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Elevated CO_2 and Nitrogen Interaction in Photosynthesis and Productivity of Modern and Local Rice (*Oryza sativa* L.) Cultivars

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Abstract

Photosynthetic rate and productivity of modern and local rice (*Oryza sativa* L.) cultivars were compared at different levels of nitrogen and elevated CO_2 concentrations. BRRIdhan 39 and Shakkorkhora representing modern and local cultivars, respectively were tested under the conditions of three nitrogen levels and three CO_2 concentrations. Nitrogen levels were (i) control (0 kg N ha^{-1}), (ii) optimum (90 kg N ha^{-1} for modern and 60 kg N ha^{-1} for local cultivar) and (iii) supra optimum (135 kg N ha^{-1} for modern and 90 kg N ha^{-1} for local cultivar). Conversely, the three CO_2 concentrations were (i) open top chamber (OTC) with elevated CO_2 (570 ± 50 ppm), (ii) OTC with ambient CO_2 (~360 ppm) and (iii) open field. It was observed that the elevated CO_2 independently increased the photosynthetic rates in both cultivars. While in interaction, elevated CO_2 and supra optimal nitrogen increased the photosynthetic rate in modern rice cultivar only. Productivity of two rice cultivars corresponded to that of photosynthetic rates. The highest yield (50.82 g $plant^{-1}$) was found in modern cultivar at supra optimal nitrogen and elevated CO_2 treatments. In contrary, the lowest yield (15.09 g $plant^{-1}$) was observed in local cultivar at zero kg nitrogen treatment. However, productivity of local rice cultivar was substantially increased either by applied optimum nitrogen or by CO_2 enrichment.

***Keywords*:** Rice, cultivar, nitrogen, CO_2, photosynthesis, yield

1. Introduction

Atmospheric CO_2 concentration is increasing gradually since prehistoric period due to human activities which is expected to become double from present level of ~350 ppm by the middle of this century (Watson *et al*., 1990; Houghton *et al.*, 1996). Rising CO_2 in the atmosphere has beneficial effect on the productivity of C_3 crops. Increased CO_2 stimulates photosynthesis and reduces photorespiration in C_3 species. This is mainly because of the oxygenase activity of the CO_2 fixing enzyme - ribulose biphosphate carboxylase / oxygenase (Rubisco), which is decreased at high level of CO_2 concentration. Therefore, enrichment of CO_2 in the atmosphere may be regarded as a global fertilization of the biosphere with most abundant plant nutrients. Several authors (Ziska *et al.*, 1997; Hamid *et al.*, 2003) have shown increased rice grain yield and biomass production under elevated CO_2 because of increase in leaf photosynthetic rate.

Nutrient relations in plants are also affected by increase of atmospheric CO_2 (Lincoln, 1993). Elevated atmospheric CO_2 does not only promote growth of C_3 plants but also regulate the demand of other nutrients (Ceulemans and Mousseau, 1994). Under enriched CO_2 concentration, C:N relationship is altered in tissues of C_3 plants (Cortufo *et al.*, 1998; Khanam *et al.*, 2004; Haque *et al.*, 2006). Continuous increase in atmospheric CO_2 leads to significant effect on C:N ratios in C_3 plants which results abundance in carbon and scarce in nitrogen.

As rice is a C_3 crop, it responses positively to elevated CO_2 concentration. Further, area and production of modern rice is increasing day by day but importance of indigenous rice can not be ignored. Because, it possesses many important physiological characters that are useful for the improvement of rice (Hamid *et al.*, 2004). Several studies (Cock and Yoshida, 1973; Imai *et al*., 1985; Makino *et al*., 1997; Hamid *et al*., 2003) were conducted to elucidate the physiological mechanism relating to positive response to elevated CO_2, but those were centered mostly on modern rice cultivars. However, information relating nutrition relation in plants of local rice under elevated CO_2 is almost lacking. The present research work was therefore, undertaken to compare the photosynthetic response and productivity of modern and local rice cultivars under elevated CO_2 and nitrogen levels.

2. Materials and Methods

Pot experiment was conducted at Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh during wet season of 2003. BRRIdhan 39 and Shakkorkhora representing modern and local cultivars respectively were grown under three nitrogen levels and three CO_2 concentrations. Nitrogen levels were (i) control (0 kg N ha^{-1}), (ii) optimum (for modern variety 90 kg N ha^{-1} and for local 60 kg N ha^{-1}) and (iii) supra optimum (for modern 135 kg N $ha^{-1}$and for local variety 90 kg N ha^{-1}). Supra optimum was 1.5 time higher than their optimum dose. Supra optimum dose was applied to meet the higher nitrogen demand of the plants for better growth under elevated CO_2 concentration. Three CO_2 concentrations were (i) open top chamber (OTC) with elevated CO_2 (570 ± 50 ppm), (ii) OTC with ambient CO_2 (~360 ppm) and (iii) open field. Construction and operation of OTC were followed as per description of Uprety (1998).

