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Potential impacts of increasing atmospheric carbon dioxide on yield and plant growth of rice (*Oryza sativa*) and maize (*Zea mays*) crops

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ABSTRACT

Free air carbon dioxide enrichment (FACE) facility was used to conduct the experiments during 2011-12 and 2012-13 cropping seasons for assessing the growth and yield attributes of rice (*Oryza sativa* L) and maize (*Zea mays* L). The concentration of CO_2 was kept 550± 30 ppm in enriched condition. The concentration of ambient condition was 395±30. Recommended doses of NPK fertilizers were given to both the crops. Plant growth and yield parameters were measured and analyzed for both the conditions. Assessment revealed that the plant height of rice and maize did not change significantly. A significant (F= 9.800; P<0.02) change was noticed in the post-harvest index of rice. However, there no change was noticed in the post-harvest percentage of maize. Leaf area of rice (P<0.01) and maize (P<0.005) increased significantly at flowering stage of plants under enriched CO_2 environment over the ambient. Under elevated CO_2 condition, biological yields of rice and maize were improved by 14.3% and 17.2% respectively. Carbon dioxide enrichment exposure improved the grain yield by16. 2% (P<0.02) and 13.8% (P<0.02) for rice and maize respectively.

Key words: Biological yield, Free air CO_2 enrichment (FACE**),** Plant growth, Yield.

The agricultural sector is unambiguously dependent on climate. The changing climate has the potential to change the crop productivity and influences the economic returns of the growers. About 40% concentration of atmospheric CO_2 levels have risen, since the industrial revolution and it is mainly because of fossil fuel combustion and changing the land use management (IPCC 2007). Due to increased concentration of greenhouse gases (GHGs) average atmospheric temperature raised by 0.85 °C between 1880 and 2012 (IPCC 2013). It is speculated that if current trend of increasing atmospheric CO_2 concentration level sustains then it's concentration will be doubled from the present level around 395 ppm by the middle of this century (Shong *et al.* 2011). Due to increase in concentration of CO_2 in the atmospheric the atmospheric temperature rises and changes the precipitation pattern, posing challenges to the productivity of present agriculture. Increase in the concentration of CO_2 may play a major role in the plant growth through fertilization (Watanabe and Kume 2009). During the 1960s the rate of enhancement of CO_2 in the atmosphere was 0.84 µ mol/yr and it was 2.04 84 µ mol/yr in the previous decade (Saha *et al*. 2015, Liu *et al*. 2015). Increase in the CO_2 concentration could be enhanced the photosynthesis in C_3 plants. Consequently, it will bring the change in agriculture pattern globally (IPCC 2007). Rice (*Oryza sativa* L) is the most consumed staple food for the 2.5 billion people across the world. The world rice production is about 701 million tonnes. This crop covers around 161.7 million ha area and covers about 9% of the world arable land (FAO 2010). Asia accounts for 90% production of rice (FAO 2010).

After rice and wheat, maize is the third important cereal crop. Maize (*Zea mays* L) is known as queen of cereals because it has highest genetic yield potential and wider adaptability under various agro-climatic conditions (Yadav *et al.* 2015). Maize share in global grain production is about 36% (782 mt) and it is being grown in 160 countries (FAO 2010). Area under maize in India is increased from 7.5 Mha to 9.4 Mha (1.9 Mha) between 2004–05 and 2013–14. Despite large area under maize the productivity is quite low compare to other major maize growing countries (FICCI 2014).

Not very wide spread studies have been conducted for the comparison between the C_3 and C_4 food crops in changing climatic scenario, which is likely to be threat for food security in future. Keeping this in view this study has been undertaken.

MATERIALS AND METHODS

The experiment was conducted on rice and maize in free air carbon dioxide enrichment (FACE) facility in pots

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during 2011-12 and 2012-2013 (June –April) at Indian Agricultural Research Institute (IARI), New Delhi, India, located at 28°35'N latitude and 77°12'E longitude. Daily mean of maximum and minimum temperatures were 30.55 and 17.2 and 32.8 and 17.42^{0}C for 2011-12 and 2012-013, respectively. The maximum and minimum temperatures inside the FACE, were 31.30 and 18.51 and 33.6 and 18.1^{0}C recorded on daily basis for the year 2011-12 and 2012-13 respectively. Rainfall was recorded with the help of a FRP rain gauge in the nearby meteorological observatory (25 m away from the experimental site). Total rainfall received during the experimentation was 695 mm and 740 mm respectively.

Pots were filled by the soils belong to Topic Haplusteps of upper Gangetic plains. The nature of the soil used was sandy loam texture (68.6% sand, 19.4% silt and 12.1% clay).

