Lesser Chamber Effect inside Open Top Chambers Provides Near-Natural Microenvironment for CO_2 Enrichment Studies in an Alpine Region of India

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Abstract: Open top chambers (OTCs) were designed and established for the first time in an Indian alpine territory for revealing the effects of realistic elevated carbon dioxide (CO_2) concentrations on growth forms of alpine region of India in natural conditions. Comparison of the microclimatic parameters which affect the growth and physiology of alpine plants was done in three conditions viz. open field, polyhouse and OTCs to trace out the chamber effect inside OTCs. Present communication reveals the efficiency of Open Top Chambers for climate simulation techniques in Indian alpine region. Simple designing and construction of open top chambers make them the most probable method to be used for long-term elevated CO_2 revelation of alpine ecosystems. The operation of the system was satisfactory during the first growing season and repeatability of the gas treatments can be regarded well in this low cost exposure system. [Journal of American Science 2010;6(3):109-117]. (ISSN: 1545-1003)

Keywords: Climate change; Open Top Chambers; CO_2 enrichment; Alpine region; Garhwal Himalaya

1. Introduction

The Himalaya represents the largest mountain chain covering approximately 8 million km^2 in surface area and occupying a length of approximately 3000 km. Owing to enormous size and elevation, the Himalaya represents a complete transaction from tropical to temperate conditions despite its location near the tropics. Out of 7000 endemic species of plants found in India, over 3000 grow in the Himalayan region (Chatterjee, 1980). Whereas alpine environment is exceptionally variable and as a result of decreasing atmospheric pressure, the partial pressures of O_2 and CO_2 in the atmosphere fall with altitude. For overcoming all these adverse climatic factors, the alpine plants adapt themselves morphologically as well as physiologically. The prediction of global climate change has extracted a wide multiplicity of research in the past 25 years. One of the aspects that have received liberal attention is prickly rise in the atmospheric CO_2 concentration and the effects thereof on plant growth and functioning (Ward and Strain, 1999; Körner, 2001; Bazzaz and Catovsky, 2002). Changes in ecosystem carbon and water balance have been predicted to result from increased temperature and from the direct effect of rising CO_2 on photosynthesis and evapotranspiration. But ecosystem retorted for elevated CO_2 cannot be forecasted without field experiments, because the interface of elevated CO_2 with other environmental factors particularly temperature, nutrient and water supply is complex chiefly in alpine region. Such field experiments will essentially be enduring and the intrinsic inconsistency in native ecosystems experiments will require many replications. All experimental methods for exposing plants to altered atmospheric composition also alter the microenvironment which means that the need to understand the effect of the chamber microenvironment on the experimental results increases with the complexity of the questions concentrated on.

An immense work has already been done on the alpine communities of Garhwal (Semwal et al, 1981; Ram and Arya, 1991; Nautiyal et al, 1997) but to the best of our knowledge, research using climate simulation experiments in alpine region of India is still lacking. A simple hypothesis on climate change research needed in alpine region of India has been forecasted by some workers (Chaturvedi et al, 2007). Research investigations for climate change on plants have given three possible equipments, namely open-field CO_2 enrichment (FACE) systems (Mcleod and Baker, 1988), fully-enclosed chambers (Lucas et al, 1987) and Open top chambers (Heagle et al, 1973). The three techniques, namely FACE, OTCs and fully-enclosed chambers, have different performance/cost benefits and cannot be compared directly. The research reported in this communication identifies the sensitivity of OTCs microclimate, capabilities and limitations of open top chambers for elevated CO_2 studies and to demonstrate the potential applications in context to alpine regions of India.

2. Materials and methods

2.1 Site description

The selected site for the establishment of Open top chambers is the alpine field station (Figure1) of High Altitude Plant Physiology Research Centre of H.N.B. Garhwal University, Srinagar, Garhwal, situated at Tungnath (30^0 14'N Latitude and 79^0 13'E longitude at an altitude of 3600m above MSL). The heavy snowfall, frost, high wind velocity, low oxygen and carbon dioxide concentration have a great impact on the habit of plant species including their growth forms, life form and life cycle pattern. The site is also famous as treasury of diverse alpine medicinal plants.

