Natl. Acad. Sci. Lett. (March–April 2020) 43(2):109–113
https://doi.org/10.1007/s40009-019-00816-y

SHORT COMMUNICATION

Yield and Nitrogen Uptake in Wheat and Chickpea Grown Under Elevated Carbon Dioxide Level

B. Chakrabarti[1] · S. D. Singh[1] · A. Bhatia[1] · V. Kumar[1] · R. C. Harit[1]

Received: 26 May 2017 / Revised: 11 January 2019 / Accepted: 29 January 2019 / Published online: 7 May 2019

Abstract Increase in the atmospheric carbon dioxide (CO_2) concentration has fertilization effect on crops if nutrient supply remains adequate. Response of cereals and legumes to increased CO_2 concentration might differ due to the nitrogen fixing ability of leguminous crops. Considering the importance of differential response of cereal and legumes under elevated CO_2 concentration, a field study was conducted to compare the effect of elevated CO_2 on yield and plant nitrogen uptake in wheat and chickpea crop. Elevated CO_2 level (550 ppm) increased yield by 15.1% and 16.7% over ambient in wheat and by 21.1% and 21.9% in chickpea ($p \leq 0.05$) during the first and second years of the study. Nitrogen content in wheat grains decreased under elevated CO_2 concentration. Chickpea, being a leguminous crop, showed no change in grain N content. However, higher biomass and grain yield resulted in higher N uptake in both the crops under elevated CO_2 level. Under elevated CO_2 concentration more partitioning of biomass toward seeds lead to higher seed N partitioning in chickpea. The study showed that although growth and yield of crops might increase in high CO_2 condition, nitrogen concentration in grains and soil available N status might decrease in cereals like wheat. But chickpea might not get affected due to their ability to fix atmospheric N_2.

Keywords Elevated carbon dioxide · Wheat · Chickpea · Yield · Nitrogen partitioning

Significance Statement In the following study, an attempt has been made to quantify the impact of elevated CO_2 on yield as well as on nitrogen content of wheat and chickpea crops. Comparison has been made between one legume and one non-legume crop, and results show that non-legumes like wheat will suffer more under high CO_2 condition in terms of decrease in its nutritional quality as compared to chickpea. Legumes will get added advantage due to their N fixing capacity under future climate change condition. The issue addressed in the manuscript is of relevance in the present context of changing climate.

✉ B. Chakrabarti
bidisha2@yahoo.com

[1] Centre for Environment Science and Climate Resilient Agriculture, ICAR-Indian Agricultural Research Institute, New Delhi 110012, India

Global climate change associated with rise in concentration of atmospheric greenhouse gases (GHGs) has emerged as an important environmental challenge with the considerable impact on agriculture sector. According to the 5th Assessment Report (AR5) of the Inter-Governmental Panel on Climate Change (IPCC), atmospheric carbon dioxide (CO_2) concentration is increasing at the rate of nearly 2 μmol mol^{-1} annually [1]. Although increased CO_2 concentration has a fertilization effect on crops in terms of their yield increase, but to achieve the benefits of enriched CO_2, supply of adequate amount of nutrients is essential. Inadequate supply of nitrogen could limit the development of new sinks and alter the source–sink balance in plants grown under high CO_2 concentration [2]. Several workers have earlier reported decrease in N concentration in plants under elevated CO_2 level [3, 4]. Abebe et al. [5] reported that N and crude protein content in maize decreased under elevated CO_2 concentration. Legumes, however, have the ability to fix atmospheric nitrogen (N) and may have advantage over non-legumes when grown under increased CO_2 concentration [6].

Wheat (*Triticum aestivum* L.) and chickpea (*Cicer arietinum* L.) are the two important crops which contributed significantly in India's food security. Considering the imminent impacts of climate change on crops, a study was conducted to quantify the impacts of elevated atmospheric

CO_2 on wheat (C3 cereal) and chickpea (C3 legume) crops. The study was aimed for comparing the effect of elevated CO_2 on tissue N concentration and crop N uptake in wheat and chickpea.

