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Research Article

Interactive Effect of Elevated Carbon Dioxide (CO_2) and Temperature on Growth and Plant Nitrogen in Rice Varieties

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ABSTRACT

Elevated CO_2 and temperature will affect productivity of crops along with change in nutrient supply and demand. Rice (*Oryza sativa* L.) is one of the important cereal crops and building block for national food grain supply. The current study was undertaken to quantify the interactive effects of elevated CO_2 and temperature on growth and plant N in different rice varieties. Four different varieties (Pusa basmati 1509, Pusa 44, PRH 10 and Nagina 22) of rice were grown inside the Open Top Chambers (OTCs) under two different CO_2 concentrations, ambient (400 ppm) and elevated (550 ± 25 ppm) as well as two different temperatures (ambient and elevated). Photosynthesis rate of rice varieties increased under elevated CO_2 concentration resulting in more biomass accumulation. Temperature elevation by 2°C decreased grain yield in Pusa Basmati 1509, Pusa 44 and PRH 10 varieties by 2.8%, 3.8% and 2.6% respectively than chamber control. Nagina 22 being a heat tolerant variety was not affected by the temperature rise. Elevated CO_2 concentration of 550 ppm was able to compensate the yield loss caused by 2°C rises in temperature. Grain N concentration reduced in elevated CO_2 treatment. Increased root weight under elevated CO_2 concentration resulted in more N uptake leading to depletion of available N in soil.

Key words: Rice, Elevated CO_2, Temperature, Nitrogen

Introduction

Food production is both directly and indirectly affected by the changing climate. Atmospheric carbon dioxide (CO_2) concentration has increased from 280 ppm during preindustrial time to 400 ppm at present (Dlugokencky and Pieter, 2015) leading to rise in the temperature. Increase in temperature and carbon dioxide (CO_2) concentration will significantly affect agricultural productivity and food security (Ainsworth *et al*., 2007). Although increase in temperature has harmful effect on crops but elevated CO_2 level can negate the harmful effect of rising temperature to certain extent (Singh *et al*., 2013). Rising CO_2 concentration along with increased temperature will affect crop productivity, nutrient cycling, and also the soil hydrothermal regimes (Chakrabarti *et al*., 2021; Maity *et al*., 2020; Pramanik *et al*., 2018). There are reports that increase in CO_2 concentration increases growth and yield of different cereal crops like rice, wheat, maize (Chakrabarti *et al*., 2020a,b; Raj *et al*., 2019) while increased temperature shortens the crop growth duration and reduces yield (Chakrabarti *et al*., 2013; Sandhu *et al*., 2017).

Rice (*Oryza sativa L.*) is one of the most important cereal crops and forms the backbone for National food grain supply (Raj *et al*., 2016). Global climate change can affect rice crop through increased

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atmospheric CO_2 concentration, rising temperature and changes in the precipitation pattern (Soora *et al*., 2013). Inadequate nutrient supply could also alter the source–sink balance in crop plants under elevated CO_2 concentration (Hymus *et al*., 2001). Elevated CO_2 concentration and high temperature is affecting the carbon cycle leading to both positive and negative feedbacks to the climate system (Pendall *et al*., 2004). Among the mineral nutrients, nitrogen (N) plays a very important role in regulating productivity and quality of rice crop. Availability of N in plants depends on the soil N cycle and N inputs added to the agro ecosystem (Rütting and Andresen, 2015). There are reports that, under future climatic condition N uptake by the crop would be more which would further deplete soil N (Maity *et al*., 2020). Earlier researchers reported that plant nutrient requirement will increase in future due to the CO_2 fertilisation effect thereby causing N limitation in plants (Lenka *et al*., 2021; Raj *et al*., 2019). Besides this N demand and its availability might vary with crop growth stages affecting productivity of the crop. Higher air temperature can alter nutrient cycling thus affecting fertility of the soil (Auyeung *et al*., 2013). Some researchers also reported that in a changing climate, soil N mineralisation will be more resulting in a positive effect on growth of plants (Joshi *et al*., 2006; Norby *et al*., 2004). Studies on the interactive effect of elevated CO_2 and temperature on rice varieties is still very limited especially under tropical condition. The following study was undertaken to study the interactive effect of elevated CO_2 and temperature on growth, yield and plant N in different rice varieties.

