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ARTICLE

Effect of Elevated [CO_2] and Nutrient Management on Grain Yield and Milling Quality of Rice in Subtropical India

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ABSTRACT

The climate change due to mingled effect of rising [CO_2] level and temperature will influence crop production by affecting various components of the production system. In the present study, Open Top Chamber (OTC) facility has been used to realize the consequence of rising [CO_2] with nutrient management on rice crop. The experiment was organized in open field and inside OTC with ambient [CO_2] (400 ppm) and elevated [CO_2] (25%, 50% and 75% higher than ambient) in wet season of the year 2017-18 at Kharagpur, India. Increase in [CO_2] level resulted decreasing trend in growth, yield attributes (filled grains number) and grain yield. The nutrient management with use of only chemical fertilizer at recommended dose gave highest grain yield, which was comparable with integrated management using chemical and biofertilizer. Post-harvest processing quality such as head rice percentage and the head rice yield decreased significantly with CO_2 elevation. The elevated [CO_2] with 25 to 75% higher than ambient, reduced the head rice percentage by 13 to 21 %. The research stated that investigations on climate change adaptations should be made to avoid the negative impact of rising [CO_2] level and temperature on crop yield and processing quality.

1. Introduction

Climate change and its variability is a major issue and has greater impact on global food production. Along with this, growing population and increasing demand for food is a threat for survival of upcoming generations. Due to rising levels of greenhouse gases mainly [CO_2], temperature is increasing and causes uncertainty in rainfall, which further has both absolute and erratic effect on global food production [13]. Increasing atmospheric [CO_2] influences all the physiological process in plants, and are expected to influence the growth and yield of the crop, composition of grains, and post-harvest qualities of grains.

According to previous studies, rising atmospheric [CO_2] level increased yield of food grains in absence of temperature increase [2, 18]. Rice being C3 crop, behaves positively with increasing atmospheric [CO_2] due to increasing carbon assimilation rates. But the combined effect of erratic rainfall and rising temperature will have variable effect on the production. Rising temperature with atmospheric [CO_2] elevation increases respiration rate in plants, which is likely to affect the yield of food grain under [CO_2] elevation. The temperature rise diminishes the absolute effect of rising [CO_2] level on grain yield of cereal crops [16, 17]. As rice crop is very sensi-

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tive to temperature, it is adversely affected by varying temperature and results in yield loss. The temperature rise can minimise the duration of crop, expedite evapotranspiration and respiration rates, and reduce fertilizer use efficiency. The rice production in India is highly susceptible to changing climate, and since 1990s, the productivity of rice cultivation has declined as compared to population growth rate [1]. Rising temperature and erratic rainfall due the climate change/variability are some of the key reasons for the decreasing rice productivity [11]. It is important to understand and find out the solutions of these problems arising due to changing climate and its rapid variability, as atmospheric [CO_2] is predicted to reach 535 – 983 ppm by 2100 [11].

According to previous studies, increasing level of [CO_2] increased soil microbial use of N, which resulted in decreasing soil available N [10]. Decreasing soil available N influences crop growth, yield, and post-harvest processing qualities. Insufficient nutrient supply and high temperature affects the grain quality of rice and produces chalky grains which breaks very easily while undergoing the process of milling. It has been observed that higher amount of nitrogen increases the grain hardness and provide resistance from deterioration during the process of milling [14]. Open Top Chambers (OTCs) are the most widely used and accurate method for exposing field-grown crops to elevated CO_2 and other atmospheric gases [20]. There is limited research on the effect of nutrient management and elevated [CO_2] on growth, yield and processing quality of rice. Hence, it is necessary to adapt nutrient management treatments to maintain the available nutrients in the soil for meeting the crop demand under varying environment. In view of this, the present investigation was formulated to study the effect of elevated [CO_2] with varying nitrogen management in OTC experiment on grain yield and milling qualities of rice.

2. Materials and Methods

2.1 Experiment Site

The field experiment was performed in the research farm of Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, Kharagpur (22°19'N latitude and 87°19'E longitude). The soil of the field experimental site is red lateritic type with sandy loam in texture. The relevant soil properties are low available N content, available K content, and organic C with medium available P content. The location meet with an average annual rainfall of 1500 mm having humid and subtropical climate. The average maximum and minimum temperature ranges from 25°C in December/January to 38°C in April/May and 15°C in December/January to 25°C in June, respectively.