Thirty days old rice seedlings were transplanted in plastic pots containing approximately 12 kg clayed soil on 2 August, 2003. The treatments were replicated thrice and each pot had one seedling. Except nitrogen, a common dose of fertilizer at the rate of 20 kg P, 60 kg K, 20 kg S and 3.5 kg Zn ha^{-1} was applied prior to transplanting while nitrogen was applied in three installments at 4, 21 and 52 days after transplanting (DAT). Weeding, irrigation and pest control measures were done as and when necessary.

Flag leaf photosynthetic rates were measured during flowering stage. The measurements were taken under natural sunlight using portable photosynthesis measuring device (LICOR 6200, Lincon, Nebraska). In each treatment, the measurements were carried out on the fully expanded flag leaf of the mother shoot on clear sunny days during 1100 to 1300 hours.

At maturity, yield attributes and yield of rice cultivars were recorded for each plant. Number of panicles per plant and spikelets per panicle were counted. Filled sikelets were also separated and counted manually from all of the panicles of sampled plant. Thousand grains were randomly counted by multi auto counters and weighed in an electronic balance (AND, Counting, FX-300). Grain yield was recorded on per plant basis and adjusted at 14% moisture content.

The data recorded on different parameters were statistically analyzed by partitioning the total variance with the help of computer using MSTAT - C program. Differences between the treatment means were compared using Duncan’s Multiple Rang Test (DMRT).

3. Results and Discussion

3.1. Photosynthesis

Leaf net photosynthetic rate at the elevated CO_2 treatment was significantly greater than in the ambient and open field condition at flowering stage of rice (Fig.1). Irrespective of varieties, elevated CO_2 increased photosynthetic rate by 24.2 and 25.4% compared with ambient CO_2 and field grown plants. Similar trends were also reported for rice by Ziska and Teramura (1992) and Hamid *et al.* (2003). It is because CO_2 is substrate for photosynthesis and elevated CO_2 decreased photorespiration in C_3 plants (Ziska and Bunce, 1993). The supra optimal treatment of nitrogen also increased the photosynthetic rates although it was significant only under elevated CO_2 conditions. As nitrogen is a major constituent of chloroplasts, application of higher amount of nitrogen might have maintained higher leaf chlorophyll and eventually enhanced the net leaf photosynthetic rate of rice. Varietal difference indicated that BRRIdhan 39 showed the highest leaf photosynthetic rate (41.1 μ mol m^{-2} s^{-1}) under elevated CO_2 and supra optimum nitrogen and it was the lowest (12.29 μ mol m^{-2} s^{-1}) in Shakkorkhora in ambient and no nitrogen conditions. Such variation in stimulation of photosynthetic rate due to CO_2 enrichment and application of nitrogen may be caused by differential sink capacity of rice cultivars (Sakai *et al*., 2001). As modern rice cultivars are more responsive to applied inputs, BRRIdhan 39 responded positively to both elevated CO_2 and higher nitrogen level. However, local cultivar Shakkorkhora responded only at elevated CO_2 and not at higher nitrogen level. The results indicated that modern rice cultivars need additional nitrogen supply to sustain better photosynthetic rate under elevated CO_2 which might not be necessary for local cultivars.

