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Long-term atmospheric CO_2 enrichment impact on soil biophysical properties and root nodule biophysics in chickpea (*Cicer arietinum* L.)

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ABSTRACT

Impact of atmospheric CO_2 enrichment on soil aggregation, carbon and other nutrient availability and soil enzyme activities in relation to root and nodule biophysics in chickpea (*Cicer arietinum* L.; Pusa-1105 genotype) was studied in an open top chamber experiment at IARI, New Delhi, India, continuing since 2003. Soil samples were collected at the end of the crop growing seasons of 2010–11 and 2011–12, and analyzed. Root growth and nodulation were also studied in these seasons. Soil C and P pools, and associated enzyme activities responded differently to CO_2 enrichment, while total soil N did not change. Soil labile C fractions viz., water soluble carbohydrate (WSC) and microbial biomass C (MBC) significantly increased, although recalcitrant C fraction declined marginally. The soil-CO_2 flux increased by 28%. Dehydrogenase and fluorescein diacetate hydrolysis activity in soil increased by 44% and 67% respectively; and the β-glucosidase activity enhanced by 20% under enriched CO_2 condition. The CO_2 enrichment induced root growth and N_2-fixation by root nodules, which were evidenced by increase in legheamoglobin content and nitrogenase activity. Nodules were bulky and had higher starch and soluble sugar contents under enriched atmospheric CO_2 condition, allowing for greater N_2-fixation. The rhizosphere C:N ratio, however, remained unaffected. It could be possible that larger partitioning of C to roots along with greater N_2-fixation by nodules in chickpea might stabilize the net C:N ratio in the soil. Moreover, the increased soil biological activity under CO_2 enrichment resulted in marginal depletion of soil recalcitrant C with increase in labile C pools. These are likely to offset the stability of soil C pools in a legume-based agroecosystems under the enriched CO_2 condition in the semi-arid climate.

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1. Introduction

The atmospheric CO_2 concentration has increased by 26.2% during last 55 years resulting in considerable anthropogenic environmental change (ESRL, 2014). Several studies have been conducted on the direct and indirect effects of the rising of CO_2 on agricultural productivity. The direct effect involves the primary response by the plats to the elevated CO_2 (Aranjuelo et al., 2008; Saha et al., 2012), while the indirect impact could be through changes in soil biophysical properties (Prior et al., 2004). Soil carries the most stable and largest terrestrial C pool accounting to nearly 80% of global terrestrial C. Its capacity depends on the balance between rate of biomass C inputs and C released (as CO_2) through microbial activities. Atmospheric CO_2 enrichment alters the balance, and gives substantial feedbacks to increasing CO_2 concentration, thereby affecting the global biogeochemical cycles (Nielsen et al., 2011).

Atmospheric CO_2 enrichment has the potential to increase and stabilize soil aggregation through greater synthesis of microbial byproducts forming an organo-mineral sheath with the surrounding mineral particles (Chenu, 1993; Rilling et al., 1999). Higher CO_2 concentration induced labile C and below-ground root biomass, but had no effect on water stable aggregates (Eviner and Chapin, 2002). After a 6-year long CO_2 enrichment, proportion of macroaggregates for *Lolium perenne* L. increased with no significant change in total soil C (Six et al., 2001). In contrary, no impact of 6-year enriched CO_2 was observed on *Trifolium repens* L. in *Eutric Cambisol* (Six et al., 2001), *Gleyic Cambisol* after 5-year enriched CO_2 exposure (Dorodnikov et al., 2009), and *Typic Endoaquoll* after 8-year SoyFACE experiment (Pujol Pereira et al., 2013)

Lin and Zhang (2012) reported small-yet-measurable increase in soil C under CO_2 enrichment. Contrary results also exist, where soil C remained unaffected (Guenet et al., 2012). Rising atmospheric

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CO_2 increased available C and N contents in soil under rice (*Oryza sativa* L.) (Das et al., 2011), although no significant difference in C:N ratio of the agriculturally managed soils was recorded under 6 years of free-air CO_2 enrichment as compared to ambient CO_2 (Anderson et al., 2011). However, Manna et al. (2013) and Pujol Pereira et al. (2013) did not observe any change in microbial biomass C for rice soil exposed to enriched atmospheric CO_2. Limited information is available on the effect of higher atmospheric CO_2 on soil enzymes except in rice (Das et al., 2011; Bhattacharyya et al., 2013) and pigeon pea (*Cajanus cajan* L.) (Saha et al., 2011). Increase in lateral root number, root length, surface area, diameter and root volume in pigeon pea have been reported in pigeon pea (Saha et al., 2011), suggesting the potential of C sequestration in below-ground plant parts.

