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Growth, yield and nitrogen uptake in rice crop grown under elevated carbon dioxide and different doses of nitrogen fertilizer

Amita Raj[1]*, B Chakrabarti[1], H Pathak[3], SD Singh[1], U Mina[1] & TJ Purakayastha[2]

[1]Centre for Environment Science and Climate Resilient Agriculture; [2]Soil Science and Agricultural Chemistry,
ICAR-Indian Agricultural Research Institute, New Delhi-110 012, India

[3]National Rice Research Institute, Cuttack, Odisha-753 006, India

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Climate change associated with rising atmospheric carbon dioxide (CO_2) concentration may have impact on crop production and soil health. Increase in atmospheric CO_2 concentration may enhance crop growth with higher demand for nutrients by the crop. An experiment was conducted during July-October, 2013 using Free Air Carbon Dioxide Enrichment facility at the Indian Agricultural Research Institute, New Delhi to study the impact of elevated CO_2 and nitrogen (N) dose on growth, yield and nitrogen uptake in rice crop. Four doses of N, i.e., control, 0.6 g N pot^{-1} (75% recommended dose of N), 0.8 g N pot^{-1} (100% recommended dose of N) and 1.0 g N pot^{-1} (125% recommended dose of N) were applied in both ambient (395 ppm) and elevated CO_2 (550±20 ppm) conditions. Grain and biomass yield of rice was significantly higher under elevated CO_2 condition. Plant growth and yield parameters also increased with increased N doses in both elevated and ambient CO_2 conditions. Nitrogen concentration of grain and straw decreased under high CO_2 level but N uptake increased under elevated CO_2 condition. Agronomic efficiency of N was higher under elevated CO_2 while recovery efficiency of N remained unaffected. The study showed that although yield of rice increases under elevated CO_2 condition, to maintain plant nitrogen concentration, application of additional dose of N is required.

Keywords: Climate change, Elevated CO_2, Paddy, *Oryza sativa*

Climate change due to rising concentrations of greenhouse gases (GHGs) in the atmosphere may possibly affect crop production and soil health. The Inter-Governmental Panel on Climate Change[1] in its 5th Assessment Report (AR5) mentioned about the adverse consequences of climate change on agriculture, human health, settlements and natural resources. According to the Inter-Governmental Panel on Climate Change report, baseline scenarios (those without additional mitigation), result in increase in global mean surface temperature by 3.7 to 4.8°C by 2100 compared to the pre-industrial levels[1]. Atmospheric CO_2 concentration increased from 280 µmol mol^{-1} in 1750 to 400 µmol mol^{-1} in 2015[2]. The food grain production of tropical and subtropical countries including India is likely to be severely affected under changing climatic scenario[3]. Climate change can affect rice production mainly through increased atmospheric CO_2 concentration, temperature and changes in rainfall pattern[4]. Increase in atmospheric carbon dioxide concentration has a fertilization effect enhancing the growth and yield of crops[5]. It has been reported that C3 grain and legume crops show lower concentrations of zinc and iron when grown under elevated CO_2 concentration conditions. Also, C3 crops other than legumes reported to have lower concentrations of protein, whereas C4 crops seem to be less affected[6]. The fertilization effects of CO_2 on crop production will be necessary in future climate change scenarios to offset the anticipated negative impacts of high temperature[7].

Rice is a major food crop in Asia in particular and in the world in general, providing a significant proportion of the people's dietary needs. It is a staple diet of more than 2 billion people in Asia and millions of people in Africa and South America and is a main source of calories for about 60% of the world population[8]. With the likely growth of world's population, the demand for rice will increase. Climate change will pose a significant challenge to meet this demand and future food security[9]. It is, therefore, important to assess the response of rice to elevated atmospheric CO_2 level. Reports on yield enhancement

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*Correspondence:
E-mail: amitaraj09@gmail.com

]Supplementay data available only online in NOPR] in rice under elevated CO_2 condition varies widely due to different experimental methods adopted by different researchers. Canopy level studies showed 10–20% yield enhancement at +200 ppm CO_2 concentration under non-stress conditions[9]. Reports also showed that average grain yield of rice increased by an average of 13% grown inside free air carbon dioxide enrichment (FACE) facility[10].

