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EFFECTS OF ELEVATED CO_2 AND VARIATION IN ATMOSPHERIC TEMPERATURE ON TWO CONTRASTING RICE CULTIVARS

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Abstract

Study was conducted to understand the changes in morpho-physiological parameters of two tropical high yielding rice cultivars *CR-1014* and *Naveen* of CRRI, Orissa. These were grown under elevated (600µmol mol^{-1}) using FACE technology and ambient (370µmol mol^{-1}) CO_2 concentration in IARI, New Delhi fields. Elevated CO_2 resulted in significant changes in morpho-physiological parameters such as plant height, tiller number, leaf number, leaf area, photosynthesis, stomatal conductance, chlorophyll and carotenoid content. In addition to elevated CO_2 its combinations with variations in atmospheric temperature during the phenological stages of growth showed contrasting results in the two selected rice cultivars. The observed differences could be due to difference in the flowering time resulting in differences in maturation of these two cultivars. We conclude that elevated CO_2 in combination with lower atmospheric temperature can cease flowering in *CR-1014* cultivar while with higher atmospheric temperature and elevated CO_2 increased grain yield in *Naveen* cultivar.

Keywords: Elevated CO_2, Rice cultivars, temperature, morpho-physiological traits, grain yield.

Introduction

Climate change is a global phenomenon that has started to have adverse impact on agriculture. The global temperature is predicted to rise by 2.5 to 4.3^{o}C by the end of the century (IPCC 2007). The atmospheric CO_2 concentration has risen from 280 to 390 µmol mol^{-1} over the past 200 years. The rate of increase has accelerated during the last 50 years, increasing from an average of 0.85 µmol mol^{-1} year $^{-1}$ in the 1960s to 2.0 µmol mol^{-1} year^{-1} in 2001–2010 (http://www.esrl.noaa.gov/gmd/ccgg/trends/, accessed 8 November 2012). The CO_2 concentration is projected to rise further for the next 50 years even if various efforts are made to reduce carbon emissions (Fisher et al. 2007). Among the various climate changes expected to occur, an increase in CO_2 is one of the few that will have positive influences on crop production by promoting photosynthetic rates and possibly reduce crop water use. The mechanisms and magnitude of elevated CO_2 effects on crop productivity have been studied for decades using various research facilities including growth chambers, open-top chambers and free-air CO_2 enrichment (FACE) facilities. The yield enhancements caused by elevated CO_2 have frequently been reviewed and more recent articles have presented meta-analyses. These articles indicate that major C3 cereals show a similar yield response to elevated CO_2, i.e. 10-20%greater yield under 550-660 µmol mol^{-1} CO_2 than under 380-400 µmol mol^{-1} CO_2 (Kimball et al. 2002; Uprety et al. 2003; Long et al. 2004). Identifying and developing cultivars that respond well to elevated CO_2 can be an important option for adaptation to climate change (Tausz et al. 2011; Ziska et al. 2012) and may lead to higher resource use efficiency (Drake et al. 1997).

The limitations of Open Top Chamber (OTC) technology have been overcome by developing the FACE technology for fumigation of CO_2 in open field (Harley et al. 1992). The design of FACE system was based on the principle of injecting additional CO_2 gas in open field suitably so as to attain a pre determined elevated level of gas concentration with uniform distribution in the fields under the varying meteorological conditions of wind, temperature and humidity (Maini et al. 2002).

Rice (*Oryza sativa* L.) is unequivocally the most important food crop, feeding about a half of the world's population. As in other cereals, the rate of yield increase is slowing and even plateauing in various countries (Horie et al. 2005), yet the demand for grain continues to grow. Furthermore, the area available for rice planting is expected to decrease, so the rate of yield increase must exceed that of the demand increase. Rice productivity must therefore be increased by all available means. Improvement of the response to elevated CO_2 has the potential to increase yields but has not been given enough attention until recently (Ziska et al. 2012). Understanding the traits that can confer better adaptability to elevated CO_2 is crucial for genetic improvement of rice productivity under future climate conditions (Tausz et al. 2011). It is also important to test whether these adaptability traits function under different environmental conditions. Nakagawa et al (2002) observed about 14% increases in rice biomass production due to elevated CO_2 in CO_2 temperature gradient tunnels compared to 9% in the FACE experiment. Kim et al (1996) and Baker et al (1990) observed lesser value of biomass production in FACE studies compared to that of the values observed from open top chambers and CO_2 temperature gradient tunnels.