Materials and Methods

Study site

An experiment was conducted during the *kharif* season (July to October) of year 2016, at the Genetic-H field of ICAR-Indian Agricultural Research Institute New Delhi (28°35′N and 77°12′E). The climate of the area is subtropical semi arid with annual rainfall of around 750 mm. The seasonal mean temperature during the crop growth period was 27.9°C. Four different varieties of rice crop i.e. Pusa basmati 1509, Pusa 44, Pusa rice hybrid 10 and Nagina 22 were grown in crates inside the Open Top Chambers (OTCs). The crop varieties were subjected to two different CO_2 concentrations, ambient (400 ppm) and elevated (550 ± 25 ppm). Carbon dioxide gas was supplied from the CO_2 gas cylinders of 30 kg capacity and CO_2 concentration was measured using Infra-Red Gas Analyser (IRGA) (Fuji, Japan). When the CO_2 concentration fell below the specified value, the solenoid valves opened to release CO_2 inside the OTCs. In elevated temperature treatment, higher temperature was maintained by partially covering the upper portion of the OTCs. A digital thermometer placed within the OTCs was used to record the daily maximum and minimum temperatures throughout the crop growth period. The crop was transplanted in crates on third week of July. Each crate was filled with 40 kg soil. The soil was non-saline (EC 0.47 dS m^{-1}) and alkaline in nature (pH 7.8) containing 0.49% organic carbon. Recommended dose of nitrogen (120 kg ha^{-1}) was applied in three stages: 50 percent of the required amount at transplanting, and the remaining 50 percent in two equal splits at tillering and flowering. Phosphorus and potassium were also applied at recommended doses (60 kg ha^{-1}) through di ammonium phosphate (DAP) and murate of potash (MOP) during transplanting of the crop.

Crop growth and yield

Photosynthesis rate

At flowering stage of the crop, photosynthesis rate was recorded using portable Infrared Gas Analyzer (LI-6400XT, LiCOR, USA). Observations were recorded on physiologically matured leaves between 9 AM to 11 AM in the morning.

Yield

Plant samples were collected after harvest and dry weights were recorded. Biomass and grain yields were measured after the crop was harvested.

Plant Nitrogen

After harvest, grain samples were dried in oven at 65± 2°C for 72 h. Dried samples were ground in a Wiley mill. Nitrogen concentration in rice grains was analysed by the method given by (Jackson, 1973).

Table 1. Treatment details

Ambient CO_2		Elevated CO_2	
Chamber control temperature	Elevated temperature	Chamber control temperature	Elevated temperature
PB 1509	PB 1509	PB 1509	PB 1509
Pusa 44	Pusa 44	Pusa 44	Pusa 44
PRH 10	PRH 10	PRH 10	PRH 10
Nagina 22	Nagina 22	Nagina 22	Nagina 22

Available nitrogen

Soil samples were collected from three crates in each treatment at flowering stage. Available nitrogen content in soil was estimated following the method given by (Subbiah and Asija, 1956).

Statistical analysis of data

The experimental design was factorial Completely Randomised Design (CRD). There were 16 treatments with three replications (Table 1). Statistical analysis of the data was done using SAS software (ver. 9.3; SAS Institute Inc., CA, USA).

Results and Discussion

Impact of elevated CO_2 and temperature on growth and yield of rice crop

Results showed that photosynthesis rate of rice varieties significantly increased under elevated CO_2 condition. Maximum photosynthesis rate (18.2 µmol CO_2 m^{-2} s^{-1}) was recorded in PRH 10 variety in elevated CO_2 treatment at flowering stage (Fig. 1). Although elevated temperature caused reduction in photosynthesis rate in all rice varieties but elevated CO_2 along with elevated temperature treatment increased photosynthesis rate as compared to chamber control. Earlier researchers also observed that increase in CO_2 concentration increases photosynthesis rate and productivity in crop plants (Dey *et al*., 2017; Wang *et al*., 2012). Increased photosynthesis rate in elevated CO_2 treatment caused production of more tillers than chamber control. Rise in temperature by 2°C significantly reduced tiller number in Pusa Basmati 1509, Pusa 44 and PRH 10 varieties while in Nagina 22, temperature rise had no effect on number of tillers per plant. Elevated temperature decreased grain yield in Pusa Basmati 1509, Pusa 44 and PRH 10 varieties by 2.8%, 3.8% and 2.6%, respectively than chamber control while Nagina 22 variety showed no significant change in yield with 2°C temperature rise (Fig. 2). But in