Increased growth of crops under elevated CO_2 condition will require higher nutrient uptake and assimilation. The demand for nutrients by crops might also get changed in future under increased CO_2 concentration. Numerous studies suggested that nitrogen could be a key factor in regulating the response of ecosystem to elevated CO_2[11]. Lenka & Lal[12] reported that elevated CO_2 condition increases recalcitrant carbon fractions in plant biomass causing progressive decline in availability of soil N which necessitates application of supplemental N. Besides this, increased N uptake under high CO_2 condition also induces a negative feedback in soil N dynamics. Hence, the management of nitrogen will play crucial role in future climate change scenarios for enhancing yield and nutrient uptake in rice crop. Only limited reports are available on the effect of elevated CO_2 on yield as well as nutrient dynamics in rice crop in Indian condition. The following study was conducted to assess the impacts of elevated CO_2 on yield, plant nitrogen concentration and nitrogen uptake in rice crop under varying nitrogen doses.

Materials and Methods

Site

The experiment was carried out during the *kharif* (June-October) season of 2013 in a Free Air Carbon Dioxide Enrichment (FACE) facility, at the Indian Agricultural Research Institute farm, New Delhi, India. The site is located at 28°35'N and 77°12'E. The climate of Delhi is subtropical, semi-arid. The region receives about 750 mm annual rainfall, 80% of which occurs from June to September. The mean annual maximum temperature is 35°C while the mean annual minimum temperature is 18°C.

Meteorological condition

During the entire growing season of the rice crop the average temperature ranged from 25.4°C to 30.2°C (Fig. 1). A total rainfall of 112.2 mm was reported during the entire crop growth period. Maximum rainfall (28 mm) was observed during the 33rd standard meteorological week.

Treatments and experimental design

The experiment was conducted by growing rice crop (variety Pusa 44) in pots filled with 15 kg soil, under elevated CO_2 in FACE rings and ambient condition. The soil was sandy loam in texture with pH of 7.6. Two rice seedlings (30 days old) were transplanted in each pot in July, 2013. The CO_2 concentration in the FACE ring was set at 550±20 ppm at crop canopy level using the supervisory control and data acquisition (SCADA) software-based FACE facility[13]. In control, the ambient CO_2 concentration was around 395 ppm. Four different nitrogen (N) doses were applied in both ambient and elevated CO_2 conditions (Table 1) in 3 split doses (50% as basal dose, and rest at 25 days intervals). The recommended dose of N was 120 kg N ha^{-1} which was supplied through urea and diammonium di-ammonium phosphate (DAP). In total there were 8 treatments with 4 replications each. Basal dose of phosphorous and potassium was applied through DAP and muriate of potash (MOP). Irrigation was provided on every alternate day to maintain the saturation level and 3-4 cm standing water throughout the cropping period.

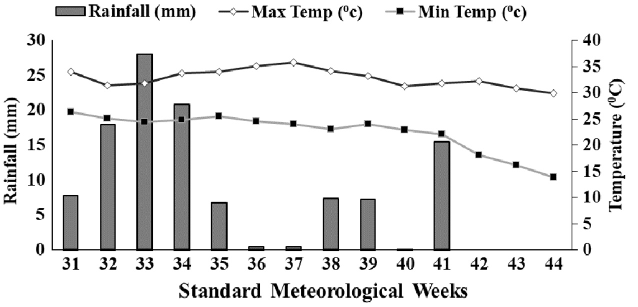

Fig.1 — Variation in air temperature and rainfall during the crop growth period

Table 1 — Treatment details for the experiment

CO_2 level	Treatment	N (g pot^{-1})
Ambient (395 ppm)	N0	0 (No nitrogen)
	N1	0.6 (75 % recommended dose)†
	N2	0.8 (100 % of recommended dose)
	N3	1.0 (125% of recommended dose)
Elevated (550±20 ppm)	N0	0 (No nitrogen)
	N1	0.6 (75 % recommended dose)
	N2	0.8 (100 % of recommended dose)
	N3	1.0 (125% of recommended dose)

†Recommended dose of N: 120 kg ha^{-1}

Plant sampling and analysis

At harvesting stage of the crop grains were separated from the straw, dried, and weighed. Subsamples were dried in an oven at 65°C for 48 h for further chemical analysis. Growth parameters like plant height was recorded at flowering stage, number of tillers at maximum tillering stage and aboveground biomass of the crop at maturity. Roots were collected from the pot using water and *khurpi*. The soil was removed from the root by placing the root in a water flow. Oven dry weight of root was recorded. Yield parameters like panicle number, number of grains per panicle, number of filled and unfilled grains per panicle, grain biomass, and thousand grain weights (test weight) were recorded. Oven dried grain and straw samples were analysed for nitrogen content using micro-Kjeldahl method[14].