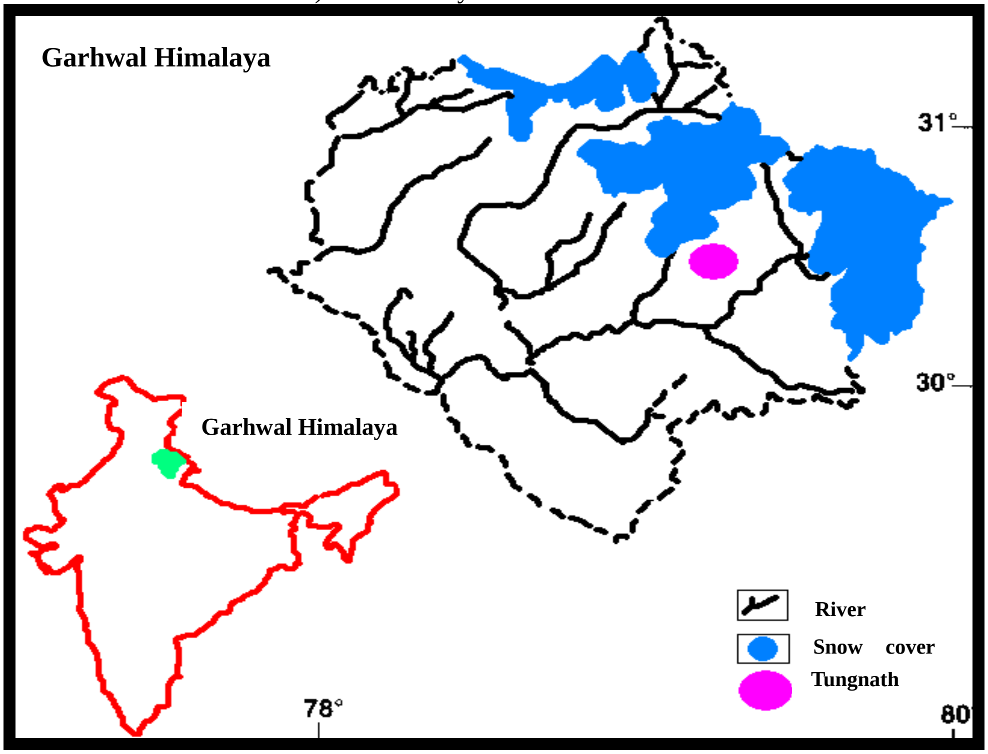

Figure1. Location map of the study site

2.2 Indian Scenario regarding CO_2 enrichment facilities

For studying the response of crop plants under elevated CO_2 conditions in India design (3 m diameter x 3 m height) used for OTCs was according to South Asian climatic conditions (Uprety, 1998). These Chambers with frustum are being used by South Asian CO_2 research network for multi country multidisciplinary CO_2 crop response studies.

Besides Open Top Chambers, a new advanced "Free Air CO_2 Enrichment Technique" also provides a technology for enriching larger areas of vegetation with CO_2 for extended areas of vegetation with CO_2 for extended period of time at lesser cost per unit area than any other known technique. FACE concept of producing CO_2 concentration gradient experiments are done with promising results (Uprety et al, 2007).

2.3 Alpine scenario for CO_2 enrichment facilities in India

An alpine region due to its harsher climate is much tougher region to conduct climate change experiments. Thorny transportation and hard conditions throughout the season makes it difficult for designing the experiments soon.

Therefore, we have designed the Open Top Chambers that can survive in harsher conditions of alpine. We have modified the design for alpine region as the vertically 3 m high OTCs can't withstand the higher wind velocity of alpine. So, in this design the OTCs of 3 m diam. and 2.4 m in height are installed at the alpine region of Tungnath.

