Indian Journal of Ecology (2022) 49(6): 2194-2201
DOI: https://doi.org/10.55362/IJE/2022/3809

Manuscript Number: 3809
NAAS Rating: 5.79

Micro-Climatic Variations in Naturally Ventilated Polyhouse Under Cucumber Cultivation

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Abstract: The experiment was carried out to investigate the seasonal variations of climatic parameters inside a naturally ventilated poly house during various stages of cucumber crop growth. Micro-climatic parameters such as ambient temperature (T), relative humidity (RH), light intensity (LI), and carbon dioxide (CO_2) were analyzed on daily basis in the polyhouse's vertical, spatial, and temporal scales. These parameters fluctuated at various stages of crop development. The weekly average maximum temperature of 38.73 °C was recorded in the polyhouse during the afternoon. The weekly average relative humidity (84.40%) was higher in the morning and lower in the afternoon (44.96 %). The light intensity inside the polyhouse was higher in the afternoon (43 klux) and lower in the morning and evening. The variations in CO_2 levels inside the polyhouse at different locations were observed to be very small. Micro-climate changes varied spatially and temporally within the polyhouse during crop growth. For every one-meter increase in height, the vertical gradient of temperature increased by 0.1°C and RH decreased by about 1%.

Keywords: Micro-climate, Cucumber, Naturally ventilated, Temporal & Spatial

The impact of biotic stresses and climatic variations on the crop in the open field is a challenge to overcome. As a result, adopting protected cultivation practices such as polyhouses, shade nets, tunnels, etc. could be an alternative crop cultivation option (Pattnaik and Mohanty 2021). Polyhouse cultivation is the best method for dealing with all biotic and abiotic stresses on plants. In natural ventilation, pressure is created mainly due to temperature and wind differences between the outside and inside of a polyhouse. Natural ventilation occurs as a result of the pressure difference. It also regulates temperature and humidity within the polyhouse and allows for adequate air exchange. Photosynthesis-induced growth requires a number of climatic parameters, including temperature, relative humidity, carbon dioxide (CO_2), and light intensity, all of which influence plant growth at every stage. Specific climatic changes can alter yield, productivity, plant characteristics (quantitative and qualitative), and disease development (Egel and Saha 2015), which is due to the non-uniformity of microclimate inside the polyhouse (Qian et al 2015). A distributed monitoring system will be useful for monitoring and modifying the microclimate within the polyhouse. Knowledge of the effects of climatic factors such as light, temperature, soil, and water on plant growth provides an insight into how to increase crop yield. By monitoring these variables, one can learn more about how each element affects crop growth and how to maximize agricultural productivity.

The polyhouse remains heterogeneous with irregular temperature, relative humidity, CO_2 concentration, and irradiation distributions that require management. A single measurement cannot represent the entire polyhouse or provide complete information on the distribution of temperature and relative humidity (Korner et al 2007). Spatial and temporal variations of climatic parameters within a polyhouse lead to the careful consideration of sensor placement, data processing, and maintenance. The planning of an automated or internet-connected irrigation system will be possible with the knowledge of microclimatic fluctuations within the polyhouse. This allows the identification of ideal sensor locations as well as the calculation of the number of sensors required for accurate system operation and maintenance. The primary goal of this research is to detect and analyse spatial and temporal variations in climatic parameters inside a naturally ventilated polyhouse used for cucumber cultivation in a subtropical climate, as well as to investigate the possibility of detecting difficult situations for the plants and developing environmental control approaches for better micro-climate management.

MATERIAL AND METHODS

Study area: The current study was carried out in a naturally ventilated ridge-vent polyhouse at the ICAR-Central Institute of Agricultural Engineering in Bhopal (23.31° N, 77.40° E). Bhopal's climate is classified as sub-humid. Winter temperatures range from 1°C to a maximum of 25°C, while summer temperatures range from 22°C to 48°C. The average annual rainfall is 1160 mm. The soil in Bhopal is categorized as vertisols.

Description of polyhouse: In cucumber cultivation, a 375 m^2 naturally ventilated polyhouse with dimensions of 25m (L) × 15m (W)× 6m (H) was used to monitor microclimate parameters. The polyhouse cladding material is a 200μ thick translucent polyfilm with an 80 percent diffusivity. Rollable curtains on all four sides of the polyhouse were used to control micro temperature. Insect-proof nylon nets with a mesh size of 40 were used as side curtains to allow for natural airflow while protecting the plants from insect/pest entry. Hundred percent evapotranspiration (ET) based irrigation was given to the crop by using a low-pressure inline drip irrigation system with a discharge rate of 2 lph was used. 24-day-old hybrid cucumber (KCUH-10) seedlings were transplanted in a randomized block design.