Partitioning coefficient

Partitioning coefficient of root, shoot and grain was calculated by dividing root, shoot and grain dry biomass to the total dry biomass of the crop.

Plant N use efficiencies

Nutrient uptake was calculated as given below.

$$\text{Grain N uptake (g pot}^{-1}\text{)} = \text{Grain weight (g pot}^{-1}\text{)} \times \text{Grain N concentration (\%)} / 100 \quad \ldots(1)$$

$$\text{Straw N uptake (g pot}^{-1}\text{)} = \text{Straw weight (g pot}^{-1}\text{)} \times \text{Straw N concentration (\%)} / 100 \quad \ldots(2)$$

$$\text{Aboveground N uptake (g pot}^{-1}\text{)} = \text{Grain N uptake (g pot}^{-1}\text{)} + \text{Straw N uptake (g pot}^{-1}\text{)} \quad \ldots(3)$$

Agronomic efficiency (AE) was calculated as given below[15].

$$\text{AE (g grain g}^{-1}\text{ N applied)} = \frac{\text{Grain wt. in N treatment}\left(\text{g pot}^{-1}\right) - \text{Grain wt. in no N treatment}\left(\text{g pot}^{-1}\right)}{\text{N dose}\left(\text{g pot}^{-1}\right)} \quad \ldots(4)$$

Recovery efficiency (RE) was calculated as given below[16].

$$\text{RE (\%)} = \frac{\text{Plant N in N treatment}\left(\text{g pot}^{-1}\right) - \text{plant N in no N treatment}\left(\text{g pot}^{-1}\right)}{\text{N dose}\left(\text{g pot}^{-1}\right)} \times 100 \quad (5)$$

Statistical analysis

Design of the experiment was factorial Completely Randomised Design (CRD). Statistical analysis of the data was done using ANOVA (analysis of variance) technique recommended for the design[17] to test whether the differences between means were statistically significant or not. Unless indicated otherwise, differences were considered significant at $P < 0.05$.

Results

Impact of elevated CO_2 on rice growth

Plant height significantly increased under elevated CO_2 condition. In elevated CO_2 treatment, height of rice plants was 81.7 cm while in ambient condition plant height was 76.9 cm with recommended dose of N fertilizer (Table 2). Similarly, tiller number also increased under elevated CO_2 condition. Number of

Table 2 — Effect of different nitrogen (N) levels on yield and its components of rice crops grown under ambient and elevated CO_2 condition

N dose	CO_2 level	Plant height (cm)	No. of tillers pot^{-1}	Root weight (g pot^{-1})	Above ground biomass (g pot^{-1})	Panicle length (cm)	No. of panicles pot^{-1}	No. of grains panicle^{-1}	Grain yield (g pot^{-1})	Harvest index	1000 grain weight (g)
N0	Ambient	72.3	52.0	20.7	107.2	22.3	38.0	93.0	43.7	38.0	15.6
	Elevated	80.9	56.0	38.2	142.6	24.3	39.0	103.0	51.2	38.0	15.5
	% Change	11.9	7.7	84.3	33.0	9.0	2.6	10.8	16.9	0	-0.6
N1	Ambient	75.0	56.0	32.6	131.1	21.5	43.0	104.0	51.5	39.3	14.5
	Elevated	81.7	62.0	55.0	162.8	24.8	46.0	111.0	60.5	37.2	14.9
	% Change	8.9	10.7	68.6	24.2	15.3	7.0	6.7	17.6	-5.3	2.8
N2	Ambient	76.9	65.0	42.3	135.65	24.3	50.0	108.0	54.5	40.2	14.5
	Elevated	81.7	72.0	69.6	163.9	23.7	54.0	118.0	68.4	41.7	15.6
	% Change	6.2	10.8	64.7	20.8	-2.5	8.0	9.3	25.5	3.9	7.6
N3	Ambient	78.3	71.0	49.0	136.8	24.0	56.0	114.0	57.0	41.7	15.2
	Elevated	83.3	80.0	76.9	170.9	24.0	62.0	125.0	71.9	41.5	15.1
	% Change	6.4	12.7	56.9	24.9	0.0	10.7	9.6	26.1	-0.5	-0.7
ANOVA (P = 0.05)	N	NS	7.0	2.6	25.8	NS	8.0	5.0	8.6	NS	NS
	CO_2	3.5	5.0	3.7	18.2	1.0	6.0	9.0	6.1	NS	NS
	N x CO_2	NS	9.0	5.2	36.4	NS	11.0	NS	12.2	NS	NS

