low tunnel effect decreases the relative humidity in the morning but in the daytime it increases the relative humidity to provide favourable condition for plant growth. The above mentioned results were in close proximity with those of Chaugule *et al* (1990).

Table 3 Variation of relative humidity in different heights of low tunnel with various irrigation treatments

Week after covering of crop	Mean Relative Humidity (%) (Open Field)		Mean Relative Humidity (%)					
			Low Tunnel Heights					
			45cm		60cm		75cm	
7:30 am	2:30 pm	7:30 am	2:30 pm	7:30 am	2:30 pm	7:30 am	2:30 pm	
IW/ CPE= 0.60 (I1)								
1. (27 Nov -3 Dec)	98.71	42.14	93.76	63.75	93.52	65.33	94.00	64.8
2. (04 - 10 Dec)	98.14	48.85	91.8	66.33	91.9	67.04	92.09	66.99
3. (11 -17 Dec)	97.71	51.42	90.47	67.47	90.61	69.37	90.87	68.09
4. (18- 24 Dec)	94.14	65.42	88.78	77.99	88.87	80.47	89.21	78.76
5. (25- 31 Dec)	98.14	80.14	91.9	88.04	92.47	90.8	93.18	89.09
6. (01 -7 Jan)	96.85	62	89.95	75.85	90.42	76.8	90.8	76.37
7. (08 - 14 Jan)	97.42	58.85	92.13	74.09	92.61	75.56	92.76	74.85
8. (15 -21Jan)	96.57	68.71	90.33	82.18	90.66	83.09	91.13	82.66
9. (22 -28 Jan)	94.14	66	88.71	78.94	88.85	79.56	89.23	79.18
10. (29 Jan - 4 Feb)	97.57	57.28	89.66	71.71	90.28	74.23	90.9	73.9
IW/CPE= 0.75 (I2)								
1. (27 Nov -3 Dec)	98.71	42.14	93.42	63.71	93.9	67.04	93.61	65.56
2. (04 - 10 Dec)	98.14	48.85	91.85	66.28	91.9	68.28	92.47	67.52
3. (11 -17 Dec)	97.71	51.42	90.4	68.23	90.83	69.9	91.54	68.85
4. (18- 24 Dec)	94.14	65.42	88.26	79.18	89.16	82.04	89.73	79.8
5. (25- 31 Dec)	98.14	80.14	92.37	89.8	92.47	91.66	92.56	90.57
6. (01 -7 Jan)	96.85	62	90.28	75.99	90.61	78.28	90.99	77.71
7. (08 - 14 Jan)	97.42	58.85	92.56	74.75	92.8	77.28	93.04	76.18
8. (15 -21Jan)	96.57	68.71	90.66	82.18	91.18	83.47	91.33	81.85
9. (22 -28 Jan)	94.14	66	89.18	81.09	89.23	83.04	89.57	81.61
10. (29 Jan - 4 Feb)	97.57	57.28	90.18	73.8	90.37	75.18	91.37	74.04
IW/CPE= 0.90 (I3)								
1. (27 Nov -3 Dec)	98.71	42.14	93.99	63.61	94.13	66.23	93.8	64.09
2. (04 - 10 Dec)	98.14	48.85	92.09	66.04	92.13	67.8	92.66	66.09
3. (11 -17 Dec)	97.71	51.42	91.21	66.47	91.73	69.61	91.83	68.42
4. (18- 24 Dec)	94.14	65.42	89.3	78.75	89.73	80.47	90.11	79.94
5. (25- 31 Dec)	98.14	80.14	92.85	88.94	93.33	90.75	93.47	89.39
6. (01 -7 Jan)	96.85	62	90.94	75.94	91.42	76.85	91.99	76.71
7. (08 - 14 Jan)	97.42	58.85	92.61	73.99	92.99	75.85	93.71	74.37
8. (15 -21Jan)	96.57	68.71	91.14	80.23	91.33	83.04	91.9	82.28
9. (22 -28 Jan)	94.14	66	89.37	80.51	89.61	81.13	89.8	81.09
10. (29 Jan - 4 Feb)	97.57	57.28	91.66	72.23	92.8	74.66	93.13	73.8
Paired Row Planting (I4)								
1. (27 Nov -3 Dec)	98.71	42.14	92.85	61.23	93.23	62.99	93.33	59.76
2. (04 - 10 Dec)	98.14	48.85	91.04	65.18	91.23	65.42	91.52	63.42
3. (11 -17 Dec)	97.71	51.42	90.59	66.14	90.78	67.18	91.44	64.33
4. (18- 24 Dec)	94.14	65.42	88.54	77.23	88.73	78.33	89.16	76.66
5. (25- 31 Dec)	98.14	80.14	91.94	88.37	91.99	88.8	92.13	88.09