The experiment was carried out for two consecutive years (2011–2012 and 2012–2013) at ICAR—Indian Agricultural Research Institute (IARI) farm, New Delhi (28°35′N and 77°12′E), India. Wheat (variety PBW 343) and desi chickpea (variety BGD 72) crops were grown both inside and outside the Free Air Carbon dioxide Enrichment (FACE) facility at IARI, New Delhi. Design of the experiment was randomized block design (RBD). The FACE ring was made up of eight horizontal pipes, which release CO_2-enriched air at the crop canopy level. Pipes were perforated with holes of 3 mm diameter facing the inner side of the ring to disperse the air inside the ring [7]. Concentration of CO_2 inside the ring was maintained at around 550 ppm, while crops grown outside the FACE ring were subjected to ambient CO_2 concentration (390 ppm). Nitrogen was applied through urea in both the crops. In wheat crop, nitrogen (N) was applied at the rate of 120 kg N ha^{-1} in 3 splits (half as basal; remaining half in 2 equal splits at vegetative and flowering stage) while in chickpea a starter dose of 25 kg N ha^{-1} was applied.

Both grain and biomass yields were recorded by harvesting plants from the four quadrants of the FACE ring. Harvest Index of both the crops was calculated using formula:

$$\text{Harvest Index (HI)} = (\text{Grain or seed yield/total dry matter}) \times 100 \quad (1)$$

Plant samples collected at harvesting stage were dried in oven at 65 ± 2 °C for 72 h and ground in a Wiley mill. Nitrogen content in plant samples was analyzed following the micro-Kjeldahl method as described by Jackson [8]. Available nitrogen content of soil was estimated at flowering stage of the crops in both the years using Subbiah and Asija [9] method. Statistical analysis of the observations was performed using ANOVA (analysis of variance) technique recommended for the design [10] to test whether the differences between means were statistically significant or not. Unless indicated otherwise, differences were considered significant at $p \leq 0.05$.

Wheat yield significantly increased under elevated CO_2 level. Grain yield increased by 15.1% and 16.7% ($p \leq 0.05$) in the first and second years of study "respectively" (Fig. 1). Earlier workers reported an increase in biomass yield by 11.8% and grain yield by 10.4% in wheat under elevated CO_2 condition [11]. A review of fifty experiments studying the impact of elevated CO_2 on wheat crop showed that on average doubling of CO_2 from 350 to

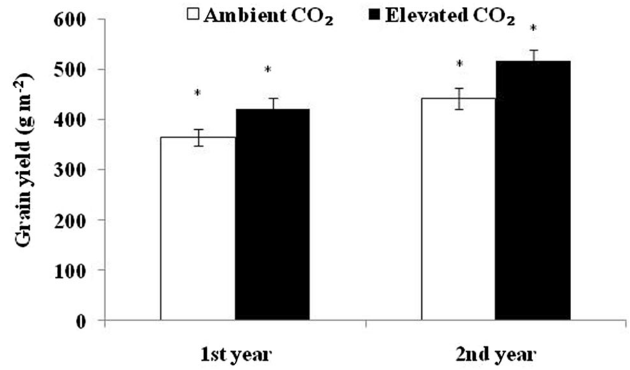

Fig. 1 Impact of elevated carbon dioxide (CO_2) level on grain yield in wheat crop (*indicate significant difference between ambient and elevated CO_2 treatments in a year at $p \leq 0.05$ level) (error bars in figure indicate standard deviation)

700 ppm increased wheat yield by 31% [12]. Among different yield parameters, maximum increase was observed in number of grains per spike in high CO_2 treatment. Higher C assimilation by the wheat crop under increased CO_2 level resulted in higher biomass partitioning causing more number of spikes as well as number of grains. Chakraborty et al. [13] also found that the increase in net photosynthesis caused more carbohydrates accumulation leading to higher productivity of Brassica cultivars. Ruhil et al. [14] also found that increased photosynthesis rate coupled with a higher leaf area increased biomass and yield under elevated CO_2 condition.

Chickpea crop showed positive response under elevated CO_2 condition. Seed yield of chickpea increased by 21.1% and 21.9% ($p \leq 0.05$) in high CO_2 treatment in the first and second years, respectively (Fig. 2). Harvest index (HI) of the crop significantly increased ($p \leq 0.05$) in the first year. This shows that allocation of assimilates to storage organs increased with increased CO_2 level. Earlier workers also reported increase in seed as well as biomass yield under

