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Atmospheric carbon dioxide enrichment induced modifications in canopy radiation utilization, growth and yield of chickpea [*Cicer arietinum* L.)]

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A B S T R A C T

Open top chamber experiments were conducted to study the response of chickpea crop (cv. Pusa-1105) to atmospheric CO_2 enrichment at 580 ± 20 ppm, in terms of radiation interception and use efficiency, biophysical parameters and yield components. The ambient (control) was kept at 384 ± 13 ppm. A significant increase in leaf area index was recorded through CO_2 enrichment, while no change in fractional intercepted photosynthetically active radiation was observed. This might be due to significant reduction (18.5%) in the canopy extinction coefficient. A 24% increase in radiation use efficiency resulted in 27.3% higher crop biomass. The specific leaf nitrogen content was higher although there was a reduction in specific leaf area, indicating increase in laminar thickness under enriched atmospheric CO_2 environment. Greater water soluble carbohydrate concentration in leaves suggests greater C assimilation under enriched atmospheric CO_2, with wide leaf C:N ratio at 50% flowering. There was no significant change in harvest index, but larger C:N in grains indicated reduction in the quality of grains. We conclude that a significant increase in chickpea productivity under enriched CO_2 will occur, although at the cost of reduction in nutritional quality of the produce.

1. Introduction

Increase in crop productivity could match the population growth during the past decades, but an understanding of how environmental conditions will affect crop production in the future is a matter of concern for the world food security (Foulkes et al., 2011). In today's world, major attention is focused on the impact of increasing atmospheric greenhouse gases (GHGs) on agro-ecosystems, threatening the sustainability of crop production in the near future. Global atmospheric CO_2 concentration has increased from 316 ppm in 1959 (Keeling et al., 2009) to the level of 399 ppm in 2014 (http://www.esrl.noaa.gov/gmd/ccgg/trends/weekly.html, accessed 13.06.14), and is likely to touch 570 ppm by 2050 (IPCC, 2007). The increase may enhance the C assimilation rates (Wu et al., 2004), and modify the biochemical and ecophysiological functioning of leaves and canopy structural elements that control the absorption of solar radiation (Drewry et al., 2010).

Atmospheric CO_2 enrichment stimulates photosynthesis, which modifies radiation interception and use-efficiency in C_3 legumes. The effect of enriched atmospheric CO_2 on increase in peak leaf area index (LAI) was reported in soybean (Sun et al., 2009), and pigeon pea (Saha et al., 2012). The LAI profile may also be altered by delaying the senescence in soybean (Dermody et al., 2006) or by early maturity in pigeon pea (Saha et al., 2012).

Higher CO_2 assimilation improved the radiation use efficiency (RUE) in wheat (Manderscheid et al., 2003) and winter barley (Manderscheid et al., 2009), leading to efficient dry matter accumulation by these crops. Modification in leaf orientation might also be a factor contributing to these differences. Smart et al. (1994) observed an increase in LAI but reduction in leaf extinction coefficient (k) in wheat under the atmospheric CO_2 enrichment. In chickpea, the plant architectural change improved the light interception, biomass production at critical growth stages and increased the seed yield at harvest (Li et al., 2010). However, the effect of greater LAI on radiation interception was offset

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by subsequent reduction in '*k*' in sunflower (Sims et al., 1999), and no effect of atmospheric CO_2 enrichment on seasonal light absorption in wheat was recorded (Manderscheid et al., 2003). A sharp decrease in RUE in rice during post-heading period under enriched atmospheric CO_2 was recorded (De Costa et al., 2006), which could be attributed to a reduction in leaf N concentration. There could be ameliorative effect of atmospheric CO_2 enrichment on decreased seasonal radiation absorption by the canopy under limited N supply (Manderscheid et al., 2009). Saha et al. (2012) found nearly 50% increase in RUE along with reduced '*k*' and increased crop LAI under enriched atmospheric CO_2 in pigeon pea.

Enriched atmospheric CO_2 changes leaf C:N ratio due to higher C assimilation but may be constrained by availability of N (Ainsworth and Long, 2005). Increase in C:N ratio in wheat leaves due to greater C partitioning was found (Pal et al., 2003), while no increase in the same in clover (Zanetti et al., 1996) was reported.

The increased partitioning of photosynthate-C toward growing organs of berseem (Pal et al., 2004) and pigeon pea (Saha et al., 2011) led to higher biomass and seed yields under atmospheric CO_2 enrichment. Increased harvest index (HI) in castor bean was reported at 700 ppm CO_2 (Vanaja et al., 2008). However, a review by Cure and Acock (1986) concluded that the changes in HI were small and inconsistent, except for soybean, where it decreased significantly with CO_2 doubling. Sun et al. (2009) also observed decrease in soybean HI along with increase in biomass and seed yield. Harvest index of pigeon pea decreased under enriched atmospheric CO_2 due to plant's inability to fully utilize the photosynthetic assimilates (Saha et al., 2012). However, Aranjuelo et al. (2013) opined that the increase in wheat yields under atmospheric CO_2 enrichment was not due to increase in total biomass but rather due to increase in HI.