Methodology: Temperature and relative humidity were measured using a hygrometer (Make: Testo, Model:623). The instrument had relative humidity measuring range of 0 - 100 %. The CO_2 was measured using a portable indoor air monitor (Make: Rotronic, Model: CP11) with a range of 0-5000 ppm. With a 3 % accuracy, a light meter (Make: Ideal, Model: 61-686) was used to measure light intensity up to 200,000 lux. The variation of micro-climatic parameters such as temperature, relative humidity, light intensity, and carbon dioxide was observed for a month before crop sowing and three months during crop cultivation. These parameters were recorded daily at 8:00 a.m., 1:00 p.m., and 4:30 p.m. (IST) and at nine different locations within the polyhouse at three different heights, namely ground level (GL), one meter, and two meters above the GL. Figure 1 depicts the layout of these locations and heights. For the meteorological weeks of July

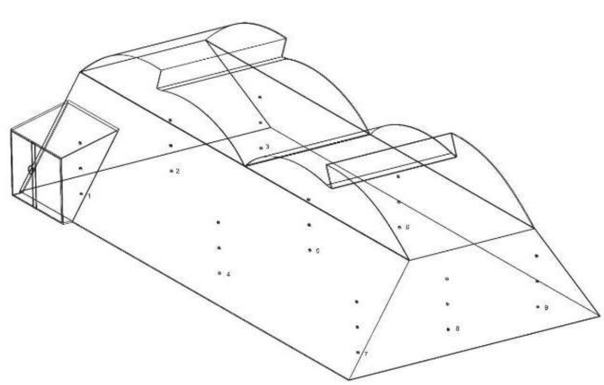

Fig. 1. Layout of the polyhouse under experiment

to September, the average weekly temperature, relative humidity, carbon dioxide, and light intensity were assessed inside a naturally ventilated polyhouse at various heights (ground level, 1m, 2m above ground) and times of day (8 am, 1pm, 4:30 pm). The weekly average weather parameters inside and outside the polyhouse were investigated for various weeks during plant growth. At monthly intervals, the spatial and temporal variability of temperature and relative humidity was examined for nine locations. The following metrics were used to investigate these variations.

Maximum average difference (MAD): The maximum average difference of monthly average values was calculated by using

$$MAD = (V_m)_{max} - (V_m)_{min}$$

Mean relative deviation (MRD): The mean relative deviation (MRD) of the monthly average values is calculated as follows.

$$MRD = \frac{\sum_{i=1}^{N} |V_i - V_m|}{N.V_m}$$

Where, N – Number of measurements of a particular variable, V_i – The ith measurement, V_m – Average value of all N measurements.

The first two metrics depict the average magnitude of measurement variability, whereas MRD is a uniformity metric, with lower values indicating greater uniformity.

RESULTS AND DISCUSSION

Ambient temperature: The weekly average temperature in the polyhouse during the crop period was be highest (38.73 °C) in the afternoon of the 39th week, followed by the afternoon of the 29th week (36.90 °C), and lowest (28.15 °C) in the 30th meteorological week. Higher temperatures were observed in the afternoon, which might be due to short-wave radiation trapping in the polyhouse under partially closed conditions. A temperature increase of 0.1 °C was observed with every 1 m increase in height at different locations of the polyhouse, which is similar to the findings of earlier researchers (Soni et al 2005, Suay et al 2008, Singh et al 2017). The temperature was increased along the length and width of a polyhouse. A similar pattern was observed for temperature variations when no crop was present inside the polyhouse (Fig. 2)

Relative humidity: The polyhouse had the lowest relative humidity in the afternoon (1 pm) during the entire crop growing period (Fig. 2). In polyhouse, relative humidity was highest (84.4%) in the morning of the 37th week, followed 34th week, and lowest (65.7%) in the 29th week. The afternoon relative humidity reached maximum (64.7 %) in the 37th week