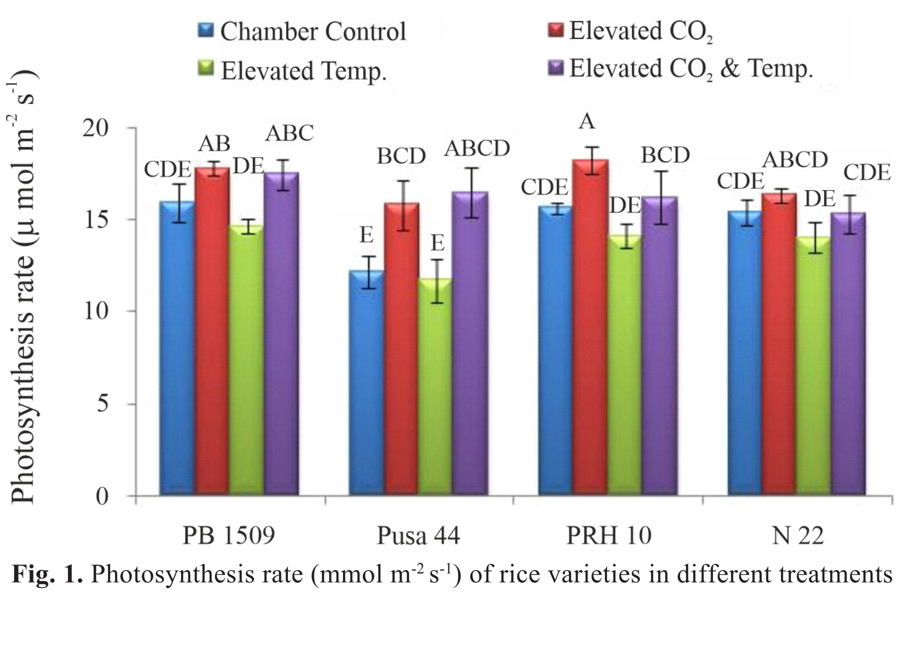

Fig. 1. Photosynthesis rate (mmol m^{-2} s^{-1}) of rice varieties in different treatments

elevated CO_2 plus elevated temperature treatment enhanced grain yield was recorded in all the varieties than chamber control treatment. Grain yield of Pusa Basmati 1509 increased by 5.7%, Pusa 44 by 7.1%, PRH 10 by 4.1% and Nagina 22 by 4% when carbon dioxide concentration was increased along with increase in temperature. Singh *et al*. (2013) also reported that elevated CO_2 concentration of 550 ppm was able to compensate the yield loss caused by temperature rise upto 3°C in rice crop.

Impact of elevated CO_2 and temperature on plant N in rice

Nitrogen (N) concentration in grains significantly decreased under elevated CO_2 concentration in PB 1509 and Pusa 44 rice varieties (Fig. 3). In chamber control treatment grain N concentration was 1.14% and 1.12% in Pusa Basmati 1509 and Pusa 44 varieties respectively while in elevated CO_2 treatment it was 0.99% and 0.98%. But there was no significant change in grain N in elevated CO_2 plus elevated temperature treatment in all the varieties. Negative correlation between grain N concentration and grain weight (Fig. 4a) depicts that under elevated CO_2 condition more carbohydrate accumulation led to the dilution of grain N (Wechsung *et al*., 1999). There are reports of decrease in N and crude protein content in different cereals under elevated CO_2 condition (Chakrabarti *et al*., 2020b; Abebe *et al*., 2016).

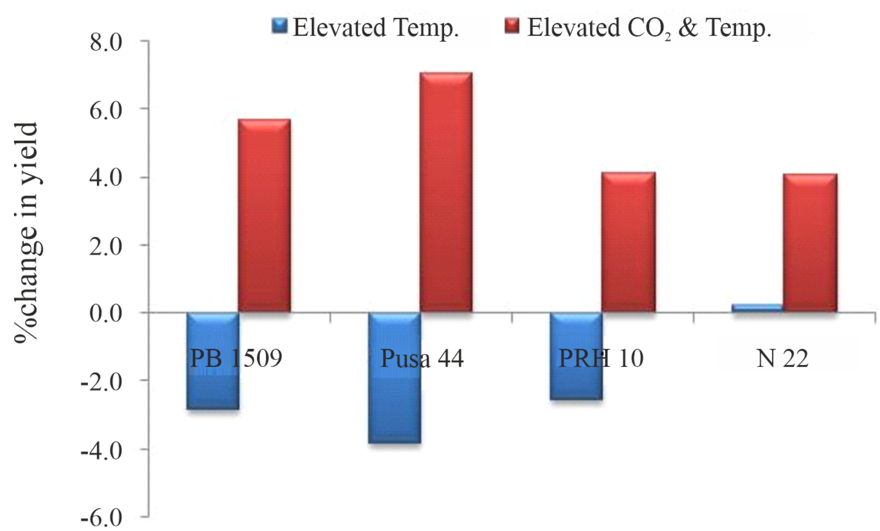

Fig. 2. Percent change in grain yield of rice varieties under elevated temperature and CO_2 condition