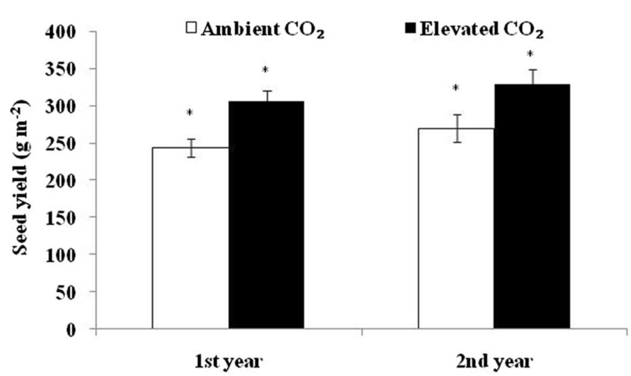

Fig. 2 Impact of elevated carbon dioxide (CO_2) level on seed yield in chickpea crop (*indicate significant difference between ambient and elevated CO_2 treatments in a year at $p \leq 0.05$ level) (error bars in figure indicate standard deviation)

high CO_2 condition in leguminous crops like mungbean [15] and pigeonpea [16]. Singh et al. [17] reported that among different crops studied, CO_2 fertilization effect was maximum in chickpea crop. Earlier researchers also found significant increase in chickpea productivity under elevated CO_2 condition; however, decline in nutritional quality was reported [18]. Nitrogen content in wheat grains decreased significantly under elevated CO_2 condition. Grain N content was 1.89% and 1.93% in high CO_2 treatment during the first and second years of our study, while under ambient condition grain N content, it was 1.95% and 2.04%, respectively (Table 1). Reduction in wheat grain N content may be the result of dilution effect of more carbohydrate accumulation under increased CO_2 condition [19]. Several researchers have reported similar decrease in overall N concentration in plants when grown in elevated CO_2 condition [3, 4, 20]. Contrufo et al. [20] reported an average of 14% reduction in N concentration in plants grown under elevated CO_2 condition. However, this effect is different for different plants.

In case of chickpea crop, no significant difference was found in seed N content between ambient and elevated CO_2 treatments. Seed N content was 3.01% in both ambient and elevated CO_2 treatments in the first year. During the second year, seed N was 2.84% and 2.85% in ambient and elevated CO_2 treatments (Table 1). This might be attributed to the fact that chickpea being a leguminous crop got the advantage of N fixation under elevated CO_2 condition. Earlier results showed that in forage crops leaf N content and C/N ratio remained unaltered in legumes while it decreased in non-legumes [21]. Contrasting results are also being reported in chickpea as high atmospheric CO_2 concentration could adversely affect the chickpea grain quality [22].

Decreased plant N content with increase in total N uptake by wheat crop was attributed to increased grain and biomass yield under elevated CO_2 treatment. Total N uptake was 10.7 and 12.9 g m^{-2} in the first and second year, respectively, under high CO_2 concentration (Fig. 3a). Similarly higher seed as well as biomass yield of chickpea crop in high CO_2 treatment led to higher N uptake. Total N uptake by chickpea plant ranged from 11.6 to 12.1 g m^{-2} in high CO_2 treatment (Fig. 3b). Higher C assimilation and higher N uptake under elevated CO_2 condition resulted in higher biomass accumulation by the crop. Earlier workers also reported that in cereal crops like rice, total nitrogen (N) uptake for the whole plant increased, while leaf N concentration decreased at elevated CO_2 level [23, 24].

Partitioning coefficient of nitrogen to grain and straw was calculated by dividing grain and straw N uptake by total N uptake of the crop. In wheat crop, nitrogen partitioned to grains was higher (0.74) in elevated CO_2 treatment than ambient (0.7) during the first year. But in the second year N partitioning was same (0.77) as that of ambient CO_2 condition. On the other hand, N partitioned to wheat straw got reduced in the first year and remained same in the second year. In chickpea N partitioning to seeds increased under high CO_2 condition during both years of study (0.76 in ambient CO_2 and 0.79 in elevated CO_2 treatment during the first year and 0.76 in ambient CO_2 and 0.78 in elevated CO_2 treatment in the second year). Under high CO_2 condition, increase in seed yield (21.1% and 21.9% in the first and second years) in chickpea was more as compared to increase in straw yield (12.4% and 12.7% in the first and second years) which led to partitioning of more amount of N to seeds. Available N of soil also significantly decreased under elevated CO_2 concentration in wheat crop. Under ambient condition soil available N was 203.2 and 198.6 kg ha^{-1}, respectively, in the first and second years of study which decreased to 185.3 and 174.5 kg ha^{-1} under elevated CO_2 concentration (Table 2). On the other hand, soil available N was not affected by increased CO_2 concentration in chickpea crop. Chickpea being a leguminous crop can fix atmospheric N which might have benefitted the crop in terms of maintaining seed N content and soil available N as compared to wheat. The results indicate that increased atmospheric CO_2 level will increase yield of C3 crops like wheat and