The present study was conducted to understand the changes in morpho-physiological parameters of two tropical high yielding rice cultivars *CR-1014* and *Naveen*. Cultivars *CR-1014* and *Naveen* of CRRI, Orissa were grown under elevated CO_2 concentration of 600µmol mol^{-1} using FACE technology at IARI, New Delhi, compared with ambient day average CO_2 concentration of 370µmol mol^{-1}. A Free Air CO_2 Enrichment (FACE) facility was developed at IARI, to study the effect of CO_2 to near natural field condition based on the principle of injecting additional CO_2 gas in open field suitably so as to attain a predetermined elevated levels of gas concentration with uniform distribution inside the ring under various meteorological conditions of wind temperature and humidity.

Materials and Methods

FACE set-up and plant growth conditions

The FACE site was located at Indian agriculture Research Institute, New Delhi (77˚12'E, 28˚40'N) 228.6 m above sea level. Two blocks, 8-m diameter, octagonal rings, one fumigated to (600 µmol mol^{-1} CO_2) and one control (370µmol mol^{-1} CO_2) were established. The plenum was made of flexible irrigation pipe and the CO_2 is injected through the large number of holes made in the pipe. All eight nodes of the octagon have independent control of CO_2 with the help of computer controlled PID valves. CO_2 was injected from 25 gas cylinders storage with manifold, valves and flow meters containing CO_2 regulating system to the input blower for mixing. The fumigation of the gas from the plenum was made at the center of the field 10x15 cm above the crop canopy level to reduce CO_2 gradients and made the CO_2 concentration uniform. The plenum height was adjusted time to time to the height of canopy with the help of adjustable stands. A PC based system controller was used to control the PID valves for achieving the required CO_2 concentration in the FACE ring. The system controller controls as well as analyses and displays the data on graphic terminal. Daily mean temperature, CO_2 concentration, relative humidity, wind speed, wind direction, light intensity data of day time were recorded for the crop season.

Two Indian rice cultivars *CR-1014* and *Naveen* of CRRI, Orissa were grown in three replicates on 7th July 2009 at IARI, New Delhi. The plot size was 0.5 m x 2.0 m with 250 plants m^{-2}. Twenty days old seedlings were transplanted in both ambient and FACE field and CO_2 in the FACE field was supplied after ten days of transplantation of rice. N, P and K fertilizers were applied as per recommended practice i.e. 90, 40 and 40 kg ha^{-1}, in the form of urea, superphosphate and potash, respectively, in two split doses. Commercial CO_2 gas was pumped in open field suitably so as to attain a predetermined elevated level of gas concentration with uniform distribution in the field under the varying meteorological conditions of wind, temperature and humidity. Flood water depth was maintained at 5cm above soil surface. Soil of the field was sandy loam.

Morpho-physiological and agronomic traits

Observations on morpho-physiological and yield related parameters such as plant height, leaf number, leaf area, tiller number, photosynthesis, stomatal conductance, chlorophyll and carotenoid content were recorded at vegetative (50 days after sowing) (DAS), flowering (85 DAS) and post-flowering (105 DAS) stages. Yield related parameters such as number of spikelets/plant, number of rachis per spikelet, spike weight, total number of grains per spike and number of filled grains per spike were recorded. Net photosynthesis rate (P_N) and stomatal conductance (g_s) of the youngest fully developed top most leaf of the main shoot was measured by photosynthetic system *Licor-6200* (LiCor Inc., Lincoln, NE, USA) between 11:00 and 11:30. Chlorophyll and carotenoid content: freshly harvested leaf material (100 mg) was homogenized in 10 ml of ice-chilled 80% acetone, followed by centrifugation at 10,000g for 10 min at 4^{o}C. The absorbance of the supernatant was recorded at 470 nm, 645 nm and 663 nm (Perkin Elmer, Lambda 2S, UV/VIS Spectrometer). Chlorophyll and carotenoid content was measured according to Lichtenthaler (1987). Observations were taken in triplicates. Statistical analysis of the data was done following the method of analysis of variance given by Snedecor and Cochran (1972).