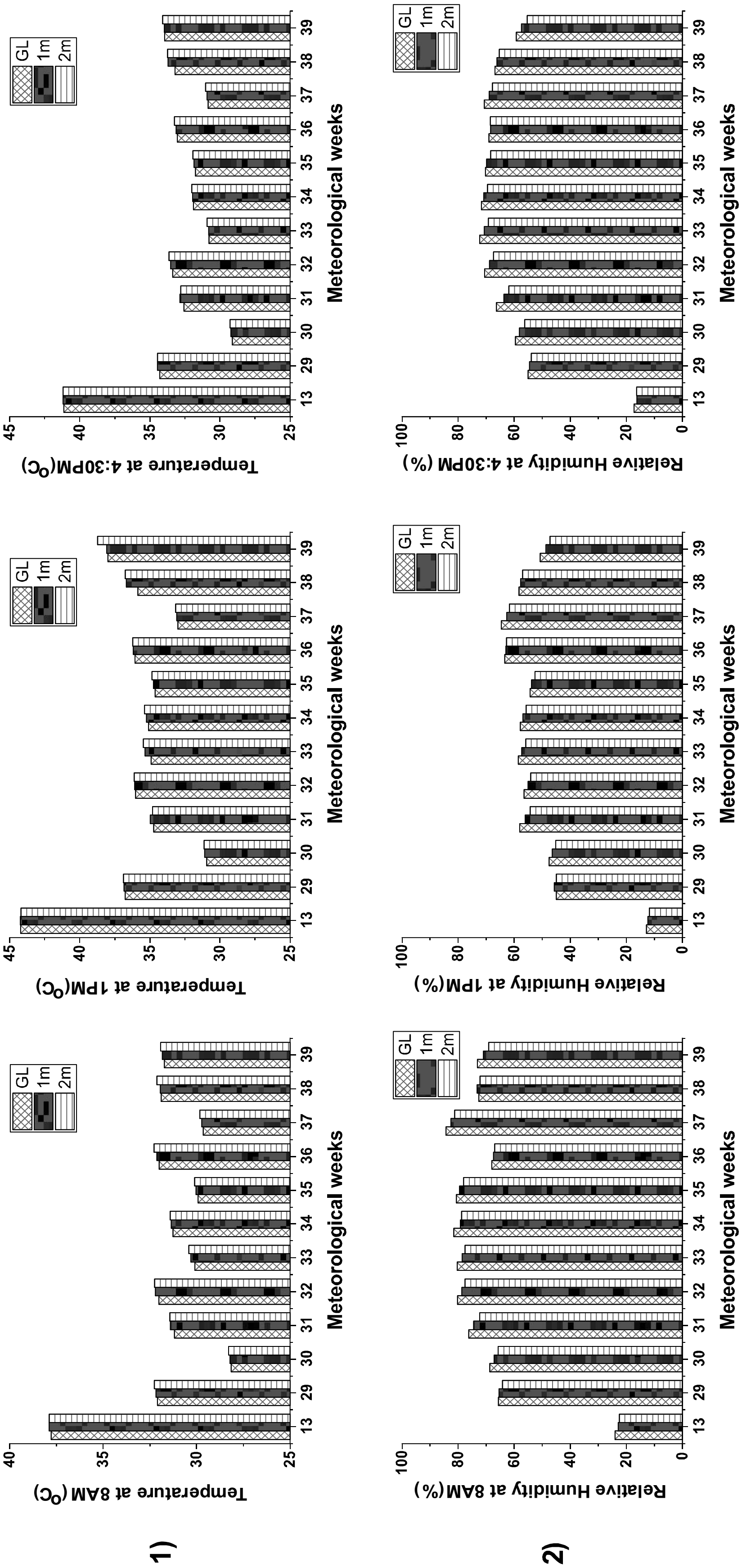

Fig. 2. Weekly average 1) temperature 2) relative humidity 3) light intensity 4) carbon dioxide at 8:00 AM b) 1:00 PM, c) 4:30 PM at different heights

