Vol. 13, No. 1, pp. 55-61 (2013)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Growth Behavior of *kabuli* Chickpea under Elevated Atmospheric CO_2

SAURAV SAHA[1*#], V.K. SEHGAL[1], DEBASISH CHAKRABORTY[1] AND MADAN PAL[2]

[1]*Division of Agricultural Physics, Indian Agricultural Research Institute, New Delhi - 110012*

[2]*Division of Plant Physiology, Indian Agricultural Research Institute, New Delhi - 110012*

ABSTRACT

An open top chamber (OTC) experiment was conducted in 2010-11 and 2011-12 to study the impact of elevated atmospheric carbon dioxide (580 ±20 ppm) on the growth, leaf pigmentation and biomass partitioning of *kabuli* chickpea (cv. 1105). There was positive response to elevated CO_2 in terms of increased plant height, leaf area index (LAI) and leaf chlorophyll content. The leaf carotenoids content and specific leaf area decreased under elevated CO_2 with more dry matter partitioned towards stem. Results suggest higher plant canopy growth with greener, thicker and long-lived leaves, under elevated atmosphere CO_2 condition.

Key words: CO_2, Biomass, Chlorophyll, LAI

Introduction

Carbon dioxide (CO_2) concentration in the atmosphere has increased by nearly 37%, since the dawn of industrial revolution (Keeling and Whorf, 2008), and is likely to increase up to 570 ppm by the middle of the current century with a consequence of 2.0 to 4.5°C warmer earth surface (IPCC, 2007). Since CO_2 is the substrate for photosynthesis, any change in its atmospheric concentration leads to enhanced carboxylation and reduced oxygenation; thereby altering partitioning efficiency i.e. carbon allocation in various plant organs (Liu *et al.,* 2005).

In a pot experiment, Morison and Gifford (1984) found that 560 ppm of atmospheric CO_2 increased leaf area with reduced transpiration rate for 16 different agricultural and horticultural species. Greater leaf area along with higher plant biomass was reported at all growth stages of wheat under 600 ppm of atmospheric CO_2 enrichment (Pal *et al.,* 2005). Similar effects were observed also in berseem (Pal *et al.*, 2004). Qiao *et al.* (2010) reported more tillers in winter wheat grown in OTC under 712 ppm of atmospheric CO_2.

Variable response of LAI was reported under elevated CO_2. In OTC experiments, significant increase in LAI was reported in wheat (Tausz-Posch *et al.,* 2012) and pigeon pea (Saha *et al.*, 2012). In contrast, reduced LAI was reported with CO_2 enrichment for maize (Kim *et al.,* 2007). Leaf chlorophyll content of wheat either increased (Demothes and Knoppik, 1994), unaffected (Donnelly *et al.,* 2000) or decreased (Cheng *et al.,* 2010) due to elevated CO_2.

Chickpea (*Cicer arietinum* L.) is the largest produced food legume in South Asia and the 3rd largest produced high-quality food legume

*Corresponding author,
Email: sauravs.saha@gmail.com
#Current address: ICAR Research Complex for North Eastern Hill Region Umiam, Meghalaya, 793103

globally. India is the largest chickpea growing country in the world, accounts 73.3% share of production within Asia and 72% of area under chickpea, with an average productivity of 801 kg ha^{-1} (Rao *et al.*, 2010).

A large number of publications are available focusing on the influence of atmospheric CO_2 enrichment on the growth behavior of several cereals, but very few for the pulses. Being an important C_3 legume of semi-arid region, information on the influence of elevated CO_2 concentration on the growth behavior of chickpea is rarely reported. Hence, the present study was planned to quantify the impact of elevated CO_2 on major growth parameters and leaf pigmentation in kabuli chickpea.