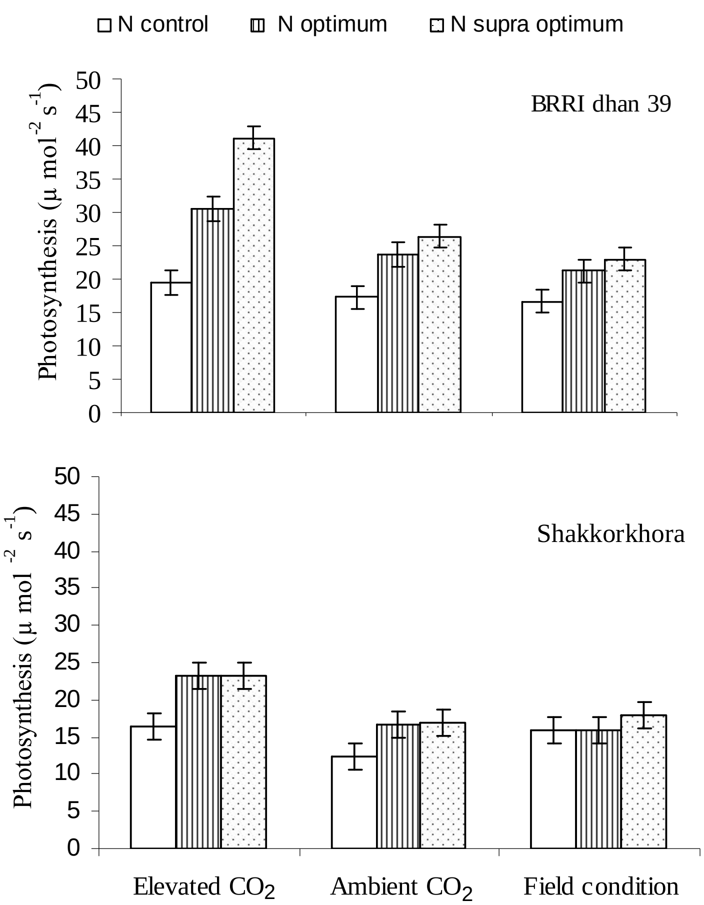

Fig. 1. Changes in leaf photosynthesis of two rice cultivars grown under different nitrogen and CO_2 conditions. Bar in each mean indicates ±SE.

3.2. Panicles per hill

Elevated CO_2 and nitrogen supply increased the number of panicles per plant of different rice cultivars than those grown under ambient and field conditions (Table 1). Crop with CO_2 and nitrogen acquired 17.8 and 17.5% more panicles per hill, respectively as compared to other two growing environments. This result compares well to earlier findings for other cereal crops (Manderscheid *et al*., 1995). As elevated CO_2 and nitrogen stimulated tillering rate of rice cultivars, it subsequently increased panicles per hill. Among the rice cultivars, modern one responded more in producing panicles per hill under elevated CO_2 and high nitrogen condition. Modern variety BRRIdhan 39 produced the highest number of panicles (17.3) per hill at high CO_2 and supra optimum nitrogen treatment.

3.3. Spikelets per panicle

Elevated CO_2 and applied nitrogen enhanced number of spikelets per panicle of both local and modern rice cultivars (Table 2). Hamid *et al*. (2003) also reported similar increase in spikelets per panicle under elevated CO_2 conditions. Both CO_2 fumigation and nitrogen have growth stimulating effect on plants which favoured formation of more spikelets per panicle of rice cultivars. Further, high CO_2 prevents flower degeneration during development which also helped in increasing spikelets per panicle of rice cultivars (Imai *et al*., 1985). There was varietal difference in producing spikelets per panicle, where the local variety produced the highest (211.36) spikelets per panicle under ambient CO_2 and control nitrogen and the lowest (109.31) was produced by BRRIdhan 39 in field condition in control treatment.

3.4. Filled spikelets per panicle

CO_2 enrichment increased filled spikelets per panicle of rice cultivars compared to ambient and field condition (Table 3). Under elevated CO_2 condition, filled spikelets per panicle varied from 95.67 to 191.00 which indicated a wide degree of responsiveness over the cultivars and nitrogen levels. Elevated CO_2 increased spikelets per panicle by 9.7 and 8.2% compared with ambient and field conditions, respectively. Manderscheid *et al.* (1995) also reported variability in the degree of responsiveness of different wheat cultivars in producing filled grains per spike under CO_2 enrichment. Increasing grain number per panicle, however, is not a common phenomenon under elevated CO_2 concentration. Nitrogen nutrition increased the filled spikelets per panicle and Shakkorkhora under elevated CO_2 and optimum nitrogen produced the highest (191.00) spikelets per panicle. Higher photosynthesis under elevated CO_2 and high level nitrogen might have translocated more photosynthates to grain which increased the filled grains per panicle of rice (Cock and Yoshida, 1973).

Table 1. Interactive effect of elevated CO_2 and nitrogen on number of panicles per hill of rice cultivars

Variety	Nitrogen levels	Elevated CO_2	Ambient CO_2	Field
	Control	11.0 d A	10.0 c A	10.0 c A
BRRI dhan39	Optimum	16.0 b A	13.5 aB	13.2 bB
	Supra optimum	17.3 aA	14.8 aB	14.2 aB
	Control	10.0 dA	7.2 dC	8.5 dB
Shakkorkhora	Optimum	13.5 cA	11.2 bcB	10.0 dC
	Supra optimum	14.5 cA	12.0 bC	13.2 bB

Means followed by same small letter (column) and capital letter (row) did not differ significantly at 0.05 by DMRT.

Table 2. Effect of elevated CO_2 and nitrogen levels on number of spikelets per panicle of rice cultivars.

Variety	Nitrogen levels	Elevated CO_2	Ambient CO_2	Field
BRRI dhan 39	Control	124.56 dB	128.63 dA	109.31 eC
	Optimum	130.78 cA	126.69 cB	128.84 dB
	Supra optimum	135.19 cB	136.33 cA	135.56 dB
Shakkorkhora	Control	182.77 bB	211.36 aA	183.76 cB
	Optimum	203.16 aB	195.71 bC	211.34 aA
	Supra optimum	198.82 aB	197.37 bB	201.40 bA

Means followed by same small letter (column) and capital letter (row) did not differ significantly at 0.05 by DMRT.

