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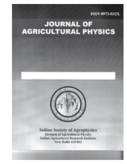

Research Article

Uptake of Iron and Zinc in Rice Crop as Affected by Elevated Atmospheric Carbon Dioxide and Nitrogen Doses

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ABSTRACT

Increasing ambient carbon dioxide (CO_2) level, affects rice crop growth, yield and nutrient uptake. An experiment was conducted during the *kharif* season (2013) in the Free Air Carbon dioxide Enrichment (FACE) facility at IARI farms, New Delhi to study the impact of elevated CO_2 and Nitrogen (N) doses on uptake of iron (Fe) and zinc (Zn) in rice crop. Three N doses (N0-control, N1-100% and N2-125% N of recommended dose) were applied in both ambient (395 ppm) and elevated CO_2 (550 ± 20 ppm) conditions. Results showed that elevated CO_2 level significantly enhanced both grain and biomass yields of rice crop, however Fe and Zn content in rough rice grain were found to be reduced significantly by 3.6% and 5.5% with recommended N dose but the effect was minimized to certain extent with additional doses of N. Although concentration of Fe and Zn in rough rice grain decreases but since the biomass and grain yield increases, uptake of Fe and Zn increased significantly with rise in CO_2 level and with N application.

Key words: Elevated CO_2, Iron uptake, Rice, Yield, Zinc uptake

Introduction

Rice (*Oryza sativa* L.) is a major staple food crop of the world and is a mainstay for the rural population and their food security. It is cultivated on nearly 162.3 million hectares (Mha) area and contributing about 738.1 million tons (Mt) i.e., 34% of the global food grain production (FAO, 2014). South and South East Asia accounts for 90% of rice grown and consumed, where the normal consumption rate lies around 300 to 800 g (per person per day) (Virk and Barry, 2009). Micronutrient malnutrition has been reported to be a major health problem affecting about 2 billion population worldwide, especially in countries with a high rate of cereal consumption (Black *et al*., 2003). Zn deficiency has affected 27% of total population in India leading to various disorders such as weak immune system, diarrhea, slow mental and physical growth (World Health Organization, 2007). Rice is consumed in large proportion and is an indispensable staple food for half of the world's population providing 50–85% of daily energy source. Rice is also vital from nutrition point of view, however low levels of vital micronutrients especially Fe and Zn are observed in rice crops similar to other staple food crops (Virk and Barry 2009; Bouis and Welch, 2010). Therefore, even a small increment/decline in the nutritive value of rice can have high impacts on human nutrition (Zeng *et al*., 2010; Chandel *et al*., 2010).

Rising CO_2 levels in the atmosphere and related CO_2 fertilization effect will likely affect

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Table 1. Treatment details of the experiment

CO_2 level	Treatment	Dose of N
Ambient (395 ppm)	N0	Control (without external input of N)
	N1	0.8 g N pot^{-1} (100% of recommended dose)†
	N2	1.0 g N pot^{-1} (125% of recommended dose)
Elevated (550±20 ppm)	N0	Control (without external input of N)
	N1	0.8 g N pot^{-1} (100% of recommended dose)
	N2	1.0 g N pot^{-1} (125% of recommended dose)

†Recommended dose of N 120 kg ha^{-1}

nutritional composition of rice grain. It has been reported that elevated CO_2 induces reduction in grain micronutrients content, particularly Zn and Fe (Kumar and Patra, 2010). Seneweera and Conroy (1997) has reported 5% decline for phosphorous (P), 28% for zinc (Zn) and 17% for iron (Fe) in rice grain grown under elevated CO_2 condition. Similarly in case of wheat grown under elevated CO_2 condition, Zn and Fe concentrations declined by as much as 25%, whereas only ~ 5% (average for two cultivars of wheat) reduction in P concentration has been reported (Manderscheid *et al*., 1995). Likewise, in another experiment under elevated CO_2 condition, P concentration in wheat grain reduced by only 3.7% (averaged for two N doses) compared to 30% for Fe and 15.1% for Zn (Fangmeier *et al*., 1997). Therefore this experimental study was set out to establish the effect of elevated CO_2 on rice yield and nutritional quality (especially for Fe and Zn) of grain and their association with N doses which could be of significance for sustaining human nutritional well-being and in the planning of bio-fortification programs in the phase of climate change.

Materials and Methods

Experimental site and soil

A pot experiment was conducted during the *kharif* season (2013) using Free Air Carbon dioxide Enrichment (FACE) facility in Indian Agricultural Research Institute farm, New Delhi. The site is located in the Indo-Gangetic alluvial tract of the subtropical semiarid region at 28°402 N and 77°122 E, at an altitude of 228 m above mean sea level. The pots (30 cm diameter) were filled with 15 kg of soil. The soil was alluvial, sandy loam in texture with pH 7.6 (Table 2).