Materials and Methods

Site characteristics

The experimental site was situated in semi-arid climate of New Delhi, at 28°35′N latitude, 77°12′E longitude and at 228.16 m above mean sea level with a fairly leveled topography. The average maximum and minimum air temperatures during crop growth seasons (*rabi* 2010-11 and 2011-12) were 19.5 °C and 6.6 °C, respectively. The total rainfall received during the crop growth period was 45.3 mm in 2010-11 and 25.8 mm in 2011-12, of which about 85% was received during post anthesis period. The site has sandy loam soil with 68.8% sand 19.2%, silt and 12.2 % clay.

Experimental details

The study was conducted in four circular OTCs, fabricated using aluminum frame as used by Saha *et al*. (2011) and were installed in the field. Chickpea seeds (*Cicer aerietinum* L.; cv. Pusa 1105- kabuli type) were treated in shade with the fungicide Captan (@ 2 g kg^{-1} of seed), *Rhizobium* culture and 10% sucrose solution. and sown manually in rows with a spacing of 30 cm row-to-row and 15 cm plant-to-plant. Basal dose of 20-40-60 NPK was applied during seed bed preparation and the sowing operation was completed within third week of November. After 3 weeks, plants were thinned to a density of 20 plant m^{-2} in each OTC.

Above ground plant parts were harvested randomly in triplicate from each OTC at three distinct crop growth stages viz., initial vegetative, 50% flowering and 50% maturity to study growth and dry matter partioning. Based on physical appearance, these growth stages appeared on 50, 94 and 125 DAS in 2010-11 and 48, 72 and 90 DAS in 2011-12.The harvested plants were washed, morphological characters (plant height, fresh biomass production) were recorded and the leaves were separated. Total leaf area per plant was measured using leaf area meter (LICOR-100) and LAI was calculated as:

$$LAI = \frac{Measured\ leaf\ area\ per\ plant\ (cm^2) \times Number\ of\ plants\ per\ m^2}{100 \times 100\ (cm^2)} \quad ...(1)$$

Leaf chlorophyll (Chl) content was determined by using a non-maceration technique of Hiscox and Israelstam (1979). Briefly here, 1 g leaf slices were kept overnight in 10 ml of dimethyl sulphoxide, the absorbance at 645 and 663 nm were recorded using spectrophotometer and the chlorophyll content was calculated following Arnon (1949). For leaf carotenoids content, absorbance at 480 nm wavelength were used in the equations proposed by Kirk and Allen (1965). For calculating dry matter yield four plants were randomly selected from each OTC (i.e. total 8 plants for each treatment of elevated and ambient CO_2) and cut at ground level. Different plant parts like leaf, stem, and pod were separated. Those plant materials were oven-dried at 65°C for 48 hours and weighed separately by precise digital balance. Dry matter in different plant parts was expressed in g m^{-2} unit. Root and stem portions were then collected for both elevated and ambient CO_2 exposed plants and ignited at 450°C for 6 hrs in a muffle furnace to estimate the mass loss in ignition (%).

Statistical analysis

The data were analyzed using complete randomized design and the significance was tested at 0.05 and 0.01 level of critical difference using SPSS version 16.

Results and Discussion

The plant height was 1.2-1.5 times (Fig. 1) higher under elevated CO_2 with a large increase in LAI (Fig. 2) than control. The effect was more visible at 50% flowering and podding stage. Elevated CO_2 accelerated plant growth by 45% (94 DAS) during 2010-11 and 13% (72 DAS) during 2011-12, with a significant increase in LAI (both significant at $p<0.05$ and $p<0.01$). Initial vegetative stage was found to be less sensitive to the CO_2 fertilization. Increased canopy photosynthesis enables plants to utilize more phtosynthates for its growth with concomitant increase in chickpea LAI. As chickpea is a leguminous crop (Singh and Diwakar, 1995), there is possibility of increased nitrogen fixation under elevated CO_2, which is subsequently utilized by the plants to support the process of growth enhancement (Gamper *et al.*, 2005).