It is apparent that the response to atmospheric CO_2 enrichment on below-ground C allocation and enzymatic activities is highly crop specific, and widely variable. Little emphasis has been given on long-term impact of CO_2 fertilization on rhizosphere C dynamics, root growth and nodulation of legume crops. Chickpea is one of the most widely cultivated legumes covering 11.5 million ha worldwide (15.3% of the total pulses area). India is the principal chickpea producing country in South-East Asia with 84% share in this region (ICRISAT, 2014). Although CO_2 impact on the growth of chickpea has been monitored (Pal et al., 2008; Saha et al., 2015), the C accumulation in the below-ground system (root, nodules and soil) and the effect on the soil biophysical properties have not been reported. Furthermore, chickpea as a legume crop, offers a unique situation where its N-fixing abilities interact with soil nutrient dynamics and enzyme activities in ways different than that in non-legume crops.

We hypothesize that (i) long-term atmospheric CO_2 enrichment augments root growth and nodulation in chickpea, and brings more C to the rhizosphere; and (ii) enhanced nodulation with increased C partioning to the roots stabilizes the C:N ratio in the rhizosphere. To test these hypotheses, a two-year open-top chamber experiment was carried out with the objective to assess the atmospheric CO_2 mediated changes in root and nodule biophysics in chickpea (*Cicer arietinum* L.), and microbial response to these changes for C and nutrient dynamics in the rhizosphere.

2. Materials and methods

2.1. Climate and soils

An open-top chamber (OTC) experiment on chickpea has been continuing since 2003 at the research farm of the ICAR-Indian Agricultural Research Institute, New Delhi (28^0 35' N latitude, 77^0 12' E longitude, 228.16 m altitude above mean sea level), and has been used for the study. The chambers had similar agronomic treatments. All observations were taken during *rabi* (winter) season (mid November-mid April) in 2010–11 and 2011–12 years after the crop harvest. The climate is typical semi-arid with dry hot summer and mild winters. The average annual rainfall is 710 mm of which only 10% is received during winter. Mean daily maximum and minimum air temperature during the experimental years ranged between 10 and 29 °C and 2–12 °C. The soil belongs to *Typic Haplustept* of upper Indo-Gangetic Plains and sandy loam in texture, non-calcareous and mild alkaline in reaction. Some major physico-chemical properties of 0–30 cm soil are presented in Table 1.

2.2. Experimental details

A set of 4 OTCs were available in our present experimentation. The detailed description of the OTCs and other experimental conditions may be obtained from Saha et al. (2015). The design of experiment was a completely randomized block design (CRD) with

Table 1
Hydrophysical characteristics of rhizosphere soil as modified by atmospheric CO_2 enrichment.

Treatment	Saturated hydraulic conductivity ($cm\,h^{-1}$)	Bulk density ($Mg\,m^{-3}$)	Mean weight diameter of aggregates (mm) in pre-treatments			Water retention ($m^3\,m^{-3}$) at matric potential in kPa			Soil pH of 1:2.5 soil to water ratio	Electrical conductivity of 1:2.5 soil to water ratio ($dS\,m^{-1}$)
			Mechanical breakdown	Fast wetting	Slow wetting	0	−33	−1500		
Ambient CO_2	1.09	1.51	0.46	0.39	0.46	0.30	0.15	0.08	7.90	0.71
Enriched CO_2	1.17	1.57	0.63	0.53	0.48	0.32	0.16	0.09	7.84	0.64
p-value	0.72	0.13	0.02	0.005	0.68	0.24	0.67	0.81	0.877	0.921

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