Results

In comparison to ambient CO_2, elevated CO_2 in FACE treatment showed a significant increase in the morpho-physiological parameters related to phenological stages of growth in both cultivars (Fig 1). A significant increase ($p<0.05$) in plant height with 26.6% in *CR-1014* (vegetative stage) and 10.3% (post flowering stage) in cv. *Naveen*. *CR-1014* produced more tillers than Naveen in ambient conditions (Table 1). The significant increase of 19% was found at flowering stage and in cv. Naveen and it was 17.9% at post flowering stage. No. of leaves were found maximum at in *CR-1014* which was 44.3% and in cv. *Naveen* it was 13.9% increase. Maximum increase in leaf area was found almost double in cv. *Naveen* at flowering stage and in *CR-1014* a maximum increase of 40% was observed at vegetative stage. An increase in net photosynthesis was 38.7% found in *CR-1014* and it was 32% increase in cv. *Naveen* under FACE (elevated CO_2) grown plants respectively. Stomatal conductance was reduced in both the varieties under elevated CO_2 grown plants as compared to ambient field. Chlorophyll a, chlorophyll b and carotenoids pigment was greater in ambient condition as compared to the plants grown under elevated CO_2 condition (Fig 3 A).

The Leaf and stem dry weight in *CR-1014* cultivar was significantly greater than *Naveen*. An increase of 60% in leaf biomass and 11.3% was found in the stem biomass in *CR-1014* and in cv. *Naveen* it was found 38% in leaf and 58% in stem dry weight at flowering stage. There was only increase in size of plant (vegetative growth) at all the three stages of growth in *CR-1014* as there was no flowering in *CR-1014* cultivar till 160 days. In cv. *Naveen* maximum increase of 22.2% in spikelet number, 3.7% in length of spikelet, 14.2% increase in number of rachis / spikelet, 14% increase in weight of spikelet, 33.6% increase in total number of grains per spikelet, 38.8% increase in the weight of spikelet and an increase of 5.7% in the 1000 grain weight , a decrease in filled grain was 16.2% and a decrease of 39.3% in unfilled grains per spikelet was found in cv. *Naveen* cultivar in plants grown under FACE (elevated CO_2) compared to the plants grown under ambient field. (Table 2) The different canopy zone temperature differed with cultivars in middle zone and lower zone of the plant, but, much difference not observed at the canopy zone. Changes in atmospheric temperature, RH%, light intensity, wind speed, wind direction and rainfall have been recorded throughout the cropping season (Fig 2 A, B, C). The response of both the cultivars to the elevated CO_2 was greater under FACE. However, there was variation in the intensity of the effect. Cultivar *CR-1014* responded relatively more than *Naveen* except at flowering and harvest stage.

Cultivar *Naveen* is early flowering and *CR-1014* is a late flowering cultivar. Atmospheric temperature at flowering period for both the varieties differed as cv. *Naveen* crop duration is of 120 days and *CR-1014* is of 160 days. The atmospheric temperature faced by both the cultivar differed as Naveen is an early flowering faced the temperature of 25 to 30 ^{o}C in the month of August and September and *CR-1014* faced the atmospheric temperature of 17 to 19 ^{o}C in the month of October this variation in temperature ceased flowering in *CR-1014*. The biomass in *CR-1014* cultivar was significantly greater than *Naveen*. The spikelet number and grain yield in *Naveen* variety was greater in the plants grown under elevated CO_2 compared to ambient conditions. In comparison to plants grown under ambient conditions elevated CO_2 increased the productivity of *Naveen* as observed from the increased yield parameters (1000-grain weight, grain number, filled grain /spikelet). Cultivar *CR-1014* failed to flower and consequently invested all assimilates in biomass production and making more tillers (Fig 3B). This late flowering cultivar *CR-1014* faced elevated CO_2 in combination with lower temperature high light intensity which hampered the flowering.