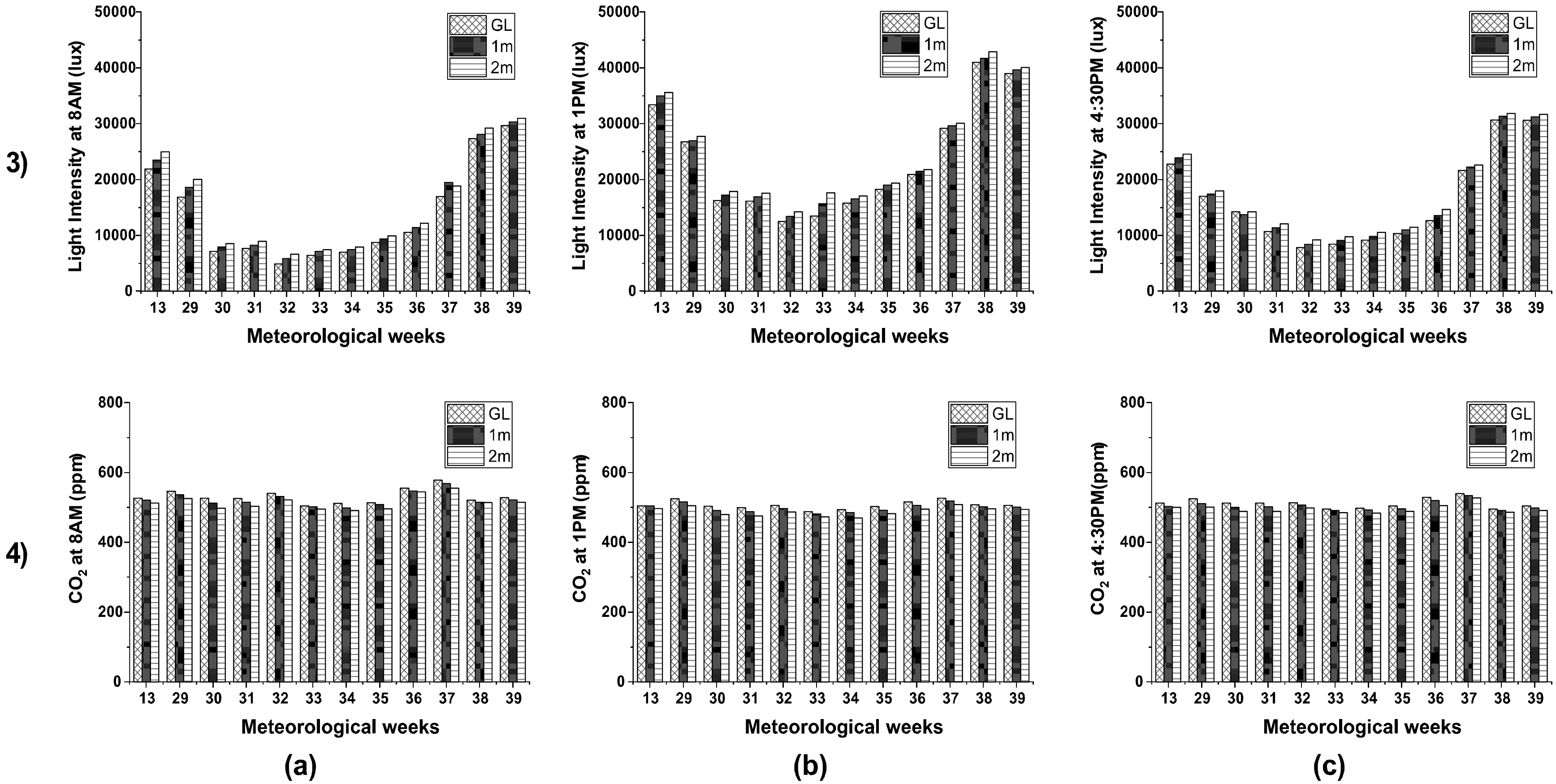

Fig. 2. Weekly average 1) temperature 2) relative humidity 3) light intensity 4) carbon dioxide at 8:00 AM b) 1:00 PM, c) 4:30 PM at different heights

and its minimum (45 %) in the 29th week. The findings were in accordance with Zorzeto et al. (2014). The relative humidity drops by 1% for every 1m increase in height which may be due to the increased temperature. The current findings revealed that RH ranged between 45 and 84.4 % during the crop period in which the plant growth was found to be optimum which was also similar with Deogirikar et al (2005).