6. (01 -7 Jan)	96.85	62	89.47	74.09	90.18	75.42	90.23	74.13
7. (08 - 14 Jan)	97.42	58.85	91.71	73.61	91.94	72.32	92.32	71.18
8. (15 -21Jan)	96.57	68.71	90.04	82.09	90.56	81.18	90.9	80.37
9. (22 -28 Jan)	94.14	66	88.37	75.71	88.42	76.71	88.47	75.56
10. (29 Jan - 4 Feb)	97.57	57.28	89.8	72.14	90.09	71.71	90.8	69.75
Single Row Planting (I5)								
1. (27 Nov -3 Dec)	98.71	42.14	92.61	59.71	92.85	61.75	92.9	60.04
2. (04 - 10 Dec)	98.14	48.85	91.04	63.13	91.18	64.42	91.37	63.28
3. (11 -17 Dec)	97.71	51.42	89.49	64.13	90.3	65.14	90.78	64.61
4. (18- 24 Dec)	94.14	65.42	87.59	75.85	88.11	77.57	88.4	76.85
5. (25- 31 Dec)	98.14	80.14	91.13	88.9	91.51	89.66	91.7	89.18
6. (01 -7 Jan)	96.85	62	89.37	73.04	89.61	74.09	88.99	73.42
7. (08 - 14 Jan)	97.42	58.85	91.33	72.56	91.56	72.28	91.66	71.47
8. (15 -21Jan)	96.57	68.71	89.71	81.8	89.76	81.75	89.9	81.56
9. (22 -28 Jan)	94.14	66	88.42	76.28	88.47	77.37	87.9	76.75
10. (29 Jan - 4 Feb)	97.57	57.28	88.76	71.56	89.71	70.95	89.76	69.85

3.4 Solar radiation

The measurement of solar radiation depends on the tunnel height and the type of irrigation applied as presented in Table 4. At 2:30 pm the solar radiation in low tunnel which varied from 19614 lux to 43242.66 lux was lower by 16.65% to 37.45% in comparison with open field whose solar radiation varied from 31360 lux to 51885.71 lux during the low tunnel coverage period. Among the tunnel height treatments, in H3 treatment the solar radiation was highest which varied from 19861.66 lux to 43242.66 lux and was higher by 1.26% to 9.01% in comparison with H1 treatment whose solar radiation was lowest which varied from 19614 lux to 39666.33 lux. Among the irrigation treatments, in I5 treatment the solar radiation was highest which varied from 19718.66 lux to 43242.66 lux and was higher by 0.53% to 6.97% in comparison with I1 treatment whose solar radiation was lowest which varied from 19614 lux to 40423.33 lux. For the treatment combination in I5H3 treatment the solar radiation was highest which varied from 19994.66 lux to 43242.66 lux and was higher by 1.94% to 10.97% in comparison with I1H1 treatment whose solar radiation was lowest which varied from 19614 lux to 38966.33 lux. Differences in solar radiation between low tunnels treatments may be due to different surface area of the tunnel and soil moisture distribution. The above mentioned results were in close proximity with those of Siwek *et al* (1994) who reported that on average 70.3% of radiation reached to the plants inside the tunnel.

Table 4 Variation of solar radiation in different heights of low tunnel under various irrigation treatments

Week after covering of crop	Mean Solar Radiation (Lux) (Open Field)	Mean Solar Radiation (Lux)		
		Low Tunnel Heights		
		45cm	60cm	75cm
IW/ CPE= 0.60 (I1)				
1. (27 Nov -3 Dec)	40328.57	26361.66	27647.00	28399.66
2. (04 - 10 Dec)	50471.42	38304.33	40166.33	40423.33
3. (11 -17 Dec)	45514.28	30399.66	31409.00	33032.66
4. (18- 24 Dec)	48614.28	35270.66	37866.33	38147.00
5. (25- 31 Dec)	31360.00	19614.00	19747.33	19866.00
6. (01 -7 Jan)	33342.85	23380.33	23557.00	23904.33
7. (08 - 14 Jan)	44128.57	29647.00	29871.00	30285.00
8. (15 -21Jan)	51885.71	38966.33	39728.33	39842.33
9. (22 -28 Jan)	46342.85	33914.00	34499.66	34694.66
10. (29 Jan - 4 Feb)	51442.85	36556.66	37004.33	37104.66
IW/CPE= 0.75 (I2)				
1. (27 Nov -3 Dec)	40328.57	27218.66	27518.66	28385.33
2. (04 - 10 Dec)	50471.42	39176.00	40361.66	41737.66
3. (11 -17 Dec)	45514.28	31118.66	31823.33	32261.33