Table 2. Physico-chemical properties of the experimental soil

Parameters	Values
Texture class	Sandy loam (Sand - 48%, Silt - 26%, Clay - 26%)
pH (1:2::Soil:Water)	7.6
Electrical conductivity (d S m^{-1})	0.47
Available Fe (ppm)	9.5
Available Zn (ppm)	5.7

Experimental design and treatments

The experiment was conducted by growing rice variety Pusa 44 in pots kept inside and outside the FACE ring to maintain elevated and ambient CO_2 level respectively. Rice seedlings (30 days old) were transplanted in duplicate in each pot. At crop canopy level, CO_2 concentration was set at 550±20 ppm using the SCADA software based-FACE facility whereas ambient CO_2 concentration was about 395 ppm (Chakrabarti *et al*, 2012). The three N levels were without external nitrogen input (N0), 0.8 g N pot^{-1} (N1) and 1.0 g N pot^{-1} (N2), which were equivalent to control, 100% and 125% recommended dose of N respectively. Recommended dose of N was taken as 120 kg N ha^{-1}. In total there were 6 treatments with 3 replications each (Table 1).

Soil and plant analysis

Physicochemical properties of soil were analyzed using standard methods.

Available zinc (Zn) and iron (Fe) were determined by extracting soil sample with DTPA-

Table 3. Impact of elevated carbon dioxide and N doses on micro-nutrients (Fe and Zn) in rough rice grain

N dose	Fe (ppm)				Zn (ppm)			
(g pot^{-1})	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	145.7	132.1	138.9	-9.3	34.4	31.5	32.97	-8.5
0.8	150.2	144.8	147.5	-3.6	34.8	32.9	33.85	-5.5
1	150.9	148.6	149.8	-1.5	35.0	33.6	34.30	-4.0
Mean	148.9	141.8			34.7	32.7		
LSD		N: 6				N: 0.14		
(P = 0.05)		CO_2: 4				CO_2: 3		
		N × CO_2: NS				N × CO_2: NS		

LSD: Least Significant Difference

extractant as outlined by Lindsay and Norvel (1978) and metals in the extracts were estimated by using an atomic absorption spectrophotometer (AAS). Zinc and iron contents in the extract of rough rice grain (with husk) obtained after digestion in di-acid mixture (HNO_3:$HClO_4$ :: 10:4), were determined by an atomic absorption spectrophotometer AAS (Jackson, 1973).

Nutrient uptake (Fe and Zn) in rough rice grain (with husk) and other parts of rice plant was calculated using following formula:

$$\text{Nutrient (Fe and Zn) uptake (mg pot}^{-1}) = \frac{\text{Nutrient content (ppm) in dry matter} \times \text{Dry matter yield (g pot}^{-1})}{1000}$$

Data analysis

Analysis of variance (ANOVA) technique was used for the statistical analysis of the data recommended for the design (Gomez and Gomez, 1984). Unless indicated otherwise, differences were considered significant at $P<0.05$.

Results and Discussion

Impact of elevated CO_2 on soil micronutrients (Fe and Zn) content under rice crop

Available iron and zinc content of soil was neither affected significantly by elevated CO_2 nor by N levels in the experiment. The available Fe content in soil was at par under both CO_2 and N treatments. Similar result was observed with the available Zn content in the soil.

Impact of elevated CO_2 on grain and biomass yield in rice crop

An elevated CO_2 level of 550±20 ppm, enhanced grain and biomass yield of the crop. Application of nitrogen significantly increased grain and biomass yield of rice crop in both ambient and elevated CO_2 condition over control. Similar result has been reported by earlier workers who found that rice yield increased about 30% with doubled CO_2 concentration (Horie *et al.*, 2000).

Impact of elevated CO_2 and N doses on Fe and Zn content in rough rice grain

Fe as well as Zn content (%) in rough rice, i.e. consisting of edible portion, rice caryopsis, and its covering structure, the fibrous husk, significantly decreased under elevated CO_2 condition (Table 3). On the other hand, application of N fertilizer significantly increased Fe and Zn content in rough rice grain under both ambient and elevated CO_2 condition. Under elevated CO_2 condition, Fe and Zn content in rough rice grain were reduced but the effect was minimized to some extent with additional doses of N. Fe content in rough rice grain was found to be highest under N2 treatment both under ambient (150.9 ppm) and elevated CO_2 (148.6 ppm) conditions (Table 3). Similar was the case with Zn content. Grain Zn concentration was 34.7 ppm under elevated CO_2 treatment while in ambient condition Zn concentration in rough rice grains was 32.7 ppm (Table 3). Increased biomass under elevated CO_2 condition resulted in dilution effect which has lowered Fe and Zn concentration in rice grain. Some other researchers have also reported CO_2-induced grain micronutrients reduction particularly Fe and Zn concentration in plant grown under elevated CO_2 condition (Kumar and Patra, 2010).