tillers per pot was maximum in N_3 treatment under both ambient (71) and elevated (80) CO_2 conditions (Table 2). The productive tiller fraction ranged 0.73–0.79 under ambient condition and from 0.70 to 0.78 under elevated CO_2 condition, across all N levels (Fig. 2). Higher crop growth in elevated CO_2 treatment was reflected in higher biomass of rice crop. Elevated CO_2 level increased above ground biomass by 20.8% and 24.9% in N_2 and N_3 treatments, respectively (Table 2). Higher N doses along with elevated CO_2 level significantly increased biomass yield of the crop (suppl. Table 1).

Root dry weight also increased significantly under elevated CO_2 condition. Elevated CO_2 level along with higher N doses further increased root weight of the crop significantly (suppl. Table 1). Root biomass was found to be maximum (76.9 g pot^{-1}) in N3 treatment under high CO_2 level (Table 2). Partitioning of biomass to root and shoot got altered in elevated CO_2 treatment. Partitioning of biomass to rice roots significantly increased in elevated CO_2 treatment while that for shoots, it remained unaffected by CO_2 level (Table 3).

Impact of elevated CO_2 on yield parameters of rice crop

Grain yield of rice crop increased significantly under elevated CO_2 concentration as compared to ambient condition irrespective of N doses (Table 2). Elevated CO_2 level increased grain yield by 25.5% over ambient treatment with recommended dose of N. Maximum grain yield was obtained in N3 treatment both under ambient (57 g pot^{-1}) and elevated (71.9 g pot^{-1}) CO_2 condition (Table 2). Although grain yield increased at elevated CO_2 level but partitioning of total biomass to grains decreased under high CO_2 concentration (Table 3).

Number of grains per panicle was found to be maximum in N3 treatment in both ambient (114) and elevated (125) CO_2 level (Table 2). Harvest index (HI) of rice crop ranged from 38.0% to 41.7%. Test weight of rice grains varied from 14.5 g to 15.6 g under ambient and from 14.9 g to 15.6 g at elevated CO_2 condition (Table 2).

Impact of elevated CO_2 on nitrogen content in rice

Grain as well as straw nitrogen (N) concentration significantly decreased under elevated CO_2 condition. On the other hand, application of N fertilizer significantly increased N concentration in grain as well straw in both ambient and elevated CO_2 treatment (suppl. Table 1). Grain N concentration was 1.31% in elevated CO_2 treatment while in ambient condition N concentration in rice grains was 1.46% (Table 4). Application of nitrogen significantly increased grain N concentration over control. Maximum N content in rice grains (1.66%) was observed in N3 treatment under ambient CO_2 condition. Maximum N content in straw was observed in N3 treatment under both ambient (0.82%) as well as elevated CO_2 condition (0.78%) (Table 4).

Grain as well as total nitrogen (N) uptake in rice crop significantly increased under elevated CO_2 condition (suppl. Table 1). N uptake in grains was found to be positively correlated (r = 0.88) with grain yield of rice crop (suppl. Table 2). Application of nitrogen fertilizer also significantly increased N uptake over control. Maximum N uptake in rice grains (0.97 g pot^{-1}) was observed in N3 treatment under elevated CO_2 condition (Fig. 3). Total N uptake was also highest in N3 treatment in both ambient (1.57 g pot^{-1}) and elevated (1.79 g pot^{-1}) CO_2 conditions. Significant positive correlation (r = 0.86)

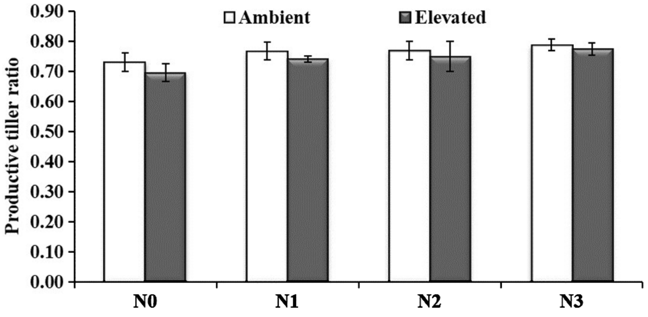

Fig. 2 — Effect of different nitrogen (N) levels on the productive tiller ratio of rice crop grown under ambient and elevated CO_2 condition. [N0, 0.0 g N pot-1 (control); N1, 0.6 g N pot-1 (75% of recommended dose); N2, 0.8 g N pot-1 (100% of recommended dose); and N3, 1.0 g N pot-1 (125% of recommended dose)]