Discussion

This is a unique study where two contrasting effects of elevated CO_2 were observed with changing abiotic environmental factors. Unlike the fumigation methodologies, FACE technology allows plants to be grown in elevated CO_2 with minor changes in the micro-climate. Elevated CO_2 alone can increase crop productivity but the accompanying changes in atmospheric temperature, light intensity and humidity may have negative effects. Growth at elevated CO_2 increases photosynthesis by competitively inhibiting the *Rubisco* catalyzed oxygenation (Ainsworth et al. 2003). The large positive effect on photosynthesis immediately following harvest coincides with an increase in total dry matter and leaf area (Suter et al. 2001). The large Elevated CO_2 on one hand increased grain yield in the early flowering cv. *Naveen* while in cv.*CR-1014* increased the biomass (source) and hampered flowering (sink) by low temperature and high light intensity and consequently resulted in increased vegetative phase which could not be converted to reproductive phase. The transition of the shoot apical meristem from vegetative to reproductive growth is a critical developmental switch in plants that is regulated by both environmental and endogenous factors (Baurle and Dean 2006). The abscisic acid (ABA) pathway responds to endogenous factors, such as plant age or leaf number, and is largely independent of environmental signals. The photoperiod and vernalization pathways respond to environmental factors (Mouradov et al. 2002).

In rice, photoperiod is the most important environmental cue for signaling flowering. Wu et al (2008) demonstrated that the *Rice Indeterminate1* (*RID1*) gene acts as the master switch for the transition from the vegetative to reproductive phase. *RID1* encodes a Cys-2/His-2-type zinc finger transcription factor. A *RID1* knockout (*rid1*), mutated by T-DNA insertion, never headed after growing for >500 days under a range of growth conditions and is thus referred to as a never-flowering phenotype**.** The mutation in *RID1* affected expression of the genes known to be involved in flowering. *RID1* gene seems to be independent of the circadian rhythm in expression pattern nor affected the circadian clock. Similar observations were obtained in the cv. *CR-1014* in this study. This variety never headed after growing for 160 days under variable growth conditions. This may be due suppressed expression of gene(s) responsible for the switch for the transition from the vegetative to reproductive phase.

In conclusion, elevated CO_2 on one hand increased grain yield in the early flowering variety *Naveen* while hampered flowering and consequently resulted in increased biomass production in the late flowering cultivar *CR-1014*. The growth parameters in *Naveen* variety were higher in the plants grown under elevated CO_2 compared to ambient conditions. However, cv. *CR-1014* responded relatively more than that of cv. *Naveen* for all other parameters, except flowering. Hence, steps to address differential response of rice cultivars under variable atmospheric temperature and elevated CO_2 conditions are needed in future studies.

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Appendix

Table 1. Morpho-physiological parameters of the rice cultivars *CR-1014* and *Naveen* under elevated CO_2 and ambient conditions during vegetative, flowering and post flowering stages of the crop

		Ambient CO_2		**Elevated CO_2**		**CD at 5% P**		
		CR-1014	**Naveen**	**CR-1014**	**Naveen**	**Variety (V)**	**CO_2**	**VxCO$_2$**
Plant height	Vegetative	71.3	77.3	90.3	75.0	4.28	4.28	6.06
	Flowering	115.0	99.3	136.0	102.6	5.29	5.29	7.49
	Post-flowering	125.0	106.0	137.6	117.0	3.66	3.66	N.S.
No. of tillers/plant	Vegetative	32.6	21.0	37.0	22.6	3.411	N.S.	N.S.
	Flowering	37.6	36.0	45.0	42.0	N.S.	2.14	**3.02**
	Post-flowering	39.3	37.3	45.0	44.0	1.978	1.97	N.S.
No. of leaves/plant	Vegetative	106.0	69.3	138.0	74.6	19.522	N.S.	N.S.
	Flowering	185.0	153.0	196.0	174.3	5.917	5.91	N.S.
	Post-flowering	117.3	114.3	169.3	120.0	17.414	17.4	N.S.
Leaf area (cm^2)/plant	Vegetative	1259.9	850.1	1775.2	1326.3	319.5	319.5	N.S.
	Flowering	2812.9	1573.6	3689.2	3232.2	199.0	199.0	218.5
	Post-flowering	2367.8	1312.4	3129.2	2487.9	304.2	304.2	N.S.
Total no. of spikelet/plant	Flowering	No flowering	21.6	No flowering	26.3	N.S	2.40	1.7
	Post-flowering	No flowering	27.0	No flowering	33.0	2.67	0.57	0.40
Leaf DW(g)/plant	Vegetative	9.79	9.02	12.08	9.40	N.S	N.S	N.S
	Flowering	26.23	18.26	35.23	25.26	2.94	2.94	N.S
	Post-flowering	25.25	9.40	40.61	12.03	3.55	3.55	5.03
Stem DW(g)/plant	Vegetative	8.51	6.88	14.37	10.56	N.S	3.88	N.S
	Flowering	25.50	25.17	54.36	39.90	2.92	2.92	N.S
	Post-flowering	63.50	45.12	97.73	53.06	6.27	6.27	8.87