Chickpea [*Cicer arietinum* (L.)] is an important semi-arid tropical legume crop and a cheap source of protein for millions of families in developing countries. India is the largest producer of this crop (3rd most important food legume in the country) with a share of 14.6% in global pulse production (FAOSTAT, 2010) and grown on about 11.9 million hectares of cultivable land (in 2010), adding 10 million tons to the global food basket (http://www.cgiar.org/our-research/crop-factsheets/chickpea/, accessed 13.06.14). The crop is well-adapted to drought-prone environment, and is mostly grown on residual soil moisture, without much additional irrigation inputs. As a legume crop, chickpea is able to exchange C for N (available through symbiotic N_2 fixation). We hypothesize that this gives a competitive advantage when the crop is grown under enriched atmospheric CO_2 (i.e., more photosynthate-C) and hence, is more responsive than cereal crops. The objective of our study was to examine how the increased growth and biomass under enriched CO_2 environment could modify the RUE, the C:N ratio in leaf and grains of chickpea, and finally on its harvest index and grain yields.

2. Materials and methods

2.1. Site description

The experiment was conducted on chickpea (*C. arietinum* L.; cv. Pusa 1105-*kabuli* type) in open-top chambers (OTCs) on a fairly leveled topography, during *rabi* (winter) seasons (mid-November–mid-April) of 2010–2011 and 2011–2012, at the Indian Agricultural Research Institute, New Delhi. The study site was located at 28°35′ N, 77°12′ E and with an altitude of 228.16 m above the mean sea level.

2.2. Climate

The climate of the site was characterized by a typical semi-arid with dry hot summer and mild winters and with an average annual rainfall of 710 mm (80% is received during southwest monsoon during July–September). The mean daily maximum and minimum air temperatures were between 10–29 °C and 2–12 °C respectively, during the period of our experimentation. The mean daily evaporation (USWB open pan evaporation) was 1.8 mm d^{-1} during the crop growth period.

2.3. Soil

The surface soil (0–30 cm) is non-calcareous and sandy loam in texture with 68.8% sand, 19.2% silt and 12.2% clay. The average bulk density was 1.61 Mg m^{-3}; water holding capacity, 32.6%; saturated hydraulic conductivity, 1.17 cm h^{-1}; pH (1:2.5 soil:water suspension) 7.9; electrical conductivity, 0.46 dS m^{-1}; organic C, 0.03 g kg^{-1}; total N, 0.03%; and available P and K, 5 and 454 kg ha^{-1}, respectively.

2.4. Experimental details

In two OTCs (3 m in diameter and 2.5 m in height), enriched CO_2 level of 580 ± 20 μmol mol^{-1} was maintained between 6:00 and 18:00 h starting from crop emergence. The other two OTCs were used as chamber controls without any external supply of CO_2 (CO_2 level was recorded as 384 ± 13 μmol mol^{-1} during the experiment). The circular structure of OTCs was fixed in the field and fabricated using aluminum frame as described in Saha et al. (2011). Pure CO_2 gas (99.7% (v/v) CO_2 and less than 10 μmol mol^{-1} CO) was released from a commercial grade cylinder fitted with a regulator (DURA, make ESAB, India) through solenoid valve and PV tubing connected to air-exhaust blower mounted at the base of each OTC.

2.4.1. Crop management practices

Seeds were treated with captan at 2 g kg^{-1} of seed, and were surface-sterilized in the following day by dipping in 0.1% $HgCl_2$ for 2 min. After rinsing in sterile distilled water, seeds were allowed to imbibe water for 6 h and then coated with *Rhizobium* culture, and 10% sucrose solution in shade. Seeds were sown manually in rows at 10 cm depth by putting 2–3 seeds per hole and maintaining 30 cm (row-to-row) and 15 cm (plant-to-plant) spacing. Basal dose of 20–40–60 kg ha^{-1} NPK was incorporated during seedbed preparation. The sowing was done in 1st week of November, 2010 and 1st week of December, 2011. After 3 weeks, the newly emerged seedlings were thinned to 20 plants m^{-2}. Weeding was done manually, while fungicide mixture (Bavistin + Dithane M-45) was sprayed at 50 days after sowing (DAS) to prevent fungal infection. The date of floral bud initiation and the date of physiological maturity were recorded based on visual appearance. The crop was grown on soil profile-stored water with supplemental irrigations of 20 mm to avoid water stress. The crop received 63.5 and 14.8 mm rains during the vegetative periods (Fig. 1a).

2.4.2. Weather during crop growth

During the entire period of experiment, temperature and humidity inside the chambers were recorded with automatic sensors (Model TRH 511) connected to a data logger (Model TC 800D, Ambetronics, Switzerland) fitted in the middle of each OTC. Daily rainfall was measured by a FRP rain-gauge in the nearby meteorological observatory, located at 20 m (south) away from the study site. The details of microclimate conditions inside the OTCs for the entire crop growth period are presented in Fig. 1a and b. During 2011–2012, there was more diurnal fluctuation (range of maximum and minimum values) in air temperatures between 31 and 103