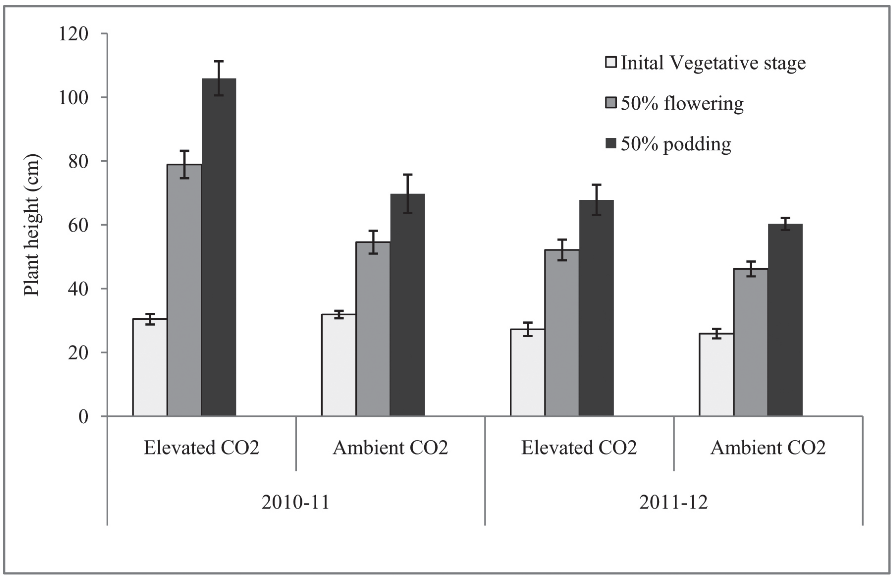

Fig. 1. Variations in plant height at different crop growth stages in chickpea

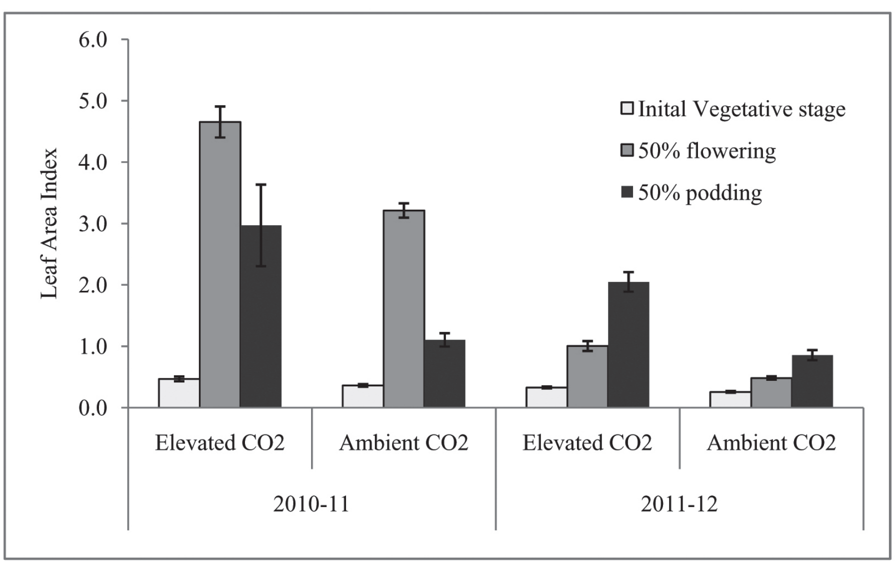

Fig. 2. Variations in Leaf Area Index (LAI) at different crop growth stages in chickpea