Table 2. Effect of elevated CO_2 on spikelet of cv. *Naveen*

Traits	**No. of spiklet/ plant**	**Length of spikelet**	**No.of Rachis/ spikelet**	**Weight/ spikelet**	**Total No. of grains/ spike**	**Filled grains/ spike**	**Unfilled grains/s pike**	**Weightof spikelets/ plant**	**1000-grain weight**
Ambient CO_2	27	27	11.66	4.32	255.66	264.66	31.33	29.01	17.55
Elevated CO_2	33	28	13.33	5.60	341.66	307.66	19	40.30	18.56
CD at 5% P	2.67	N.S	N.S	0.71	52.68	N.S	N.S	8.47	0.45
SE (d)	0.57	0.66	1.20	0.15	11.37	24.00	6.17	1.82	0.09
SE (m)	0.40	0.47	0.85	0.10	8.04	16.97	4.36	1.29	0.06
CV	2.35	2.96	11.77	3.80	4.66	10.27	30.04	6.46	0.66

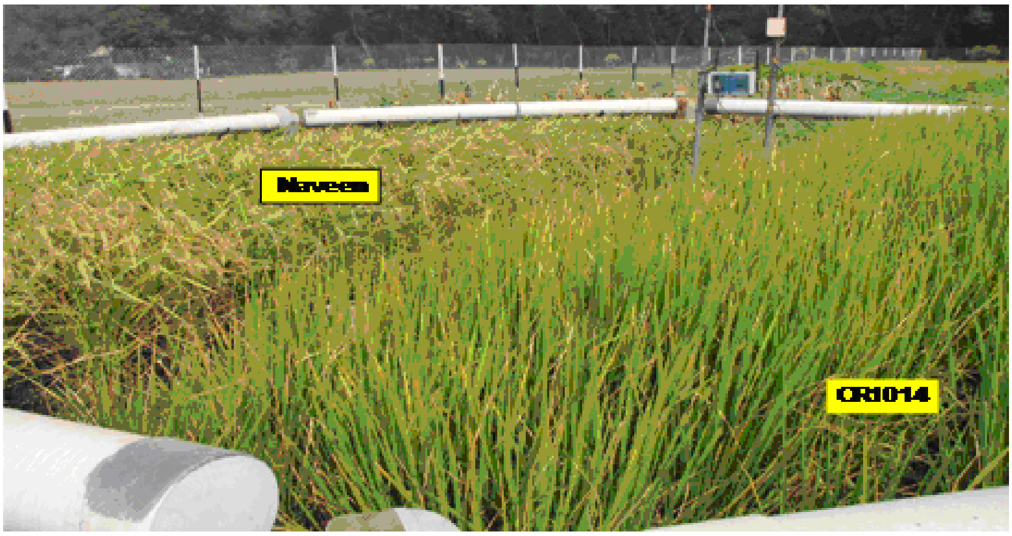

Fig 1 Response of rice cv. Naveen and CR 1014 to elevated CO_2 in FACE field.