Rice (P 44) and maize (HQPM-1) were grown. Rice transplanting was done with two hills per pot with plant to plant distance of 20cm. Maize was grown in rows with distance 50 cm and plant to plant distance 20 cm. Pots were kept inside the Free Air CO_2 Enrichment (FACE) facility. The enrichment of CO_2 in the FACE plots throughout the crop growth season was controlled to 550±30 ppm by a computer system according to the wind direction, wind speed and plant height. For avoiding treatment cross-over, buffered plots of ambient condition were maintained. The FACE plots were consisted with hexagonal rings, used to spray pure CO_2 on day time (from 07:00 AM to 07:00 PM) throughout the growing season. Rice and maize crop were grown separately in different FACE facilities. Ambient plots were without ring structures. The 120 kg N, 26 kg P and 33 kg K/ha doses of NPK for rice and 150 kg N, 75 kg P and 37.5 kg K/ha doses of fertilizer for maize were given under ambient as well as enriched CO_2 enriched pots. The experiments were carried out incompletely randomized design (CRD).

Plant height (cm) was recorded at 15 days intervals after transplanting. Leaf area (cm^2/pot) was measured by meter scale graduated at mm/cm levels at flowering stage. For measuring the leaf area of rice, each leaf attached to the stem was separated. The area of each measured leaf was calculated by multiplying their lengths and widths and factor (0.75) (Yoshida *et al.*1981). Straw yield (g/pot) was measured at flowering and harvesting stage of both the crops. Straw yield from each pot was sun dried and weighed and converted to straw yield in g/pot. Biological yield (g/pot) was recorded at flowering and at harvest stages. For this purpose root portion of the plant was discarded. The above ground portion of the plant samples was dried under the sun, then in hot air oven dry at 65 ^{0}C. The mean dry weight per pot was calculated and expressed in grams. Root shoot ratio was calculated by dividing root biomass by shoot biomass at flowering stage of crop development. The ratio of economic yield (grain yield) per pot to the biological yield (grain and straw yield)/pot was worked out as harvest index. Thousand grains for rice and hundred grains for maize were counted from each pot and weighted in grams.

RESULTS AND DISCUSSION

Concentration of CO_2 inside FACE (control) was the same as in the outside condition. Analysis stated that plant height of rice (F=0.476: P<0.509) and maize (F=3.78: P< 0.099) did not change significantly. The leaf area of rice enhanced by (13.3%) (F= 45.55; P=0.005) under the enriched CO_2 environment (Table 1) over ambient condition. Likewise the plant leaf area (cm^2/pot) of maize increased (F=6.15: P<0.04) significantly under enriched CO_2 environment. It may be attributed to improved photosynthesis and competitiveness of light availability to the plants. Abebe *et al.* (2015) found that the leaf area of maize under enriched CO_2 environment increased by 14.8% at silking, which confirms our results. Pittelkow *et al.* (2014) findings confirmed our finds for enhanced leaf area of rice under elevated CO_2 environment over the control. Assessment revealed that the stem dry weight of rice under enriched CO_2 treatment increased by 22 % (F= 8.67; P<0.025). Similarly stem dry weight of maize improved by 16.0 and 20.0% for the first and second year respectively (F=20.149; P<0.004) under enriched CO_2 environment. The enriched CO_2 condition improved cob dry weight over the control environment (F=12.940: P<0.01) (Table 1). Venkata *et al.* (2014) found similar results. The assessment of biological yield of rice at flowering stage revealed an improvement significantly (F=21.382; P<0.003) for first and second year by 16.6 and 14.3% respectively (Table 1) under the enriched CO_2 exposure. Similarly the biological yield of maize at flowering stage under enriched CO_2 environment increased by 16.7 and 17.2% for the

Table 1 Plant height, leaf area and root, stem dry weight, biological yield (g/pot), panicle dry weight of rice and maize plants height (cm), leaf area (vegetative growth), stem dry weight (g/pot), biological yield (g/pot) and cob dry weight (g/pot) under enriched and ambient carbon dioxide conditions *P<0.05; **P<0.01.

Year		Rice					Maize				
		Plant height (cm)	Leaf area (cm^2/ pot)	Stem dry weight(g/ pot)	Biological yield (g/ pot)	Panicle dry weight (g/pot)	Plant height (cm)	Leaf area (cm^2/pot)	Stem dry weight (g /pot)	Biological yield	Cob dry weight (g/pot)
2011-12	Enriched CO_2	84	597*	62*	126**	24**	150	2832**	60*	111**	19**
	Ambient CO_2	84	567	51	108	18	138	2499	52	97	15
2012-13	Enriched CO_2	82	605*	60*	123**	28**	155	2876**	61*	113**	18**
	Ambient CO_2	81	581	48	105	20	136	2410	51	96	15

Table 2 Straw weight, biological yield, 1000 grain weight, harvest index of rice and maize straw weight (g/pot), biological yield (g/pot), 100 grain weight , number of grains /pot and harvest index under enriched ambient CO_2 conditions (*P<0.05; **P<0.01)