Light intensity: During the 38th meteorological week, the weekly mean light intensity in the polyhouse peaked at around 43 klux in the afternoon, then fell to 40 klux in the 39th meteorological week. Morning light intensity reached a peak of 31 klux in the 39th week and dropped to 5 klux in the 32nd week. The 38th week had the highest evening light intensity (32 klux) and the 32nd week had the lowest (8 klux) (Fig. 2). Umesha et al (2011) observed similar results where light intensity was low in the morning and evening hours. The intensity of the light increased with height i.e for every 1 m increase in height light intensity increased by about 1000 lux. From morning to evening, the light intensity was increased along the length of the polyhouse i.e. from east to west, as well as across the width of the polyhouse i.e. from north to south. Crop growth and yield were found to be improved as a result of the light intensity fluctuations.

Carbon dioxide: The 37th week had the highest morning weekly average CO_2 (570 ppm), followed by the 36th week (554 ppm). During the afternoon, CO_2 levels were found to be lower (470 ppm) in the 34th week because of the higher temperatures, low relative humidity, and adequate light which might have boosted photosynthesis causing more CO_2 uptake. Because plants release CO_2 during the night as a result of respiration, the CO_2 levels in the polyhouse were highest in the morning. The lack of solar radiation and the use of UV stabilized sheets reduce the amount of CO_2 escaping from the polyhouse throughout the night and less photosynthesis in the early morning. This effect lasted only an hour after sunrise because the polyhouse was naturally ventilated. CO_2 levels decreased by 10 ppm for every 1 m of height when the crop was grown in the polyhouse (Fig. 2). Jerszurki et al (2021)observed similar trend of CO_2 reduction from the bottom to the plant canopy's top. The results showed that CO_2 levels varied between 470 and 570 ppm, which is the optimal range for crop growth (Xu et al. 2015) and that no CO_2 supplementation was required. The four stages of plant development followed a similar pattern.

Spatial variability of temperature and relative humidity: The largest temperature heterogeneity occurred during the afternoon in September (maximum difference of 2.4°C with a 0.72 standard deviation of average temperatures between the nine locations and an MRD of 0.01), followed by the morning in July (maximum difference of 2.16°C with a 0.72 standard deviation of average temperatures between the nine locations and an MRD of 0.01) (Table 1). The temperature variations in the polyhouse could be caused by the opening of the curtains or the orientation of the polyhouse, or they could be caused by unexpected changes in the weather during the experimental period. Other researchers (Jerszurki et al 2021) found similar or even higher air temperature differences, indicating that the polyhouse's natural ventilation system worked well. The corresponding values were considerably lower in the mornings of September and the mornings, afternoons, and evenings of the remaining months (a maximum average temperature difference of approximately 1.5°C); thus, variability during these periods was much smaller. During July and August, the greatest spatial variation in relative humidity (Table 2) occurred (maximum differences of 9.99 % and 8.99 %, and MRD around 0.04). The findings are similar to those of Tzounis et al. (2015) and Zorzeto et al. (2014). The smallest differences occurred in the afternoons during March (maximum difference of 1.94 %and MRD around 0.04).This may be due to the absence of a crop within the polyhouse. During this month, relative humidity variation appeared to be mainly distributed along the polyhouse longer (north-south) axis. In the afternoons and evenings, relative humidity measurements were fairly consistent (in March, July, August, and September). Because there was no airflow inside the polyhouse at night, there were significant differences in the morning compared to the afternoon and night. Temperature and relative humidity distributions inside the polyhouse are influenced by the intensity of light in relation to the height above the ground surface, i.e. when the light intensity is high, the highest humidity and temperature gradients occur. Changes in microclimate have a positive impact on cucumber growth and yield characteristics in polyhouses.

Comparison of weather parameters of inside and outside of polyhouse: During the crop period, the weekly average ambient temperature at 1 p.m. ranged from 31.06 °C to 38.27 °C inside the polyhouse and from 31.53 °C to 39.40 °C in open fields (Fig. 3). The findings are similar to those of Thipe et al (2018). At 1 p.m., the average weekly relative humidity inside the polyhouse ranged from 45.2 % to 63 %, while outside in the open field, it ranged from 50.6 to 62.6 % (Fig. 3). Under both climatic conditions, relative humidity displayed a more or less inverse relationship with temperature. In contrast to the temperature pattern, relative humidity in the polyhouse followed the inverse pattern as that of ambient temperature, i.e., it was lower in the polyhouse than in the open field at the beginning and higher or nearly similar in the later stages. The weekly average relative humidity difference within and outside the protected structure

Table 1. Average temperature and standard deviation of each location in the morning, afternoon and evening for the different months