2.2 Experimental Details

The experiment was conducted in open field and inside OTCs in wet season of the year 2017-18. The OTCs made up of polycarbonate sheets having at least 80% light transmitting capacity, were used to build microhabitats with different environmental conditions (ambient and elevated). The treatment details including environmental conditions and nutrient management are explained below:

Factor 1: Environmental conditions (E)

(1) Open Field (OF): Open field under ambient conditions

(2) OTC(Amb CO_2): OTC along with ambient level of [CO_2](≈ 400 ppm)

(3) OTC(+25% CO_2): OTC along with 25% higher [CO_2] level than OTC(Amb CO_2)(≈ 500 ppm)

(4) OTC(+50% CO_2): OTC along with 50% higher [CO_2] level than OTC(Amb CO_2) (≈ 600 ppm)

(5) OTC(+75% CO_2): OTC along with 75% higher [CO_2] level than OTC(Amb CO2) (≈ 700 ppm)

Factor 2: Nutrient management (N)

(1) N0-Control (no application of fertiliser)

(2) N(CF100)- Application of 100% recommended dose (N, P and K) of Chemical fertilizer (CF)

(3) N(CF50 + BF50)- Application of 50% recommended dose (N,P and K) of CF with 50% N recommendation of Bio fertilizer (BF) ; Integrated nutrient management

(4) N(BF100)-BF at 100% N recommendation

The fertilizer application for CF100 was done on the basis of recommendation (N: P_2O_5: K_2O -100:50:60 kg ha^{-1}).The BF source was blue-green algae, which was cultivated in the research farm. The blue-green algae as BF100 was applied at 1 t ha^{-1}. In all the experimental plots except N0 (control), P_2O_5 and K_2O were applied full as basal through the application of single super phosphate and muriate of potash, respectively. The source of N for CF was urea, which was applied in three equal splits i.e. planting, tillering and panicle initiation. The Nitrogen requirement For BF100, blue green algae were used as per fresh weight which contains 4% N. The BF was applied in four splits in 15-20 days interval from transplanting.

The four N management treatments were applied in each environmental condition with two replications. The experiment was conducted in a split-plot design, where environmental conditions were in main plot and N management in sub-plot of the design.

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2.3 Experimental Setup and Instrumentation

There were four OTCs and one open field and each of them were divided into eight sub-plots of size 1.8m × 1m. Carbon dioxide monitors, relative humidity sensors, and temperature probes were us ed to continuously check the level of [CO_2], relative humidity, and air temperature, respectively. Elevation of [CO_2] inside OTC was guarded by computer aided SCADA (Supervisory control and data acquisition) system. The system controlled the flow of CO_2 as per the desired level of [CO_2] inside OTC and data were logged on daily basis at 1 min time lapse. Whenever the level of [CO_2] was lower than the desired level, system passes a command for releasing CO_2 into the OTC. The release of CO_2 was automatically stopped when the flow of CO_2 reaches the desired level. The [CO_2] level for open field was about 400 ppm, and was maintained accordingly at 25%, 50% and 75% higher than in the open field for OTC with elevated [CO_2] through the computerized real system.

2.4 Crop Management

The popular rice cultivar IR36 was selected for the experiment. Tillage operations in the experimental field were performed 10 days prior to transplanting and puddled 5 days before transplanting. The seedlings of 25 days were transplanted on 14 July 2017 with row and hill spacing 20 cm and 15 cm, respectively using 2 seedlings per hill. Irrigation was given at the critical growth stages and whenever required to maintain saturation throughout.

2.5 Plant Sampling for Biomass Partitioning

Tiller numbers of twenty hills of each plot were noted, and average tiller number of illustrative hill was established at every 20 days interval till harvesting. The representative hill was treated as sample hill, and detached into leaves, stems, and panicles. The separated parts were stored in an over for drying at 70^{O}C till constant weight was recorded. The dry weight of stem, leaf and panicles were taken.

2.6 Yield Attributes and Grain Yield

Plants were harvested from 150cm × 60cm area at the centre of each experimental plot to evaluate the grain yield of rice. The total number of panicle in the selected area was assessed and two illustrative hills were selected to determine the filled grain number for each panicle. The required observations for other yield attributes were also recorded. The grains were then separated from the harvested plants of the selected area to get the grain and straw yield for each experimental plot.