2.4 Specifications of OTCs used for CO_2 enrichment in alpine region of India

Structure of OTC having a size of 3m diameter x 2.4 m height. OTCs are made of square G.I. pipe 38mm x 38mm ± 1 mm with aluminium strips, leak proof auto closing doors. Complete structure fixed at 2' below ground on a cement concrete platform up to 3' from earth surface. Covering of OTCs is UV stabilized transparent low density polythene film 200 GSM with special distribution system. In CO_2 supply control solenoid valve and pressure gauge with timer were fitted within the air blower (along with connecting duct covered with polythene sheet). Chambers are equipped with a frustum at the top to deflect air and prevent dilution of the CO_2 concentration within the chamber. A cylindrical double walled plenum around the base for uniform CO_2 circulation. Inner side of the plenum was perforated with numerous gas outlets (Figure 2). Distribution of CO_2 was done using fan 12" blower. Blowers also helped in maintaining inside air temperature closure to that of outside ambient atmosphere. Double stage double meter gas regulator of brass fitted with stainless steel diaphragm suitable for CO_2 supply was used. CO_2 gas was supplied through this whole system using CO_2 cylinders of 20 Kg gas capacities fitted in a row.

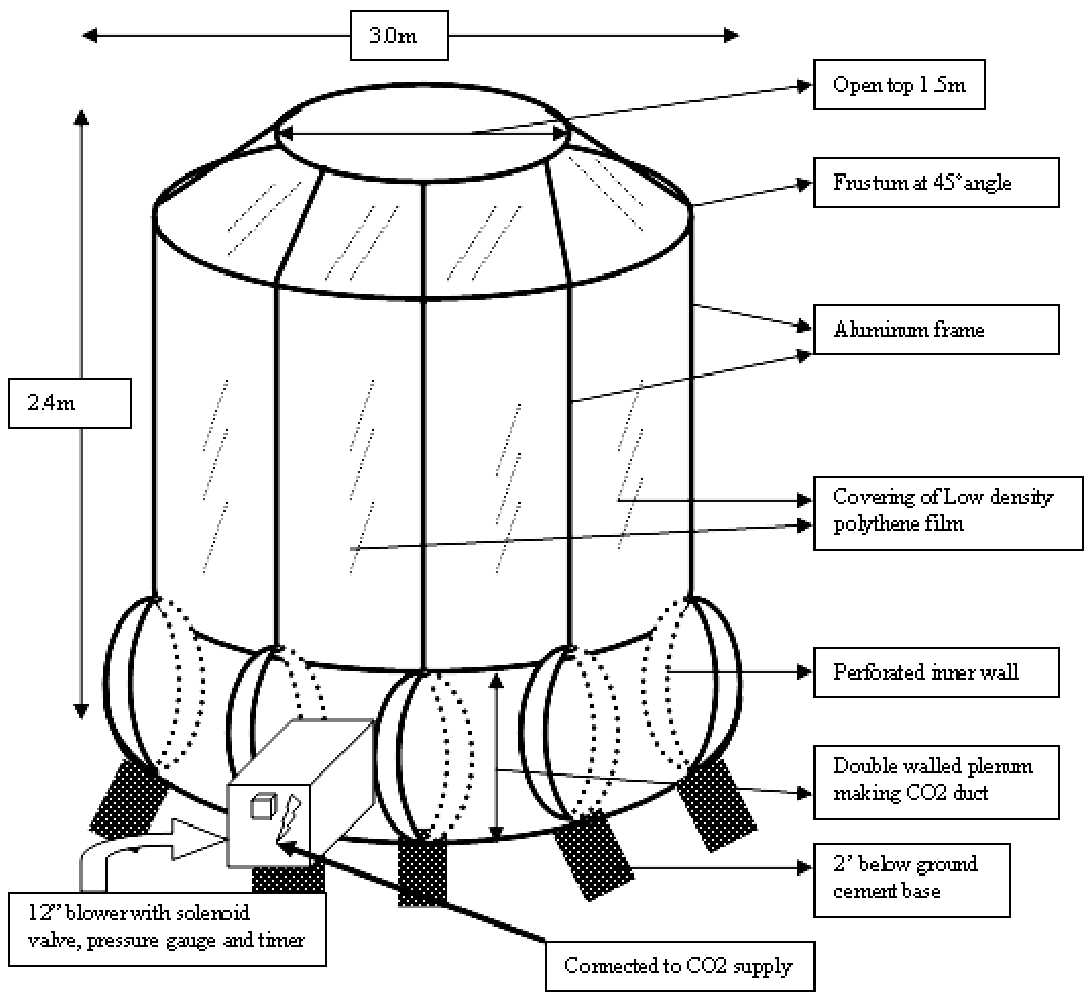

Figure2. Open top chamber design for alpine region of India

Open Top Chamber established at Tungnath (3600m above MSL), an alpine region of Garhwal Himalaya. (Photo credit: Ashish K.Chaturvedi)

2.5 CO_2 treatments and observations

In two installed Open Top Chambers (OTCs) one was treated as Control Open Top Chamber (COTC) in which ambient air was circulated and monitored whereas in other Open Top Chamber (EOTC) elevated CO_2 (600-700 µmolmol^{-1}) concentration was given. The pure carbon dioxide was supplied using 20 Kg gas capacity carbon dioxide cylinders. Air circulation was done to the chamber via air blowers located near the base of the chamber, and CO_2 was added to the incoming air maintaining a positive air pressure and flow within the chambers.

CO_2 and PAR (Photosynthetically active radiation) measurements were made by a portable Infra Red Gas Analyzer, IRGA (ADC, LCPro+ Hoddesdon, UK). Daily meteorological observations for air temperature, Humidity % and Soil temperature (15 cm Depth) inside OTCs, Polyhouse and in open conditions were done to compare the microclimatological variations. Monthly variations in CO_2 Concentration inside OTCs, Polyhouse and open conditions were recorded throughout the season from May 2008 to September 2008. For studying the diurnal variations, measurements were performed for cloudless days in the last week of May 2008. Data collected every two hours from 8:00 to 18:00 solar time were analyzed statistically.