Table 1 Effect of elevated carbon dioxide (CO_2) on N content in wheat and chickpea crop

Treatment	Wheat				Chickpea			
	N content (%)				N content (%)			
	Grain		Straw		Seed		Straw	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
Ambient CO_2 level	1.95	2.04	0.38	0.42	3.01	2.84	0.51	0.49
Elevated CO_2 level	1.89	1.93	0.34	0.39	3.01	2.85	0.51	0.47
CO_2 fertilization effect (%)	− 3.2	− 5.2	− 9.1	− 6.2	0.0	+ 0.1	+ 0.2	− 2.2
LSD ($p \leq 0.05$)	0.05	0.06	0.03	NS	NS	NS	NS	NS

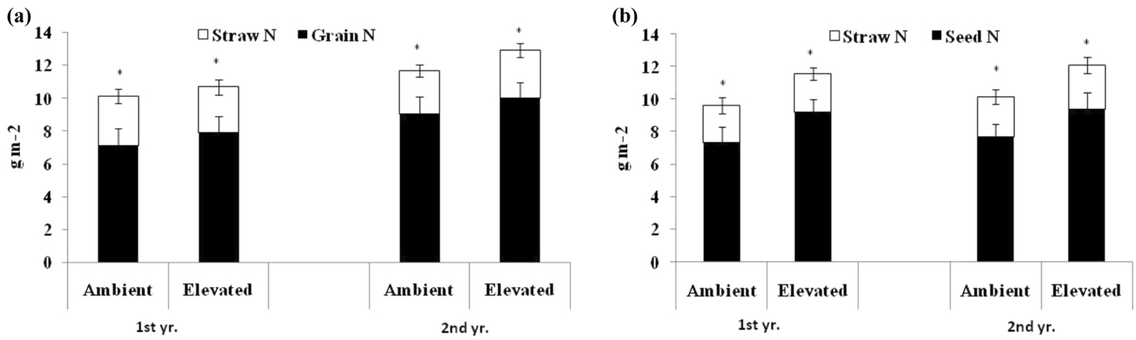

Fig. 3 Nitrogen uptake under ambient and elevated carbon dioxide (CO_2) conditions in **a** wheat and **b** chickpea crop (*indicate significant difference between ambient and elevated CO_2 treatments in a year at $p \leq 0.05$ level) (error bars in figures indicate standard deviation)

Table 2 Effect of elevated carbon dioxide (CO_2) on soil available N in wheat and chickpea crop

Treatment	Wheat		Chickpea	
	1st year	2nd year	1st year	2nd year
Ambient CO_2 level	203.2	198.6	205.4	202.3
Elevated CO_2 level	185.3	174.5	208.6	210.2
LSD ($p \leq 0.05$)	11.8	15.5	NS	NS

chickpea, but grain N concentration and soil available N status might decrease in non-leguminous crop like wheat, while it may not be affected for leguminous crop like chickpea.

Acknowledgements The authors acknowledge the generous funding from the Indian Council of Agricultural Research which supported this work. Authors are also thankful to ICAR—Indian Agricultural Research Institute, New Delhi, for providing the facilities for conducting the study.