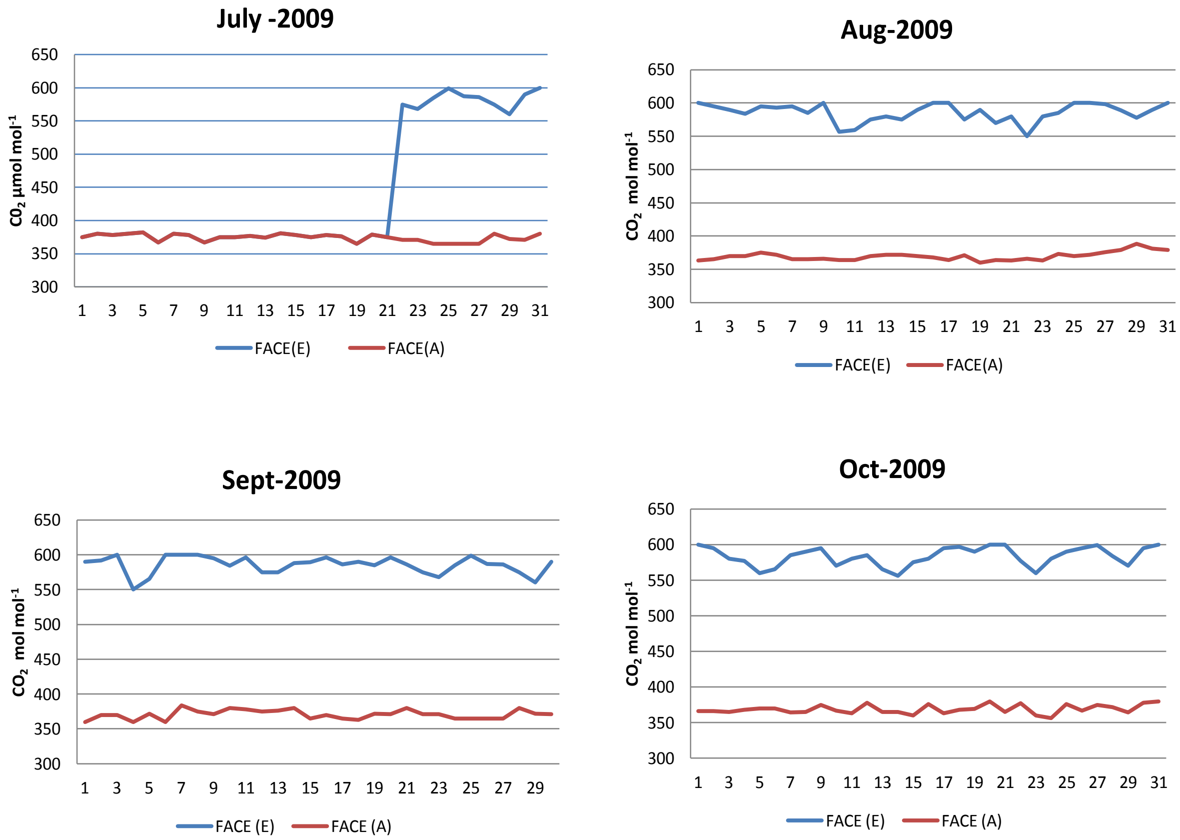

Fig 2 (A) Month-wise variation in CO_2 concentration in FACE facility. FACE (E): Free Air CO_2 enriched ring with 550 ppm CO_2; FACE (A): Free air CO_2 ring with ambient air