Table 3 — Partitioning coefficient in rice as affected by elevated carbon dioxide condition and N levels

		Partitioning coefficient		
N dose	CO_2 level	Root	Shoot	Grain
N0	Ambient	0.16	0.50	0.34
	Elevated	0.21	0.51	0.28
N1	Ambient	0.20	0.49	0.31
	Elevated	0.25	0.47	0.28
N2	Ambient	0.24	0.46	0.31
	Elevated	0.30	0.41	0.29
N3	Ambient	0.26	0.43	0.31
	Elevated	0.31	0.40	0.29
ANOVA (P = 0.05)	N	0.02	0.05	NS
	CO_2	0.02	NS	0.03
	N x CO_2	NS	NS	NS

Table 4 — Impact of elevated CO_2 and N doses on grain and straw N concentration

N dose (g pot^{-1})	Grain N (%)				Straw N (%)			
	Ambient CO_2	Elevated CO_2	Mean	CO_2 fertilization effect (% change)	Ambient CO_2	Elevated CO_2	Mean	CO_2 fertilization effect (% change)
0	1.09	1.00	1.05	-8.3	0.53	0.49	0.51	-7.5
0.6	1.49	1.39	1.44	-6.7	0.74	0.69	0.72	-6.8
0.8	1.61	1.45	1.53	-9.9	0.81	0.73	0.77	-9.9
1.0	1.66	1.48	1.57	-10.8	0.82	0.78	0.80	-4.9
Mean	1.46	1.31			0.73	0.67		
LSD (P = 0.05)	N: 0.14 CO_2: 0.10 N x CO_2: NS				N: 0.06 CO_2: 0.05 N x CO_2: NS			

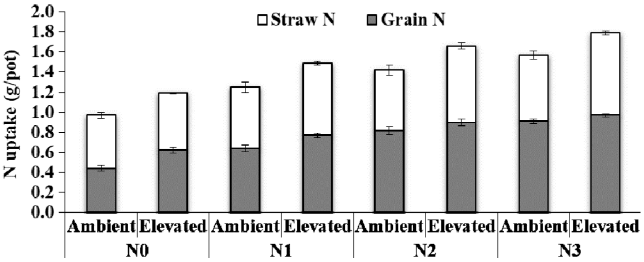

Fig. 3 — Impact of elevated carbon dioxide and N levels on N uptake (g pot^{-1}) in rice crop. [N0, 0.0 g N pot-1 (control); N1, 0.6 g N pot-1 (75% of recommended dose); N2, 0.8 g N pot-1 (100% of recommended dose); and N3, 1.0 g N pot-1 (125% of recommended dose)]

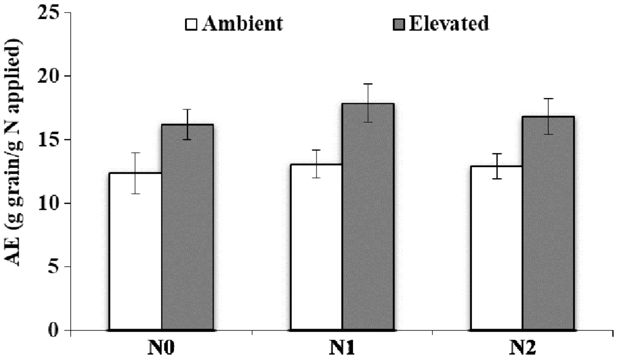

Fig. 4 — Impact of elevated carbon dioxide and N levels on (A) agronomic efficiency; and (B) recovery efficiency of rice crop. [N0, 0.0 g N pot-1 (control); N1, 0.6 g N pot-1 (75% of recommended dose); and; N2, 0.8 g N pot-1 (100% of recommended dose]

was observed between total N uptake and aboveground biomass of the crop (suppl. Table 2).