Table 3. Effect of elevated CO_2 and nitrogen levels on number of filled spikelets per panicle of rice cultivars.

Variety	Nitrogen levels	Elevated CO_2	Ambient CO_2	Field
BRRI dhan39	Control	112.50 cA	112.64 bA	95.67 dB
	Optimum	117.25 cA	113.10 bB	108.19 dC
	Supra optimum	121.62 cA	116.54 bB	114.52 dB
Shakkorkhora	Control	165.57 bA	160.69 aB	150.87 cC
	Optimum	191.00 aA	168.65 aC	176.20 aB
	Supra optimum	184.74 aA	165.78 aB	167.45 bB

Means followed by same small letter (column) and capital letter (row) did not differ significantly at 0.05 by DMRT.

3.5. Spikelet weight

Elevated CO_2 and nitrogen level had little effect in spikelet weight of rice (Table 4). Individual grain mass is a fairly stable character in rice (Yoshida, 1981) as it is mostly determined genetically. The size of the husk is determined as early as 5 days before heading which is very difficult to be changed by management (Murata and Matsushima, 1978). Weigel *et al*. (1994) reported that seed size remained unaffected in barley but decreased in wheat due to CO_2 enrichment. In the present study, spikelet weight increased slightly at elevated CO_2 condition and increased nitrogen treatments for modern rice. Imai *et al*. (1985) reported that there is negative correlation between number of spikelets per panicle and seed weight.

3.6. Grain yield

Elevated CO_2 and high level nitrogen increased the yields of rice cultivars (Table 5). Elevated CO_2 increased grain yield of rice by 27.4% over ambient CO_2 and by 31.1% over field condition. Increase in grain yield under elevated CO_2 and applied nitrogen was due to production of higher number of panicles per hill and filled spikelets per panicle. This result is supported by previous reports (Siddique *et al.*, 1989; Tuba *et al.*, 1994) that an increase in grain yield at CO_2 enrichment and higher nitrogen could be explained by increase in total biomass and in panicle number per plant. As photosynthetic rates increased at high CO_2 and high nitrogen level, it further helped better grain filling and enhanced grain yield of rice (Reddy *et al.*, 1995; Sharma *et al.*, 1997). Elevated CO_2 coupled with high nitrogen increased more yield in modern variety than local one. Thus, the highest yield (50.82 g $plant^{-1}$) was found in BRRIdhan 39 at supra optimum nitrogen level under elevated CO_2 and the lowest yield (15.09 g $plant^{-1}$) in Shakkorkhora at ambient condition.

Table 4. Elevated CO_2 and nitrogen effects on 1000 grain weight (g) of rice cultivars.

Variety	Nitrogen levels	Elevated CO_2	Ambient CO_2	Field
BRRI dhan39	Control	20.44 bB	21.65 cA	20.75 cB
	Optimum	23.91 aA	23.09 aB	22.12 bB
	Supra optimum	24.44 aA	22.82 bC	23.54 aA
Shakkorkhora	Control	13.39 cA	13.00 dB	13.04 eB
	Optimum	13.61 cA	13.30 dB	13.31 dB
	Supra optimum	13.08 dA	13.00 dB	13.09 eA

Means followed by same small letter (column) and capital letter (row) did not differ significantly at 0.05 by DMRT.

Table 5. Interactive effect of elevated CO_2 and nitrogen on grain yield (g $plant^{-1}$) of rice cultivars**.**

Variety	Nitrogen levels	Elevated CO_2	Ambient CO_2	Field
BRRI dhan39	Control	26.04 eA	23.70 cdB	21.67 dC
	Optimum	43.37 bA	39.06 abB	32.22 bC
	Supra optimum	50.82 aA	41.27 aB	37.50 aC
Shakkorkhora	Control	22.12 fA	15.09 eC	16.94 eB
	Optimum	34.76 cdA	25.63 cB	22.79 cdC
	Supra optimum	35.00 cA	26.77 cC	29.54 bcB

Means followed by same small letter (column) and capital letter (row) did not differ significantly at 0.05 by DMRT.

4. Conclusions

Elevated CO_2 increased leaf photosynthetic rates of both modern and local rice cultivars. But photosynthetic rate under the condition of enriched CO_2 and high nitrogen was pronounced only in modern rice cultivar. Thus, grain yield of modern rice cultivar can be increased by applying higher amount of nitrogen under elevated CO_2 concentration. In local rice cultivar, yield can be increased either by applying optimum nitrogen or by elevated CO_2 concentrations.

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