2.7 Rice Milling Quality

200g of cleaned and air-dried grain samples were collected from the harvested grains of each plot and stored for a month at ambient condition before milling, for further analysis of processing qualities. Rubber Roll Sheller was used for dehulling the rice grains to produce brown rice (BR), and then milled with rice polishing machine to calculate percentage of brown rice [12]. The degree of polish, brown rice percentage (BRP), milled rice percentage (MRP) and head rice percentage (HRP) were calculated after separation of head and broken rice. The brown rice yield (BRY), milled rice yield (MRY) and head rice yield (HRY) was calculated by multiplying each of them with rough rice yield [20].

$$\text{Degree of polish (DP)} = \frac{\text{weight of bran (g)}}{\text{weight of brown rice(g)}} *100$$

$$\text{BRP} = \frac{\text{weight of brown rice (g)}}{\text{weight of rough rice (g)}} *100$$

$$\text{MRP} = \frac{\text{weight of milled rice (g)}}{\text{weight of rough rice (g)}} *100$$

$$\text{HRP} = \frac{\text{weight of head rice (g)}}{\text{weight of rough rice (g)}} *100$$

2.8 Statistical Analysis

The experiment was conducted in a split plot design with 20 treatment combinations [environmental conditions (5) × nutrient management (4)] and two replications. The significance of factors was tested for each observations at p=0.05 by preparing Analysis of variance (ANOVA) of the observed data. Evaluation of treatment effects is done by calculating Least significant difference (at p=0.05) among the treatment means.

3. Results and Discussion

3.1 Above Ground Biomass

The observations for above ground biomass including leaf, stem and panicle at 60 DAT (Days after transplanting) are shown in Table 1. Rising atmospheric [CO_2] level up to 75 % above ambient increased the above ground biomass up to 32%, though they were comparable. Increasing [CO_2] level 25% above ambient resulted in increased biomass of rice by 13% [19]. It has been also stated that rice crops grown at 570 ppm acquired biomass faster than those grown under ambient [CO_2] during critical stages [6]. Rising [CO_2] level accelerates photosynthesis and thus resulted in more biomass production. It has been stated that increased biomass under elevated [CO_2] is mainly due to increased net assimilation capacity and photosynthesis rate by stimulating carboxylation and retarding oxygenation of ribulose bisphosphate carboxylase [15].The nutrient management had significant effect on biomass accumulation of rice. The recommended dose of chemical fertilizer (CF100) gave significantly ($p<0.05$) highest above ground biomass followed by integrated nutrients (CF50+BF50). The nutrient management treatments with full dose through chemical fertilizer or integration of bio and chemical source met the N requirement of the crop, hence increased the biomass production. However the application of biofertilizer alone was not effective to supply the desired quantity of nutrient for rice production.

3.2 Filled Grains Number and Grain Yield

The elevation of [CO_2] in OTC by 25%, 50% and 75% increased the mean air temperature by 0.62^{0}C, 1.75^{0}C, and 2.12^{0}C, respectively as compared to ambient environment. The increasing [CO_2] level decreased the number of filled grains as compared to ambient due to the negative effects of temperature associated with stomatal closure, which resulted in less number of filled grains. The adverse effect of high temperature becomes maximum when it coincides with flowering and grain-filling period [8]. Our results indicated that rising [CO_2] level above ambient by 25% , 50% and 75% decreased filled grains number significantly ($p<0.05$) (Table 1). Increase in temperature will affect rice growth and spikelet formation leading to grain yield reduction [21] .The elevated [CO_2] alone may increase the grain yield mainly because of more number of tiller production, but the associated higher temperature induces spikelet sterility, hence reduced the grain yield. We observed that rising [CO_2] level up to 75 % above ambient decreased the grain yield up to 19%. The recommended dose of chemical fertilizer (CF100) gave significantly ($p<0.05$) highest filled grains number and grain yield followed by integrated nutrients (CF50+BF50). As CF100 and CF50+BF50 produces more biomass, hence resulted in more filled grains number and grain yield.