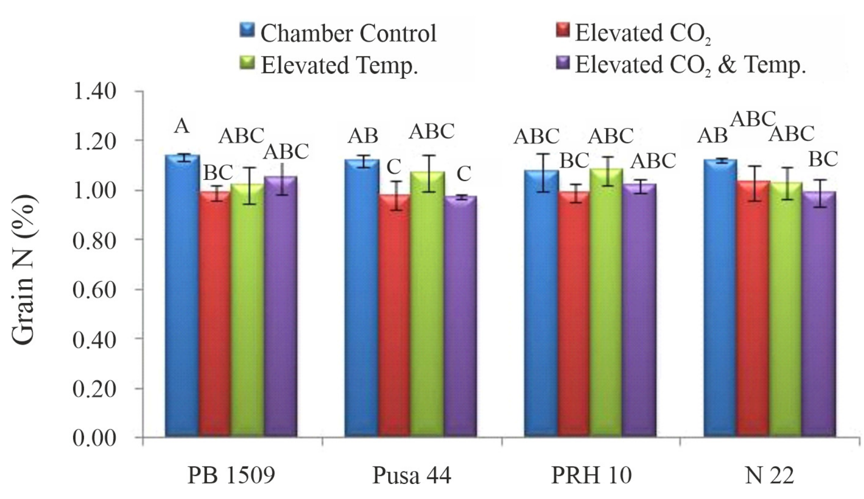

Fig. 3. Grain N content (%) of rice varieties in different treatments

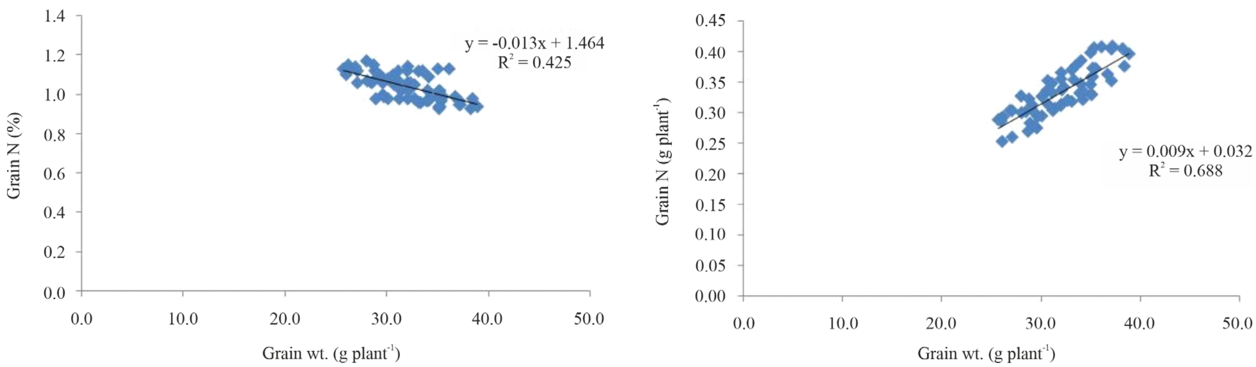

Fig. 4. Correlation between (a) grain weight and grain N concentration and (b) grain weight and grain N uptake in rice varieties in different treatments

Nitrogen uptake in rice grains ranged from 0.31 to 0.37 g plant^{-1} in different treatments (Table 2). N uptake by rice grains significantly decreased in elevated temperature treatment due to lower grain weight of the crop. In elevated CO_2 plus temperature treatment, grain N uptake was lower than chamber control in Pusa 44 and Nagina 22 varieties (Table 2). Increased CO_2 concentration was able to compensate for the rise in temperature in terms of maintaining grain N uptake in rice varieties. Similar results were reported by Raj and Chakrabarti (2016) who found that N uptake in rice grain as well as total N uptake significantly decreased with rise in temperature. Although N concentration in rice grains decreased under elevated CO_2 condition but there was no change in grain N uptake in elevated CO_2 treatment due to increased grain yield of the crop. Correlation analysis between grain weight and grain N concentration showed that grain N concentration is negatively correlated with grain weight of the crop (r = -0.72) (Fig. 4a). But N uptake in rice grains is positively correlated with grain weight (r = 0.82) (Fig. 4b). Positive correlation analysis between grain N uptake and grain weight shows that increase in grain yield led to higher N uptake by the rice varieties.