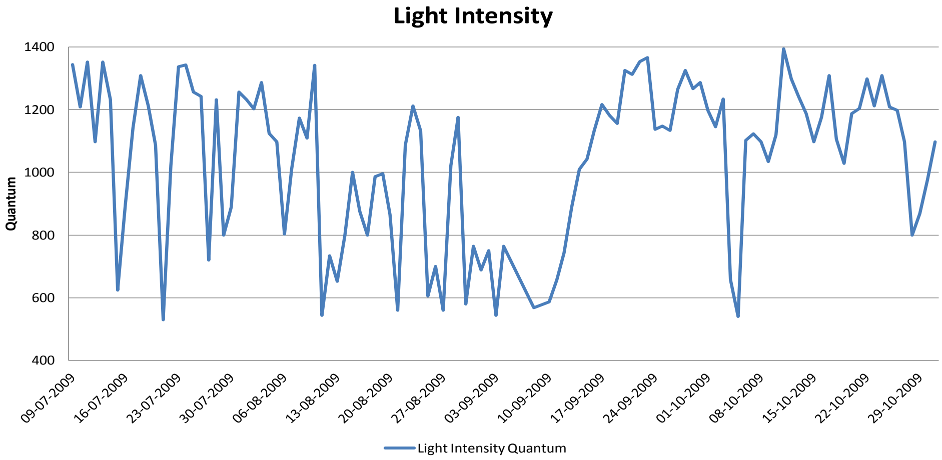

Fig 2 (B) Month-wise variation in light intensity in FACE facility FACE (E): Free Air CO_2 enriched ring with 550 ppm CO_2; FACE (A): Free air CO_2 ring with ambient air.

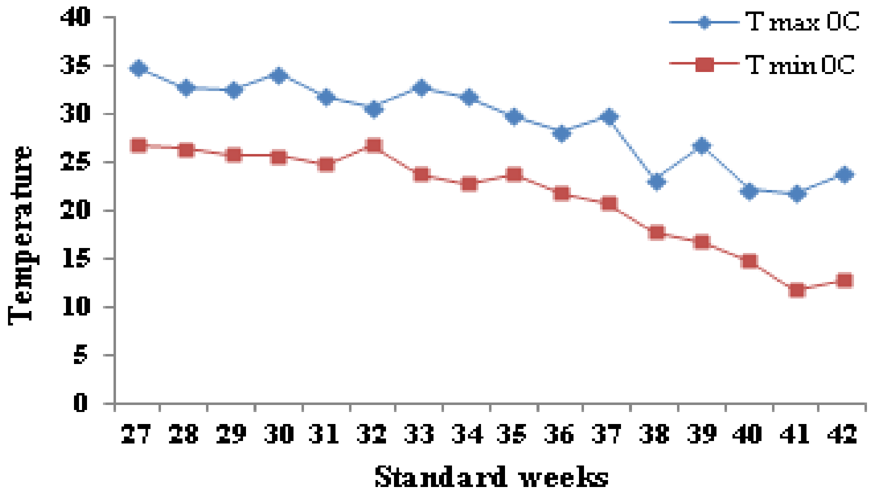

Fig 2 (C) Month-wise variation in temperature in FACE facility.