Year		Rice				Maize				
		Straw weight (g pot^{-1})	Biological yield (g/pot)	1000 grain weight (g)	Harvest index (%)	Straw weight (g pot^{-1})	Biological yield (g pot^{-1})	100 grain weight (g)	No. of grains / cob	Harvest index (%)
2011-12	Enriched CO_2	94*	184**	20.2	51*	124	209	25.2	170*	41
	Ambient CO_2	86	165	20.6	44	109	184	26.0	140	41
2012-13	Enriched CO_2	95*	181**	20.1	50*	126	212	25.0	180*	40
	Ambient CO_2	85	159	20.3	45	110	185	25.6	147	41

first and the second year (F=11.077; P<0.013) respectively (Table 1). It may be attributed to the improved vegetative growth under enriched CO_2. These results are similar to Usui *et al*. (2016) who, inferred that the biological yield of rice increased by approximately 14% averaged over 3 years. Yield attribute analysis at the maturity stage of both crops showed the positive response to the enriched CO_2 environment. Analysis of dry weight of rice (F=7.244; P<0.03), biological yield/pot (F= 12.805; P<0.0.01) and harvest percent (F= 9.800; P<0.02) at maturity increased significantly under the enriched CO_2 levels. The 1000 grain weight of rice was unaffected under enriched CO_2 environment (F=1.807; P<0.22). Likewise yield attributes of maize assessment showed that the dry straw weight (F=1.147; P<0.3), 100 grain weight (F=2.280; P<0.18) and harvest percent (F=0.030; P<0.8) did not change positively under the enhanced concentration of CO_2 over the ambient condition. Number of grains/cob in maize increased by 20.2 and 19.5% for the first and second year respectively (Table 2). These results are at par with the other workers (Vanaja *et al*. 2015). Biological yield per pot recorded a significant enhancement (F=11.115; P<0.015) by 13.7 and 15.3% for the first and for the second year respectively (Table 2). The grain yield (g/pot) of rice and maize crop influenced positively under the enrichment of CO_2. Rice grain yield per pot increased by 14 and 16. 2% (F=8.991; P=0.02) for the first and second years respectively (Fig 1). Chunwu *et al*. (2015) found that the grain yield of rice increased over 30% under the elevated CO_2 environment compared to ambient. Our results are also on line with the findings of others (Roy *et al*. 2012, Guoyou *et al*. 2015). Similarly, the CO_2 enrichment ameliorated the grain yield of maize (g/pot) by 13.3 and 13.8% for first and second year respectively (Fig 2). The improvement in the yield of maize under enriched CO_2 environment may be attributed to the increased number of grains per cob and improved biological yield at harvest. These findings are similar to other workers (Bunce *et al*. 2016). Enriched condition of plant growth CO_2 had no impact on grain size of rice as well as maize. This study also revealed that test weight of 1000 rice grain weight was remained unaffected (P<0.22). Similarly the test weight of 100 maize grains did not change significantly (P<0.23).

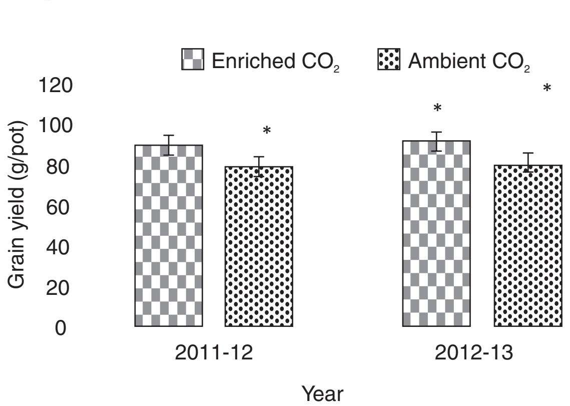

Fig 1 Grain yield (g/pot) of rice under enriched and ambient CO_2 concentration conditions (*P<0.05).

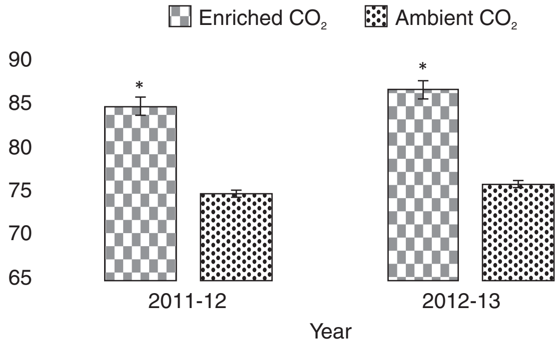

Fig 2 Grain yield (g/pot) of maize under enriched and ambient CO_2 concentration conditions (*P<0.05).

In conclusion it could be stated that the enrichment of carbon dioxide in the environment influences positively the productivity of the rice and maize crops. The plant growth parameters like leaf area and yield attributing parameters such as plant dry weight, number of grains per cob enhanced under the elevated CO_2. However, the test weight of grains and harvest index did not change significantly in both the crops. Moreover, further studies are needed to understand, how enrichment of CO_2 will combine with other factors like temperature and irrigation regimes to determine rice and maize crops performance in the future.

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