3. Results and discussion

3.1 Variation in CO_2 concentration

A representative time course of CO_2 concentration in open and polyhouse condition is shown in Figures 3 whereas Figure 4 depicted the diurnal variation in COTC (control OTC) having ambient CO_2 and in EOTC (elevated open top chambers) having elevated CO_2. Results exemplify the natural diurnal variability of CO_2 concentrations inside polyhouse, open and in OTCs and the capability of the system to maintain separation between the ambient and elevated treatments. CO_2 concentrations vary at a single monitoring location and between monitoring locations within a chamber (Drake et al, 1989). But varying CO_2 concentration inside Open top chambers in comparison to polyhouse was attributed to the storming of air surrounding the chamber and was relative to outside wind speed. The enhancement in control achieved in the chamber with frustum confirms the importance of this design characteristic. Control of CO_2 concentration can be achieved without automated CO_2 delivery (Drake et al, 1989; Rogers et al, 1983). Little advantage in scheming spatial variations in CO_2 concentrations is probably to be achieved by automating CO_2 control because these variations are mainly determined by outside wind velocity and interior variations in turbulence. Figure 8 shows the monthly variation in CO_2 concentration in different conditions.

3.2 Temperature differences

Temperature plays an important role in morphophysiology of alpine plants. Keeping this fact in view this is very necessary to see how much variation in temperature occurs inside the OTCs. Air temperature within open top chambers used in studies of crop species are commonly reported to be less than 1°C greater than air temperatures outside the chambers, but in an extensive study of the environment in open top chambers, some workers (Weinstock et al, 1982) found temperature differences of up to 3.7°C. Monthly variation in min/max temperature and air temperatures of OTC, polyhouse and open conditions are shown in Table 1 and 2 respectively. Temperature difference in the OTCs was non significant in all months except in May where on average 2.0^{0}C increased was observed in comparison to polyhouse where the increase in min as well as max temperature was significantly higher. Air temperature differences between Control OTCs (COTC) and elevated OTC (EOTC) were not much affected by CO_2 treatment (Figure5). Temperature differences can be minimized by using a high aeration rate.