Location of reading	March			July			August			September		
	Morning	Noon	Evening	Morning	Noon	Evening	Morning	Noon	Evening	Morning	Noon	Evening
1	36.78±1.36	44.01±3.74	40.7±3.20	28.98±2.42	33.23±3.78	31.09±3.65	30.52±1.32	34.43±0.93	31.94±1.20	30.21±1.98	35.10±2.76	31.96±1.97
2	37.47±1.39	44.41±2.97	40.80±2.75	29.43±2.88	33.65±3.86	31.57±3.75	31.05±1.44	35.00±1.07	32.43±1.24	30.73±2.03	35.60±2.87	32.32±1.99
3	37.81±1.27	44.82±2.73	41.00±2.12	30.06±3.36	33.96±3.99	31.91±3.93	31.30±1.46	35.38±1.00	32.59±1.15	31.10±2.08	35.89±2.88	32.69±1.93
4	38.49±1.39	44.61±2.08	40.58±1.65	30.20±3.66	34.11±3.95	31.96±3.97	31.00±1.47	35.04±1.15	32.48±1.28	30.98±2.03	34.10±7.77	31.50±4.89
5	38.48±1.59	44.09±2.17	40.57±1.76	30.65±3.86	34.40±4.04	32.32±4.04	31.20±1.44	35.18±0.92	32.78±1.19	31.41±1.92	35.79±2.93	32.80±1.91
6	38.51±1.24	44.30±1.91	40.73±2.06	30.86±3.82	34.56±4.08	32.28±3.78	31.31±1.35	35.37±0.88	32.88±1.15	31.63±2.01	36.07±2.93	33.05±2.00
7	37.80±1.15	43.71±1.57	40.50±1.99	30.75±3.99	34.55±4.13	32.08±3.91	31.17±1.49	35.45±1.11	32.67±1.16	31.60±2.10	36.01± 3.0	33.09±1.97
8	37.57±1.20	43.70±1.44	40.51±1.71	31.06±4.26	34.40±3.95	32.36±4.17	31.47±1.49	35.40±1.17	32.83±1.15	31.94±2.22	36.26±3.08	33.35±2.12
9	37.77±1.28	44.31±1.51	40.56±v2.05	31.15±4..36	34.65±3.99	32.53±4.39	31.54±1.50	35.70±0.96	33.13±1.20	32.17±2.32	36.53±3.10	33.56±2.26
MD	1.74	1.12	0.50	2.16	1.41	1.45	1.01	1.28	1.19	1.96	2.42	2.06
ASD	0.57	0.38	0.16	0.75	0.48	0.45	0.30	0.37	0.34	0.62	0.72	0.67
AMRD	0.01	0.01	0.003	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02

Table 2. Average relative humidity and standard deviation of each location in the morning, afternoon and evening for the different months

Location of reading	March			July			August			September		
	Morning	Noon	Evening	Morning	Noon	Evening	Morning	Noon	Evening	Morning	Noon	Evening
1	27.20±3.55	13.25±1.31	16.75±3.38	73.06±7.13	49.77±6.59	60.25±6.23	81.37±3.67	61.62±2.15	72.59±6.28	77.55±9.03	61.85±9.40	68.32±8.73
2	24.53±3.83	12.58±1.37	16.88±2.24	70.42±6.84	48.79±6.67	58.08±7.50	79.90 ±3.32	59.78±2.99	70.95±6.22	75.79±8.22	60.29±9.68	67.30±8.63
3	24.43±3.52	12.12±0.70	15.69±1.40	68.32±7.30	46.81±6.55	57.14±6.95	78.63±±4.22	57.90±1.95	69.33±5.82	74.68±9.63	59.30±9.55	66.48±8.61
4	21.60±4.05	11.31±1.08	15.48±2.06	64.83±9.20	45.09±5.70	55.75±7.74	75.66±6..04	56.34±1.92	68.20±5.83	73.40±8.44	58.70±9.16	65.63±8.38
5	21.35±4.19	11.97±1.47	16.49±3.40	63.65±9.40	45.12±6.61	54.85±7.74	75.62± 4.62	57.17±2.08	66.783±6.53	72.86±8.52	57.38±9.13	64.88±8.40
6	22.38±4.45	11.90±1.12	17.46±4.16	64.13±8.80	43.94±7.10	54.44±7.54	75.66±2.27	54.40±2.49	65.84±6.90	73.50±8.53	56.97±9.09	63.91±8.19
7	22.25±4.14	12.63±1.56	16.79±1.66	63.07±8.84	43.54±6.26	55.38±7.87	76.12±4.14	52.63±3.30	66.42±7.07	71.79±9.92	56.24±9.73	64.19±9.02
8	22.59±4.79	12.78±1.49	17.66±3.78	64.07±10.4	44.99±6.30	55.23±8.96	76.72±4.89	53.06±3.85	65.97±6.69	71.00±9.70	56.74±10.32	63.80±9.51
9	22.46±4.19	12.64±0.99	16.50±2.64	63.32±9.99	44.19±4.86	53.96±7.82	76.45±5.62	53.21±	65.05±6.82	71.20±9.28	56.16±10.91	63.63±9.60
MD	5.86	1.94	2.18	9.99	6.23	6.29	5.75	8.99	7.54	6.55	5.69	4.69
ASD	1.86	0.58	0.72	3.62	2.19	2.20	2.11	3.18	2.57	2.18	1.99	1.69
AMRD	0.06	0.04	0.03	0.04	0.03	0.02	0.02	0.04	0.03	0.02	0.03	0.03