Nitrogen use efficiency in rice as affected by CO_2 level

Agronomic efficiency (AE) of N application in rice was higher under elevated CO_2 condition (Fig. 4A). AE of rice was found to be maximum (17.8 g grain per g N applied) in N2 treatment under elevated CO_2 condition. Recovery efficiency of rice crop was at par in both ambient and elevated CO_2 treatment (Fig. 4B). Recovery efficiency ranged from 56 to 57.3% in ambient CO_2 treatment while it varied from 57 to 58% in elevated CO_2 treatment.

Discussion

Crop growth significantly increased under elevated CO_2 condition which was reflected in more number of tillers, higher aboveground and belowground biomass of rice crop. The interactive effect of high CO_2 along with high N doses further improved number of tillers in rice (suppl Table 1). It was found that although total number of tillers increased under elevated CO_2 condition but the fraction of productive tillers (i.e. panicle bearing) got reduced under elevated CO_2 condition. Increased N doses helped in increasing the productive tiller count. Similar result has been reported by Baker *et al.*[18] showing reduced fraction of productive tillers under high CO_2 condition. This decrease in productive tiller ratio across all N levels was possibly due to a greater response of the vegetative tissues to elevated CO_2 condition compared to the reproductive parts[5].

Earlier studies have also shown that elevated CO_2 increased photosynthesis rate and plant biomass in different crops[19-21]. Increased biomass under high CO_2 condition is primarily attributed to increased photosynthetic rates[22,23], which subsequently leads increased carbon assimilation and more partitioning of assimilates to plant parts[24] causing morphological changes, such as leaf area development, tiller production and changes in shoot to root ratios[25,26]. Increased translocation of biomass to roots and decreased amount of biomass partitioning to grains was observed in the present study under high CO_2 condition. There are similar reports, that root growth of crop plants is often stimulated to a greater extent than other plant parts due to greater C allocation under increased CO_2 concentration[27-29]. It has been observed that the fraction of biomass partitioned to rice grains under elevated CO_2 condition did not exceed than ambient condition[30]. Some researchers reported that in maize grown under elevated CO_2 level relative growth rate of roots was increased compared to the relative shoot growth rate due to increased translocation of carbon to the roots[31].

Studies with rice have shown that elevated CO_2 level increases grain yield of the crop[19]. Some scientists reported 15% increase in rice yield grown under high CO_2 condition[32]. In a study, 50% increase in biomass and 24 to 30% increase in seed yield has been reported[33]. High CO_2 concentration and increased N doses synergistically helped in increasing panicle number of rice crop (suppl. Table 1). Similar results have been reported for rice crop grown under elevated CO_2 where increased grain yield was found to be associated with increase in tiller number and subsequent increase in number of panicles[34,35].

Although N concentration in grains decreased under elevated CO_2 condition but application of higher doses of nitrogen increased grain N concentration to certain extent. Increased biomass under elevated CO_2 condition resulted in dilution effect which has lowered N concentration. Several researchers have also reported decrease in N concentration in plants grown under elevated CO_2 condition[36,37]. Reduction in N and crude protein content in Maize has also been reported under elevated CO_2 condition[38]. Higher grain as well as biomass yield under high CO_2 treatment has resulted in higher N uptake of the crop. Earlier workers also reported that in rice crop total nitrogen (N) uptake for the whole plant get increased under elevated CO_2 condition[39,40].

Higher AE of N application under elevated CO_2 shows that yield enhancement with increased N dose was more at higher CO_2 treatment. Earlier results also showed that nutrient use efficiency of N, P, K, and Mg in all organs of rice plant significantly increased in elevated CO_2 condition[41].

Conclusion

Increase in atmospheric CO_2 concentration increased both grain and biomass yield of rice crop. Application of nitrogen significantly increased various growth and yield parameters of rice in both ambient and increased CO_2 treatment. Nitrogen concentration in grain as well as straw got decreased under elevated CO_2 condition due to the dilution effect of more carbohydrate accumulation at increased CO_2 level. Nitrogen uptake by rice plants increased under elevated CO_2 condition and was more with increased N doses. Agronomic efficiency of N application was higher under elevated CO_2 condition while recovery efficiency was not affected much by the CO_2 level. From the current study it is evident that under elevated CO_2 condition growth and yield of rice crop will increase but the quality of grains might get affected. In order to increase grain nitrogen concentration of rice there may be a need to apply higher N doses at elevated CO_2 level.

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