3.3 Humidity

Humidity % was slightly higher inside the open top chambers than in open condition but statistically non significant whereas in case of polyhouse a significant increase in humidity was observed throughout the season (Table 3).

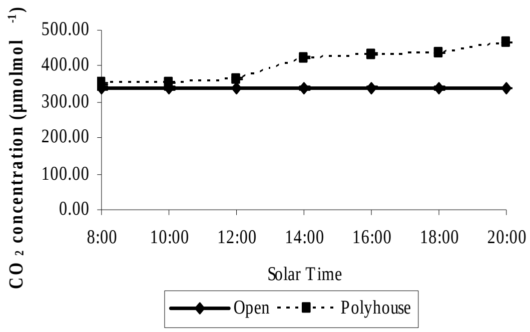

Figure 3. Diurnal Changes of CO_2 concentration in Open and polyhouse conditions

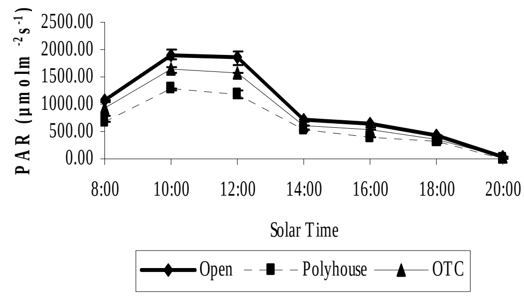

Figure 6. Diurnal variation of PAR in Open Top Chambers, Polyhouse and Open conditions

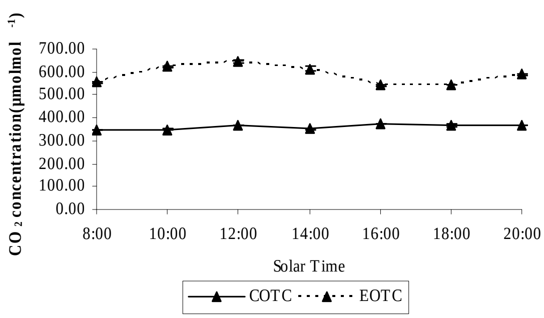

Figure 4. Diurnal Changes of CO_2 concentration inside Open Top Chambers

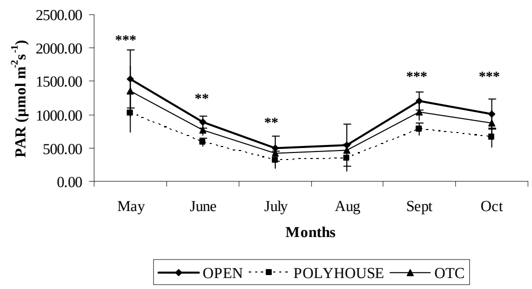

Figure 7. Monthly variation in Photosynthetically Active Radiation (PAR) in Open, Polyhouse and OTC