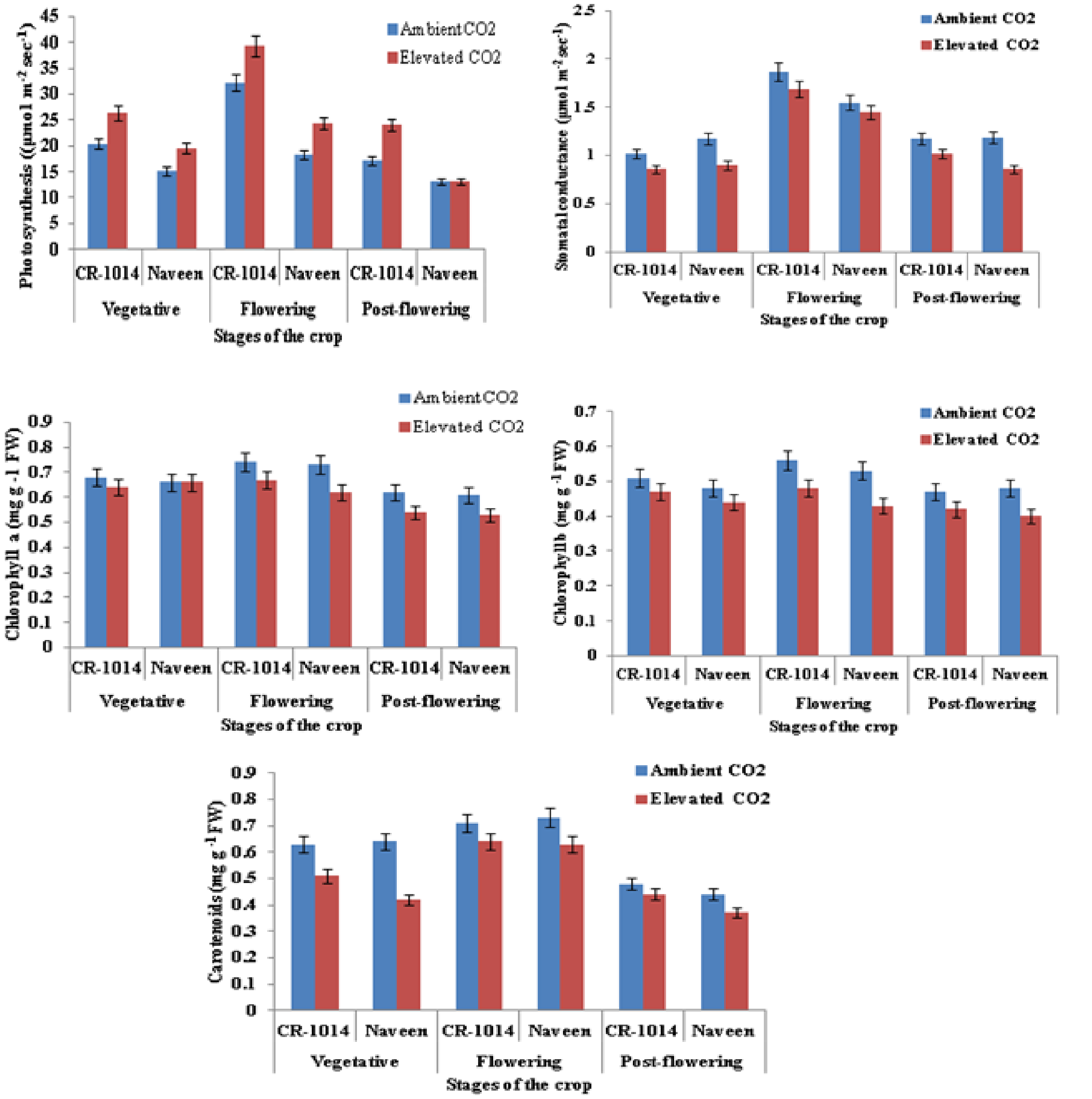

Fig 3 (A) Graphical representation of Morpho-physiological parameters such as photosynthesis, stomatal conductance, chlorophyll a, b and carotenoid of the rice cultivars *CR-1014* and *Naveen* under elevated CO_2 and ambient conditions during vegetative, flowering and post flowering stages of the crop.

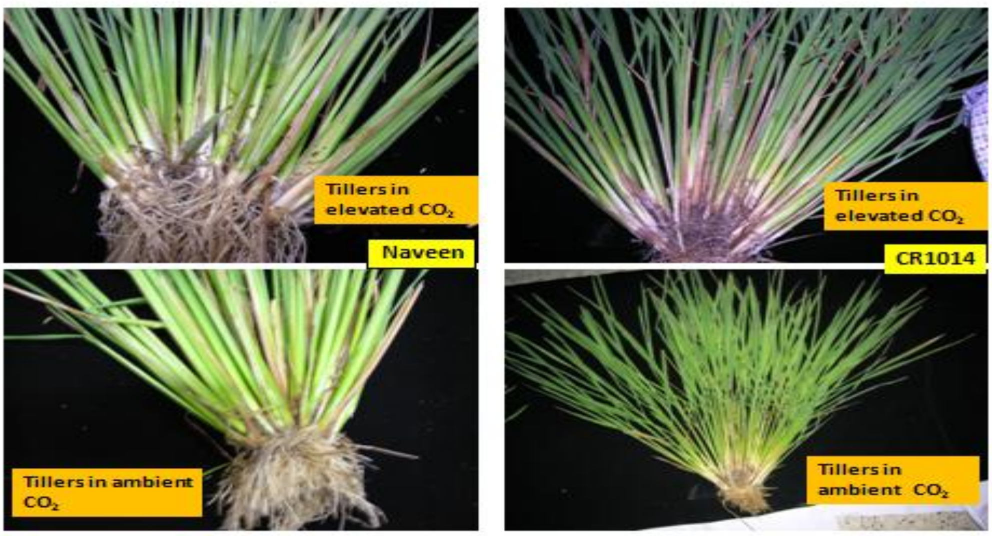

Fig 3 (B) Comparative response of rice cultivars to elevated and ambient CO_2 at maximum tillering stage of the crop.