Soil available N as affected by elevated CO_2 and temperature

Soil available N was found to be significantly lower in elevated CO_2 treatment. Soil available N at flowering stage was 217.8 kg ha^{-1} in chamber control while in elevated CO_2 treatment it was 211.3 kg ha^{-1} (Table 3). Soil available N was higher in Pusa 44 and Nagina 22 varieties than PB 1509 and PRH 10. Elevated temperature had no effect on available N of soil. But in elevated CO_2 plus elevated temperature treatment soil available N was less than chamber control. Soil available N was found to be negatively correlated with root weight at flowering stage of the crop. (r=-0.59) (Fig. 5). Higher growth and biomass

Table 2. Grain N in plant (g plant^{-1}) under elevated CO_2 and temperature condition

Varieties	Ambient CO_2		Elevated CO_2	
	Chamber control temperature	Elevated temperature	Chamber control temperature	Elevated temperature
PB 1509	0.37	0.32	0.36	0.36
Pusa 44	0.33	0.31	0.33	0.31
PRH 10	0.34	0.33	0.35	0.33
N 22	0.34	0.31	0.33	0.31
Mean	0.35	0.32	0.34	0.33

LSD ($p \le 0.05$): CO_2: NS; Temp: 0.02; Var.: NS; CO_2 × Temp: NS; CO_2 × Var: NS; Temp × Var: NS; CO_2 × Temp × Var: NS

Table 3. Impact of elevated CO_2 and temperature on soil available N at flowering stage

Varieties	Ambient CO_2		Elevated CO_2	
	Chamber control temperature	Elevated temperature	Chamber control temperature	Elevated temperature
PB 1509	228.0	207.5	201.5	221.1
Pusa 44	276.4	245.0	249.1	267.6
PRH 10	212.5	212.1	188.2	205.6
N 22	289.3	224.5	241.5	215.3
Mean	228.0	207.5	201.5	221.1

LSD ($p \leq 0.05$): CO_2: 5.6; Temp: NS; Var.: 8.2; CO_2 × Temp:8.2; CO_2 × Var.: NS; Temp × Var.: NS; CO_2 × Temp × Var.: NS

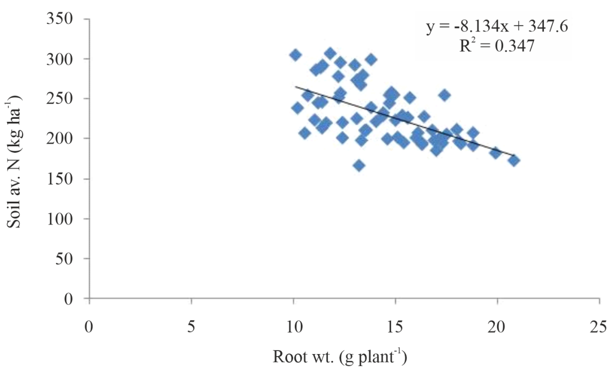

Fig. 5. Correlation between root weight and soil available N in rice varieties at flowering stage

of crop under elevated CO_2 condition led to higher N uptake resulting in lower available N status of soil. Similar results were reported by other researchers who reported that soil N status will deplete under elevated CO_2 and temperature condition to meet the plant N demand (Maity *et al*., 2020; Yang *et al*., 2007). The negative correlation between root weight and soil available N at flowering stage clearly depicts that increased root weight under elevated CO_2 concentration resulted in more N uptake leading to depletion of available N in soil. According to Weerakoon *et al*. (2005) increased N uptake by rice under elevated CO_2 condition was attributed to larger root system of the crop.

Conclusions

Carbon dioxide levels in the atmosphere are growing, causing climate change and reducing agricultural production. From the following study we can conclude that elevated CO_2 concentration of 550 ppm was be able to compensate the yield loss caused by 2°C temperature rises in Pusa Basmati 1509, Pusa 44 and PRH 10 rice varieties. Under elevated CO_2 condition, N concentration in rice grains reduced but N uptake increased leading to depletion of soil available N. As a result, it is plausible to conclude that the CO_2 fertilization effect can mitigate the detrimental effects of rising temperatures on crop to some extent.

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