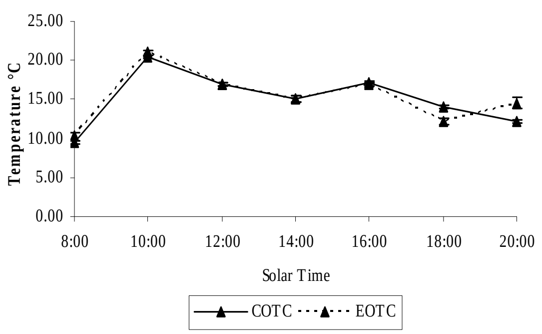

Figure 5. Diurnal changes of temperature inside Open Top Chambers

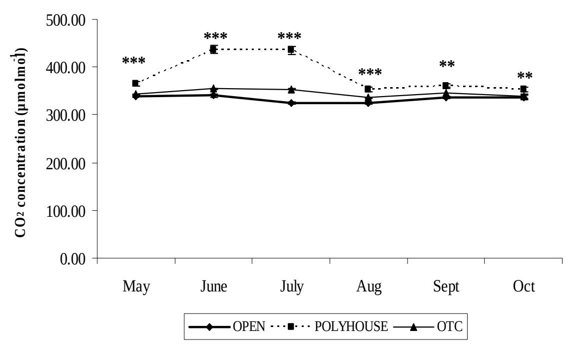

Figure 8. Monthly variation in CO_2 concentration in Open, Polyhouse and OTC

Table 1. Monthly variation in min/max temperature in different conditions

Minimum temperature (^{0}C)	Open	Polyhouse	OTC	P value (LSD)
May	6.27±1.70	11.60±2.46*	8.27±1.64*	<0.001(1.31)
June	8.23±1.68	12.73±3.18*	8.53±1.61	<0.001(1.51)
July	8.93±2.15	11.77±2.67*	9.13±2.40	<0.001(1.61)
August	9.90±1.09	15.87±1.59*	10.53±0.78	<0.001(0.80)
September	6.63±1.33	14.57±1.01*	6.90±1.18	<0.001(0.78)
October	4.23±1.45	9.60±4.86*	4.53±1.41	<0.001(2.02)
Months X Conditions		P<0.001		
Maximum temperature (^{0}C)	**Open**	**Polyhouse**	**OTC**	**P value (LSD)**
May	16.53±3.54	21.07±5.85*	18.70±3.03	<0.001(2.87)
June	20.70±4.68	30.60±5.47*	21.07±1.93	<0.001(2.86)
July	19.83±1.82	30.27±3.83*	20.03±2.41	<0.001(1.87)
August	20.47±1.41	32.80±1.99*	20.83±1.42	<0.001(1.08)
September	18.07±2.21	32.73±4.42*	18.53±2.05	<0.001(2.05)
October	12.67±4.88	26.10±6.08*	11.73±1.28	<0.001(3.03)
Months X Conditions		P<0.001		

*significant

Table 2. Monthly variations in air temperature in different conditions

Solar Time	Conditions	May	June	July	August	September	October	Months X Conditions
	OPEN	11.83±3.13	13.33±2.55	13.43±2.46	12.60±1.92	10.83±2.44	6.70±2.04	
	POLYHOUSE	15.60±4.88*	21.07±5.84*	17.77±3.43*	21.33±3.77*	20.87±3.54*	11.13±1.53*	
	OTC	13.23±3.10	13.47±2.94	13.47±3.13	12.90±1.71	11.13±2.29	7.20±1.92	<0.001
8.00	P Value (LSD)	<0.001(2.53)	<0.001(2.70)	<0.001(2.02)	<0.001(1.75)	<0.001(1.90)	<0.001(1.22)	
	OPEN	17.00±3.63	18.47±6.27	16.53±2.96	14.50±1.53	13.40±2.03	11.87±1.81	
	POLYHOUSE	21.73±3.81*	22.47±3.76*	22.03±3.79*	25.87±4.22*	26.43±5.28*	18.60±2.01*	
	OTC	18.83±3.81	18.97±3.72	17.50±2.60	14.97±1.35	13.77±1.65	12.13±1.50	<0.001
12.00	P Value (LSD)	<0.001(2.49)	<0.01(3.15)	<0.001(2.10)	<0.001(1.80)	<0.001(2.26)	<0.001(1.19)	
	OPEN	15.33±3.27	17.60±7.67	13.20±2.89	14.00±1.86	13.27±3.59	10.73±1.87	
	POLYHOUSE	21.17±3.73*	22.43±3.43*	17.33±4.80*	22.43±3.38*	25.47±6.47*	17.13±1.93*	
	OTC	16.73±3.18	18.10±2.22	14.87±2.21	14.40±1.33	13.97±2.91	11.10±1.49	<0.001
4.00	P Value (LSD)	<0.001(2.27)	<0.001(3.34)	<0.001(2.31)	<0.001(1.57)	<0.001(3.05)	<0.001(1.18)	