References

1. IPCC (2014) Summary for policymakers. In: Climate change, mitigation of climate change. Contribution of Working Group III to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 1–31
2. Hymus GJ, Baker NR, Long SP (2001) Growth in elevated CO_2 can both increase and decrease photochemistry and photoinhibition of photosynthesis in a predictable manner. *Dactylis glomerata* grown in two levels of nitrogen nutrition. Plant Physiol 127(3):1204–1211
3. Körner C, Miglietta F (1994) Long-term effects of naturally elevated CO_2 on Mediterranean grassland and forest trees. Oecologia 99:343–351
4. Poorter H, Roumet C, Campbell BD (1996) Interspecific variation in the growth response of plants to elevated CO_2: a search for functional types. In: KoÈrner C, Bazzaz FA (eds) Carbon dioxide, populations, and communities. Academic Press, San Diego, pp 375–412
5. Abebe A, Pathak H, Singh SD, Bhatia A, Harit RC, Kumar V (2016) Growth, yield and quality of maize with elevated atmospheric carbon dioxide and temperature in north–west India. Agric Ecosyst Environ 218:66–72
6. Rogers A, Gibon Y, Stitt M, Morgan PB, Bernacchi CJ, Ort DR, Long SP (2006) Increased C availability at elevated carbon dioxide concentration improves N assimilation in a legume. Plant Cell Environ 29:1651–1658
7. Chakrabarti B, Singh SD, Kumar SN, Aggarwal PK, Pathak H, Nagarajan S (2012) Low-cost facility for assessing impact of carbon dioxide on crops. Curr Sci 102:1035–1040
8. Jackson ML (1973) Soil chemical analysis. Prentice Hall India Pvt. Ltd., New Delhi
9. Gomez KA, Gomez AA (1984) Statistical procedures for agricultural research. Wiley, New York
10. Subbiah B, Asija GL (1956) A rapid procedure for estimation of available nitrogen in soils. Curr Sci 25:259–260
11. Hogy P, Wieser H, Kohler P, Kohler P, Schwadorf K, Breuer J, Franzaring J, Muntifering R, Fangmeier A (2009) Effects of elevated CO_2 on grain yield and quality of wheat: results from a 3-year free-air CO_2 enrichment experiment. Plant Biol 11:60–69
12. Amthor JS (2001) Effect of atmospheric CO_2 concentration on wheat yield: review of results from experiments using various approaches to control CO_2 concentration. Field Crops Res 73:1–34
13. Chakraborty K, Uprety DC, Bhaduri D (2017) Growth, physiology and biochemical responses of two different brassica species to elevated CO_2. Proc Natl Acad Sci India Sect B Biol Sci 87(2):389–397
14. Ruhil K, Sheeba, Ahmad A, Iqbal M, Tripathy BC (2015) Photosynthesis and growth responses of mustard (*Brassica juncea* L. cv Pusa Bold) plants to free air carbon dioxide enrichment (FACE). Protoplasma 252:935–946
15. Gao J, Han X, Seneweera S, Li P, Zong Y, Dong Q, Lin E, Hao X (2015) Leaf photosynthesis and yield components of mung bean under fully open-air 2 elevated CO_2. J Integr Agric 14(5):977–983

16. Saha S, Chakraborty D, Lata N, Pal M, Nagarajan S (2011) Impact of elevated CO_2 on utilization of soil moisture and associated soil biophysical parameters in pigeon pea (*Cajanus cajan* L.). Agric Ecosyst Environ 142(3-4):213–221
17. Singh SD, Chakrabarti B, Muralikrishna KS, Chaturvedi AK, Kumar V, Mishra S, Harit R (2013) Yield response of important field crops to elevated air temperature and CO_2 levels. Indian J Agric Sci 83(10):1009–1012
18. Saha S, Sehgal VK, Chakraborty D, Pal M (2015) Atmospheric carbon dioxide enrichment induced modifications in canopy radiation utilization, growth and yield of chickpea (*Cicer arietinum* L.). Agric For Meteorol 202:102–111
19. Rogers HH, Runion GB, Prior SA, Torbert HA (1999) Response of plants to elevated atmospheric CO_2: root growth, mineral nutrition, and soil carbon. In: Luo Y, Mooney HA (eds) Carbon dioxide and environmental stress. Academic Press, San Diego, pp 215–244
20. Cotrufo MF, Ineson P, Scott A (1998) Elevated CO_2 reduces the nitrogen concentration of plant tissues. Glob Change Biol 4:43–54
21. Winkler JB, Herbst M (2004) Do plants of a semi-natural grassland community benefit from long-term CO_2 enrichment? Basic Appl Ecol 5:131–143
22. Saha S, Chakraborty D, Sehgal VK, Pal M (2015) Potential impact of rising atmospheric CO_2 on quality of grains in chickpea (*Cicer arietinum* L.). Food Chem 187:431–436
23. Kim HY, Lieffering M, Miura S, Kobayashi K, Okada M (2001) Growth and nitrogen uptake of CO_2-enriched rice under field conditions. New Phytol 150:223–229
24. Ainsworth EA, Rogers A, Leakey ADB, Heady LE, Gibon Y, Stitt M, Schurr U (2007) Does elevated atmospheric (CO_2) alter diurnal C uptake and the balance of C and N metabolites in growing and fully expanded soybean leaves? J Experim Bot 58(3):579–591