3.4 Rice Processing Quality

Increase in [CO_2] level by 25%, 50% and 75% above ambient did not bring any significant change in BRP and MRP, but decreased HRP significantly (Figure 1). According to many reports, rising temperature when coincides with critical stages like flowering and maturity, resulted in poor grain appearance and reduced milling qualities due to increased chalkiness in rice grains, which further reduces the head rice yield [3,4,7]. The chalkiness in rice grain reduces the head rice yield due to more broken rice. Our study indicated that [CO_2] level 25 to 75% higher than ambient reduced the head rice percentage by 13 to 21 %. Increase in [CO_2] level by 75% above ambient, resulted a significant decline in BRY. However, the HRY was decreased significantly ($p<0.05$) even with 25% increase in [CO_2] level above ambient. Further increase in [CO_2] level (≥ 50%) did not bring any significant changes in HRY (Table 2). The recommended dose of chemical fertilizer (CF100) had significantly ($p<0.05$) higher HRP and HRY as compared to other three nutrient management practices. Moreover, the adverse effect of elevated [CO_2] on HRY was lower in CF100 as compared to rest nutrient management treatments. According to previous studies, higher amount of nitrogen increases the grain hardness and provide resistance from deterioration during the process of milling [14]. Insufficient N supply and high temperature affected the process of milling, thus decreased the HRY. The CF100 had higher amount of nitrogen availability in soil for crop uptake as compared to the other treatments, hence was least affected from the [CO_2] elevation.

4. Conclusions

From the study, it can be understood that increasing atmospheric [CO_2] favoured leaf and stem biomass accumulation, but affected the grain formation and post-harvest milling quality of rice. Increasing atmospheric [CO_2] level by 25% or higher than the ambient, though had no significant effect on grain yield, but affected the head rice percentage significantly, thereby reduced the processed rice yield. With the [CO_2] elevation by 25 to 75%, the head rice percentage was lowered by 13 to 21 % as compared to the ambient environment. The adverse effect, however, can be minimized by improving nutrient management in the rice crop. This study stated that a detailed investigation on nutrients management is required for developing suitable adaptations to the climate change.

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Supplements

Table 1. Effect of environment and nutrient management on above ground biomass at peak growth stage, filled grains per panicle and grain yield of rice

	Above ground biomass (kg/ha)	Filled grains number per panicle	Grain yield (kg/ha)
Environment			
OF	4250	73	2820
OTC(Amb CO_2)	3633	105	2892
OTC(+25% CO_2)	3731	79	2553
OTC(+50% CO_2)	4248	84	2443
OTC(+75% CO_2)	4789	77	2343
SEm± **LSD (p=0.05)**	326 NS	5 15	106 NS
Nutrient management			
N0	2893	67	1842
N(CF100)	6341	107	3439
N(CF50+BF50)	4445	91	3180
N(BF100)	2842	78	1980
SEm± **LSD (p=0.05)**	291 897	4 14	408 391

Note: CF-Chemical Fertilizer, BF-Biofertilizer, OF-Open Field, OTC-Open Top Chamber, SEm-Standard Error of mean, LSD- Least Significant Difference, NS- Not Significant.

Table 2. Effect of environment and nutrient management on Brown Rice Yield (BRY), Milled Rice Yield (MRY) and Head Rice Yield (HRY)

	BRY, kg/ha	MRY, kg/ha	HRY, kg/ha
Environment			
OF	1731	1389	992
OTC(Amb CO_2)	1643	1348	1008
OTC(+25% CO_2)	1688	1484	803
OTC(+50% CO_2)	1717	1333	819
OTC(+75% CO_2)	1555	1282	843
SEm± **LSD (p=0.05)**	23 71	80 NS	42 130
Nutrient management			
N0	1579	1269	815
N(CF100)	1726	1471	1036
N(CF50+BF50)	1730	1372	868
N(BF100)	1632	1358	853
SEm± **LSD (p=0.05)**	20 64	71 NS	37 116

Note: CF-Chemical Fertilizer, BF-Biofertilizer, OF-Open Field, OTC-Open Top Chamber, SEm-Standard Error of mean, LSD- Least Significant Difference, NS- Not Significant.

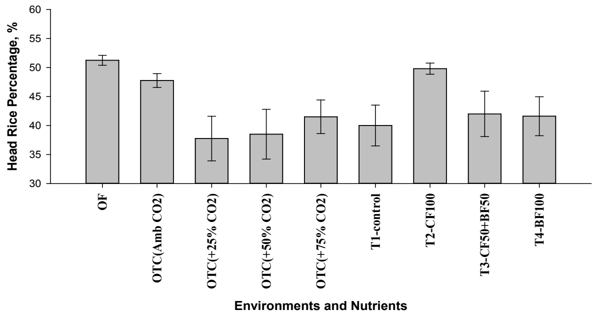

Figure 1. Effect of environment and nutrient management on head rice percentage

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