*significant

Table 3. Monthly variations in % Humidity in different conditions

Solar Time	Conditions	May	June	July	August	September	October	Months X Conditions
	OPEN	50.20±13.39	70.23±12.09	63.83±13.94	66.33±14.97	65.33±17.65	47.20±11.46	
	POLYHOUSE	72.90±8.97*	78.50±7.20*	73.57±10.51*	70.90±11.46	74.37±6.14	72.43±3.52*	
	OTC	54.60±12.59	70.40±11.76	64.60±12.97	67.87±12.74	67.33±14.82	50.67±9.70	<0.001
8:00	P Value (LSD)	<0.001(7.85)	<0.01(7.04)	<0.01(8.34)	>0.05(8.73)	<0.05(9.15)	<0.001(5.92)	
	OPEN	41.00±12.95	62.73±10.79	56.57±12.51	58.00±12.65	55.20±11.33	44.53±9.12	
	POLYHOUSE	50.93±13.88*	71.03±7.11*	70.47±12.17*	64.90±13.98	64.90±13.98*	50.63±10.47*	
	OTC	45.97±12.73	63.07±10.08	57.03±11.84	59.20±10.93	56.53±10.29	46.53±7.76	>0.05
12:00	P Value (LSD)	<0.05(8.77)	<0.01(6.29)	<0.001(8.09)	>0.05(8.36)	<0.01(7.96)	<0.05(6.10)	
	OPEN	50.10±16.23	60.23±8.86	52.77±14.38	54.80±16.54	53.87±14.66	47.50±11.40	
	POLYHOUSE	60.63±16.77*	67.27±8.14*	68.80±11.66*	61.07±8.81	68.53±9.88*	53.87±14.66	
	OTC	51.13±10.60	60.63±7.99	53.90±13.62	57.50±12.84	55.50±12.21	48.57±10.15	>0.05
4:00	P Value (LSD)	<0.05(9.84)	<0.01(5.54)	<0.001(8.82)	>0.05(8.72)	<0.001(8.25)	>0.05(8.12)	

*significant

Table 4. Monthly variations in soil temperature in different conditions

Solar Time	Conditions	May	June	July	August	September	October	Months X Conditions
	OPEN	11.73±2.03	12.10±2.66	13.50±2.22	13.43±2.37	12.93±1.82	10.30±2.77	
	POLYHOUSE	15.83±2.59*	16.30±2.76*	18.17±2.17*	16.93±2.27*	16.57±1.52*	12.73±3.47*	
	OTC	11.87±2.16	12.23±2.31	13.73±2.02	13.83±2.13	13.00±1.74	10.67±2.56	>0.05
8:00	P Value(LSD)	<0.001(1.51)	<0.001(1.72)	<0.001(1.42)	<0.001(1.50)	<0.001(1.13)	<0.01(1.96)	
	OPEN	14.67±3.46	15.20±3.00	16.13±3.20	16.00±3.14	15.53±3.09	12.13±4.07	
	POLYHOUSE	17.97±2.77*	17.90±3.13*	20.37±3.15*	19.33±2.86*	19.30±1.90*	14.40±3.99	
	OTC	14.80±3.27	15.23±3.00	16.40±2.98	16.67±2.43	15.70±2.91	12.27±3.85	>0.05
12:00	P Value (LSD)	<0.001(2.11)	<0.001(2.02)	<0.001(2.06)	<0.001(1.87)	<0.001(1.78)	>0.05(2.63)	
	OPEN	13.50±3.29	13.30±3.75	11.90±3.10	12.90±1.97	12.60±1.65	11.50±2.83	
	POLYHOUSE	15.90±3.33*	16.50±3.28*	17.13±3.01*	16.27±2.35*	15.90±1.84*	13.13±3.48	
	OTC	13.60±3.12	13.33±3.72	12.07±2.95	13.37±1.30	12.87±1.41	11.77±2.39	<0.05
4:00	P Value (LSD)	<0.01(2.15)	<0.001(2.38)	<0.001(2.00)	<0.001(1.27)	<0.001(1.09)	>0.05(1.95)	