4. (18- 24 Dec)	48614.28	36399.66	37899.66	39690.00
5. (25- 31 Dec)	31360.00	19695.00	19733.00	19914.00
6. (01 -7 Jan)	33342.85	23328.33	23666.33	23899.66
7. (08 - 14 Jan)	44128.57	29380.66	29875.66	30161.66
8. (15 -21Jan)	51885.71	38909.00	39666.00	39885.33
9. (22 -28 Jan)	46342.85	34480.33	34628.33	34842.66
10. (29 Jan - 4 Feb)	51442.85	36894.66	37066.33	37290.33
IW/CPE= 0.90 (I3)				
1. (27 Nov -3 Dec)	40328.57	27037.66	27499.33	27818.66
2. (04 - 10 Dec)	50471.42	39533.00	40076.00	41885.00
3. (11 -17 Dec)	45514.28	30652.00	31542.66	32299.66
4. (18- 24 Dec)	48614.28	37647.33	37704.33	37847.33
5. (25- 31 Dec)	31360.00	19485.33	19752.00	19899.66
6. (01 -7 Jan)	33342.85	23213.66	23490.00	23756.66
7. (08 - 14 Jan)	44128.57	29294.66	29842.33	30242.33
8. (15 -21Jan)	51885.71	39299.66	39475.66	39875.66
9. (22 -28 Jan)	46342.85	33833.00	34633.00	34880.66
10. (29 Jan - 4 Feb)	51442.85	36918.66	37014.00	37175.66
Paired Row Planting (I4)				
1. (27 Nov -3 Dec)	40328.57	26814.00	27347.00	27609.00
2. (04 - 10 Dec)	50471.42	39666.33	40433.00	41304.33
3. (11 -17 Dec)	45514.28	30318.66	31856.66	32807.66
4. (18- 24 Dec)	48614.28	35409.33	37928.00	38047.00
5. (25- 31 Dec)	31360.00	19633.00	19761.33	19861.66
6. (01 -7 Jan)	33342.85	23109.00	23433.00	23785.33
7. (08 - 14 Jan)	44128.57	29704.33	29928.33	30190.00
8. (15 -21Jan)	51885.71	39375.66	39599.66	39795.00
9. (22 -28 Jan)	46342.85	33380.33	34490.00	34652.00
10. (29 Jan - 4 Feb)	51442.85	36809.00	37128.33	37290.33
Single Row Planting (I5)				
1. (27 Nov -3 Dec)	40328.57	28123.33	28795.00	29999.66
2. (04 - 10 Dec)	50471.42	39661.66	40609.00	43242.66
3. (11 -17 Dec)	45514.28	32566.00	33209.00	33752.00
4. (18- 24 Dec)	48614.28	38356.66	38766.33	39485.33
5. (25- 31 Dec)	31360.00	19718.66	19832.66	19994.66
6. (01 -7 Jan)	33342.85	23499.33	23604.33	23956.66
7. (08 - 14 Jan)	44128.57	29723.33	29990.00	30528.33
8. (15 -21Jan)	51885.71	39370.66	39933.00	39932.66
9. (22 -28 Jan)	46342.85	34447.00	34618.66	34780.66
10. (29 Jan - 4 Feb)	51442.85	36999.66	37185.33	37352.00

IV. CONCLUSIONS

The mean air temperature was higher in low tunnel than open field by 3.25°C to 3.71°C and 6.38°C to 9.30°C at 7:30 am and 2:30 pm respectively. The mean soil temperature was higher in low tunnel than open field by 1.29°C to 4.76°C and 3.52°C to 6.30°C at 7:30 am and 2:30 pm respectively. The highest air and soil temperature was observed in H2 and I2 treatments in the tunnel height and irrigation treatments respectively. For the combinations I2H2 treatment gave higher air and soil temperature than other treatments combinations.

The highest relative humidity observed at 7:30 am and lowest at 2:30 pm. At 7:30 am, in the low tunnels mean relative humidity lowered by 4.58% to 6.55% than open field but at 2:30 it was higher by 11.52% to 17.57%. The highest relative humidity was observed in H3 and I2 treatments among the tunnel height and irrigation treatments respectively. For the combinations I3H3 gave higher mean relative humidity at 7:30 am but at 2:30 pm combination I2H2 treatment gave higher relative humidity than other treatment combinations.

The mean solar radiation under low tunnels lowered by 16.65% to 37.45% as compared to

open field at 2:30 pm. The highest solar radiation was observed in H3 and I5 treatments in the tunnel height and irrigation treatments respectively. For the combinations, in I5H3 treatment higher mean solar radiation was observed than other treatments combinations.

REFERENCES

- [1]. Anonymous (2008) *Package of Practices for Vegetable Crops*. Pp 20-25. Punjab Agricultural University, Ludhiana.
Chaugule A A, Gutal G B and Kulkarni P V (1990) The feasibility of plastic polyhouse for capsicum crop. *Proc International Agricultural Engineering Conference and Exhibition*. pp 1485-89, Bangkok, Thailand.
- [2]. Gaye M M and Maurer A R (1991) Modified transplant production techniques to increase yield and improve earliness of Brussels sprouts. *J Amer Soc Hort Sci* 116: 210-14.
- [3]. Hemphill D D (1986) Response of muskmelon to three floating row covers. *J Amer Soc Hort Sci* 111: 513-17.
- [4]. Wolfe D W, Albright L D and Wyland J (1989) Modeling row cover effects on microclimate and yield : I. Growth response of tomato and cucumber. *J Amer Soc Hort Sci* 114: 562-68.
- [5]. Lamarrel M, Larean M J, Payette S and Fortin C (1996) Influence of nitrogen fertilization, row covers and cultivars on the production of day neutral strawberry. *Canadian J Soil Sci* 76: 29-36.
- [6]. Libik A and Siwek P (1994) Changes in soil temperature affected by the application of plastic covers in field production of lettuce and water melon. *Acta Hort* 371: 269-73.