Impact of elevated CO_2 and N doses on Fe and Zn uptake in rice

Total uptake of Fe and Zn increased under both elevated CO_2 condition and increased doses of N over ambient condition. It has been found that total uptake of Fe and Zn with elevated CO_2 level, increased by 27.5% and 18.6% respectively under N2 treatment (Fig. 1 and 2). Similar was the case with grain uptake of Fe and Zn which increased by 37.7% and 20.5% respectively under N2 treatment with elevated CO_2 condition (Fig. 1 and 2).Under elevated CO_2 condition over ambient, rough grain Fe uptake increased from 7.6 mg pot^{-1} to 10.4 mg pot^{-1} with N1 dose whereas 9.5 mg pot^{-1} to 12.1 mg pot^{-1} with N2 treatment (Fig. 1). Similarly Zn uptake in rough rice grain also get increased from 1.4 mg pot^{-1} to 1.6 mg pot^{-1} under N1 dose and 1.4 mg pot^{-1} to 1.7 mg pot^{-1} with N2 dose under elevated CO_2 condition over ambient (Fig. 2).

It has been found that with the application of N dose, the per cent increase in Fe and Zn uptake was more under elevated CO_2 condition. Enhanced grain and biomass yield and also the root biomass at elevated CO_2 condition were among the major reasons which resulted in higher micronutrient uptake of the crop. Similar result

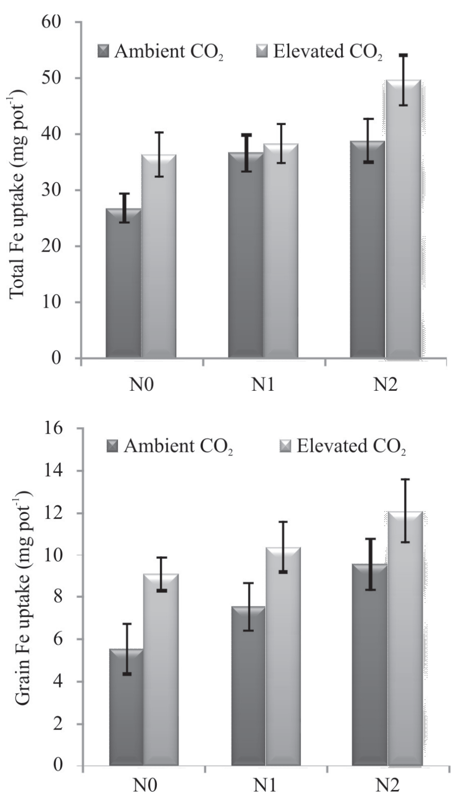

Fig. 1. Impact of elevated CO_2 and N doses on Total and grain (rough rice) Fe uptake of rice crop

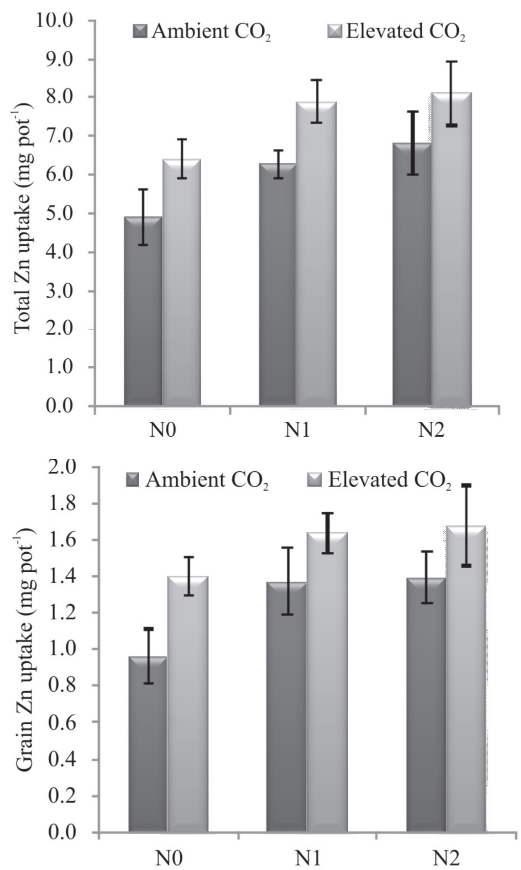

Fig. 2. Impact of elevated CO_2 and N doses on total and grain (rough rice) Zn uptake of rice crop

Note: N0 - Control (no N), N1 - 0.8 g N pot^{-1} (100% of recommended dose) and N2- 1.0 g N pot^{-1} (125% of recommended dose) has been reported for an increased level of Fe and Zn uptake in rice grain and straw with increase in rate of N application (Duhan and Singh, 2002; Dash *et al*., 2010)

Conclusion

Elevated CO_2 significantly enhanced both grain and biomass yields of rice crop. Fe and Zn content in rough rice grain (with husk) decreased significantly under elevated CO_2 condition. Total as well as rough grain uptake of Fe and Zn increased significantly with rise in CO_2 level but supplemental N application enhances the rate of uptake. Result showed that increased yield at higher CO_2 level has resulted in higher micronutrient uptake of the crop but not at the same pace as the enhancement of grain and biomass yields which lead to dilution effect. Due to dilution effect, Fe and Zn content found to be reduced under elevated CO_2 condition over ambient but with the application of N doses, dilution effect get reduced to certain extent. This indicates that in future climate change scenario of a high CO_2 world there is possibility of decline in bioavailability of Fe and Zn content in rice crop but with the application of higher N doses this problem can be minimized up to certain extent.

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