*significant

Table 5. Comparison of diurnal reductions of photosynthetically-active radiation (PAR) through polyhouse and Open Top Chambers

Solar Time	(PAR) Open	(PAR) Polyhouse		(PAR) OTC	
	$\mu mol m^{-2} s^{-1}$	$\mu mol m^{-2} s^{-1}$	% reduction	$\mu mol m^{-2} s^{-1}$	% reduction
8:00	1056.17±13.38	671.75±6.18	36.39	932.60±138.20	11.7
10:00	1908.00±74.26	1272.00±11.53	33.33	1631.75±48.04	14.51
12:00	1840.60±123.25	1172.56±75.06	36.26	1584.39±3.21	13.92
14:00	704.67±18.04	530.67±2.52	24.69	606.15±5.51	13.98
16:00	628.33±4.04	392.33±14.22	37.55	552.93±3.79	12
18:00	431.00±6.71	310.00±7.70	28.07	370.66±15.58	14
20:00	37.00±2.89	15.73±3.54	57.48	31.73±3.57	14.24

3.4 Soil temperature

Soil temperature inside the Open top chambers with little variations remains closer to the open ambient conditions in comparison to polyhouse where a significant increase in soil temperature throughout the season was recorded (Table 4).

3.5 Solar radiation dwindling

Intense solar radiation in alpine region makes the alpine vegetation to have special physioanatomical acclimation to high irradiance. Thus, necessity of less light attenuation inside open top chambers makes them easy to conduct the CO_2 enrichment studies in alpine region. Generally, solar radiation is attenuated 10-20% by open top chambers (Drake et al, 1989; Weinstock et al, 1982; Heagle et al, 1979; Sanders et al, 1991)

In this study, we have found about 12-14% decrease inside OTCs in comparison to polyhouse where the decrease was near about 33-35%. A diurnal course of incident PAR inside OTCs, polyhouses compared with open ambient condition is depicted in Figure 6. Table 5 shows comparison of diurnal % reduction of PAR in polyhouse and Open top chambers in relation to open condition. In case of monthly variation in incident PAR same pattern was observed. Figure 7 depicts that there was a significant variation in PAR in different conditions throughout the season.

4. Conclusion

In alpine environment, the dynamics and functionality are controlled by low-temperature conditions, are considered to be particularly sensitive to climate change and global warming (Körner, 1999, IPCC, 2001). Hence effect of elevated CO_2 will have unpredictable impact on the alpine plants of India. Therefore, forecasting of dynamism of morpho-physiological and biochemical response of alpine plants under elevated CO_2 can only be possible with a leak proof CO_2 enrichment facility. The system described for CO_2 exposure of alpine ecosystem is simple and many replications in a harsh natural ecosystem are possible. This makes it a cost-effective means of gathering the requirements for field research on the effect of CO_2 on alpine ecosystems. There are several research needs to improve the open top chamber as a field experimental tool in context to alpine region of India. The combined effect of increased atmospheric humidity and temperature with increased CO_2 on plant growth in the field is also desirable to be addressed. We do declare that building these systems is easy, only that these systems are intrinsically simpler than others, provided that the effects on microenvironment are not as much as inside polyhouse, Open top chambers are probably the only practical option at present for studies on effects of elevated atmospheric CO_2 on Alpine ecosystems of India. Thus establishment of Open Top Chambers in Alpine of Tungnath (at 3600m above MSL) in Garhwal Himalaya will certainly be fruitful in observing the impact of increasing CO_2 concentration on alpine plants in context to global climate change and its response on alpine plants of India.

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