Note: Location is indicated by *x-y* coordinates: *x& y* indicates the polyhouse length and width showed in the Fig. 1 for both Table 1 & 2

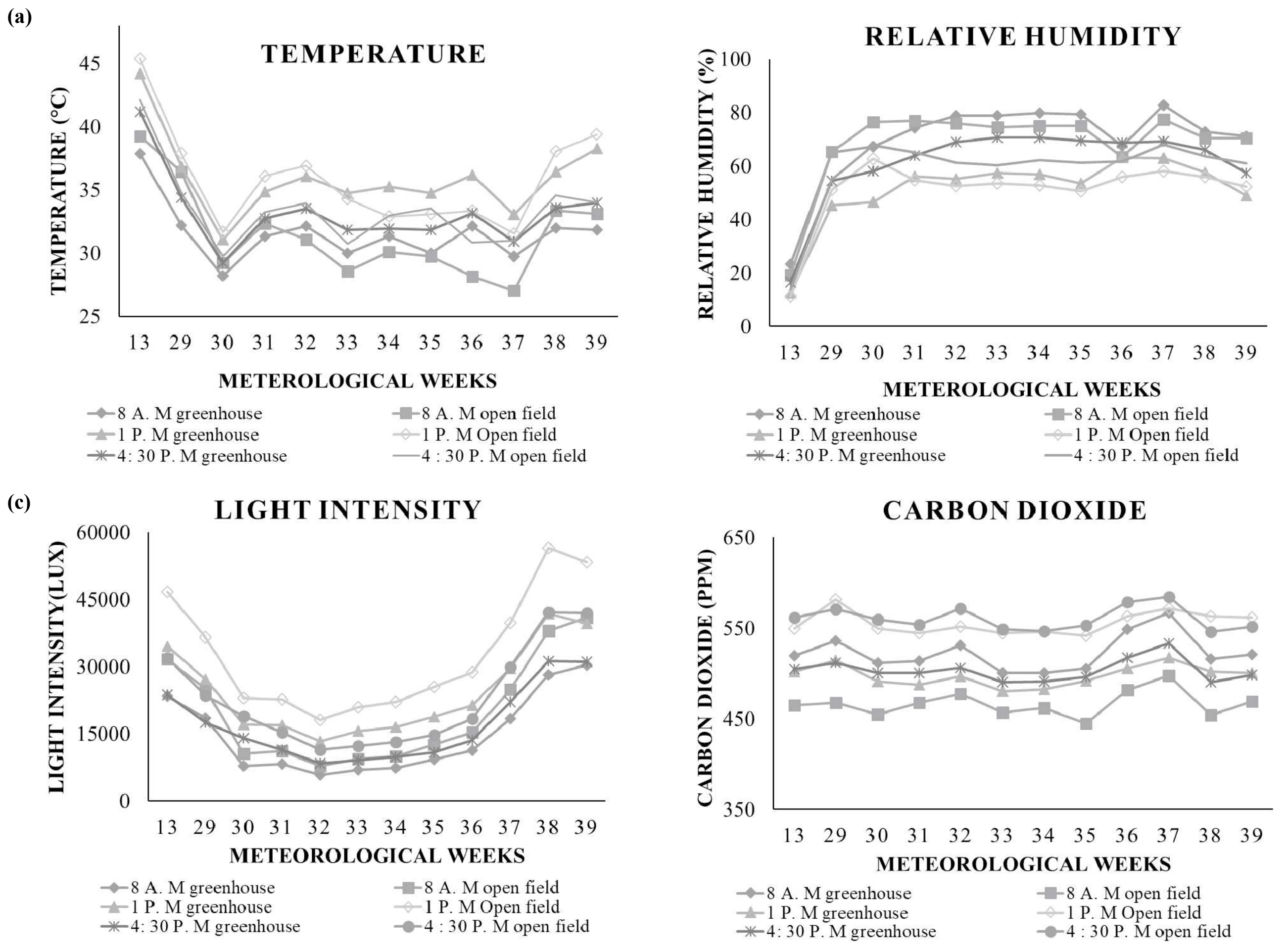

Fig. 3. Weekly average a) temperature b) relative humidity c) light intensity d) carbon dioxide in polyhouse and open field

ranged from 1.5 % to 5%. Omid and Shafaei. (2005), Ahmed et al. (2011) and Kumari et al.(2015) showed similar variations .

Inside the polyhouse, the weekly average light intensity at 1 p.m. ranged from 13 klux to 42 klux, while outside in the open field, it ranged from 18 klux to 56 klux (Fig. 3) .Plants within the polyhouse received 35% less light intensity than those outside, resulting in lower evapotranspiration. Because of the type of cover sheet used, the receiving amount of light intensity within the polyhouse was reduced. Inside the polyhouse, weekly average carbon dioxide levels were 20% lower at 1 p.m. than outside (Fig. 3). CO_2 levels within the polyhouse ranged from 480 to 518 ppm, whereas in the open field, CO_2 levels ranged from 582 to 542 ppm. The CO_2 concentration results are similar to Boulard et al (2017).

Vegetative and yield parameters of the crop: The average crop production was 57.81 t/ha under evapotranspiration (ET) based irrigation. At the final stage of the crop average height of the plant was 2.1m with 65 leaves with a 3cm girth. The average weight of the fruit was 279.3 g with average length and width of the fruit were 21.2 and 6.53cm, respectively. The fruits TSS was 5 brix. The yield and vegetative parameters were found to be satisfactory under these micro-climatic conditions (Rahil and Quanadillo 2015).

CONCLUSIONS

The goal of the experiment was to look at the seasonal variations of micro-climatic parameters in a naturally ventilated polyhouse during the cucumber crop's growth phases. Daily micro-climatic parameter changes, such as temperature, relative humidity, light intensity, and carbon dioxide, were measured. Temperature raised by 0.1 °C, RH reduced by 1%, LI increased by around 1000 lux, and CO_2 levels decreased by 10 ppm for every 1 m increase in height. Under plant growth, changes in temperature and relative humidity varied spatially and temporally along and across the polyhouse which will influence the irrigation scheduling. The average monthly temperature and relative humidity changes were 2.4°C and 9.9%, respectively, with the highest variability in September and July. A similar trend of spatial variability and vertical gradient was seen when no crop was grown inside the polyhouse. The current study revealed that the variations of micro-climatic parameters are negligible in the vertical direction, whereas horizontal variations are noticeable. Finding these variances will aid in finding the best sensor installation location for precise irrigation scheduling. Choosing the right place for sensor installation will allow for accurate real-time interpretation of operational system characteristics. Plants can grow properly in the polyhouse without being stressed during their development because of the ideal environment. Based on the current data, it can be stated that in a naturally ventilated polyhouse in a subtropical climate, putting a sensor for precise irrigation should be done in the centre of the polyhouse. All of these findings can be used to create more precise and efficient irrigation and environmental control systems. This results in highly uniform plant development circumstances, thus enhancing the quantity and quality of produce.

ACKNOWLEDGEMENT

The authors are grateful to the ICAR-CIAE, Bhopal as well as IARI-New Delhi for funding.

AUTHORS' CONTRIBUTIONS

Lakshmi Poojitha Challa, Ph. D student, conceptualized, carried out the experimental work, and prepared the manuscript, data curation, and written-original draft preparation. C.D Singh: Chairperson, Advisory committee, conceptualization, methodology, reviewing, and editing. K.V Ramana Rao, extended field facilities, reviewed and edited the manuscript.

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Received 14 July, 2022; Accepted 27 November, 2022