In spite of increase in total leaf area by 1.5 ($p<0.01$) (2010-11) and 2.1 ($p<0.01$) times (2011-12) along with increase in leaf weight by 1.6 ($p<0.01$) and 3.6 ($p<0.01$) times in 2010-11 and 2011-12, respectively, the specific leaf area (SLA) decreased by 19.3% ($p<0.01$) in 2010-11 and 22.5% ($p<0.01$) in 2011-12 at 50% flowering stage (Fig. 3a). Our result supports the findings of 159 % increase in wheat leaf area at 90 DAS under elevated CO_2 (Pal *et al.,* 2005) and 43.7% increase in plant height with a 3.3-fold increase in LAI of *Cenchrus ciliaris* fodder species (Bhatt *et al.,* 2007). Contrary to Bhatt *et al.* (2007), our result supports the decreased wheat SLA (Pal *et al.,* 2005) under elevated CO_2, indicating lesser expansion of leaf area per unit dry matter accumulation in chickpea. Although increase in LAI through CO_2 fertilization was supported by an increase in total leaf area per plant along with individual leaf weight, the magnitude of increase in weight overshadows the effect of area expansion in both of the years. Our results also support the observation that leaf thickness is increased due to higher rate of photosynthesis under elevated CO_2 (Das, 2003), and the dominance of photosynthetic carbon assimilation over individual leaf nitrogen assimilation for chickpea under elevated CO_2 environment.

During all the growing stages, stem dry weight was 1.5-2.8 times higher under elevated CO_2 and at 50% flowering stage it increased by 47.9 ($p<0.01$) and 141.8% ($p<0.01$) during 2010-11 and 2011-12, respectively (Fig. 3b). Mass loss on ignition data (Fig. 4) at 50% flowering stage

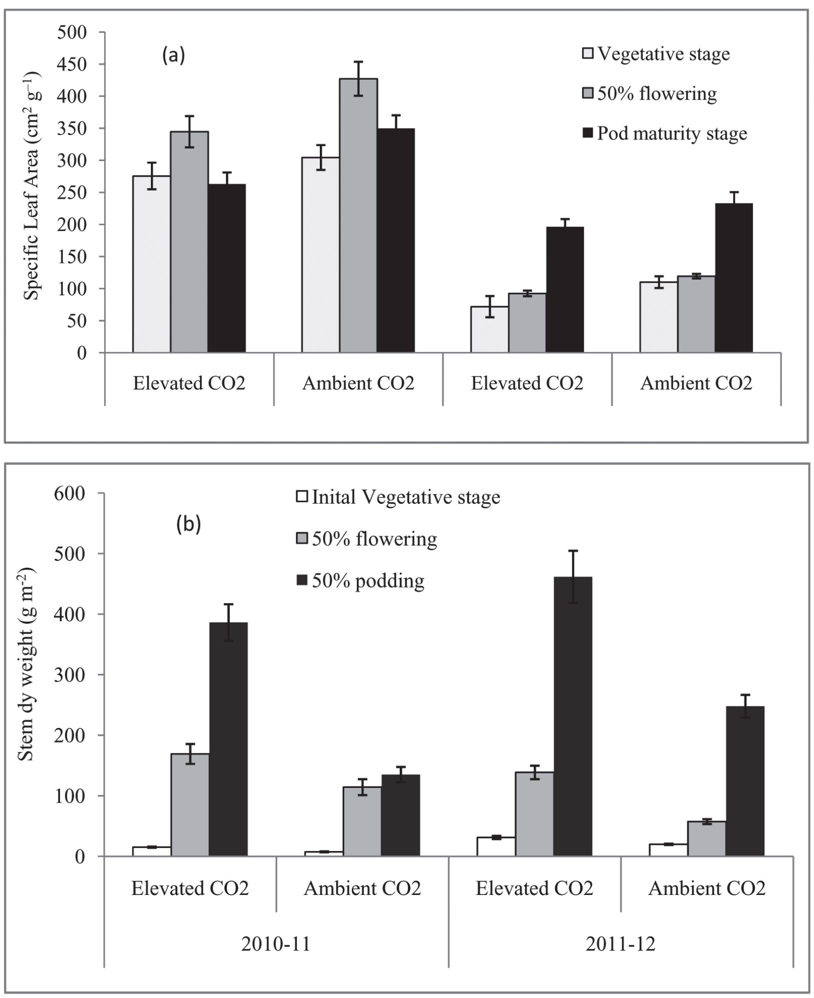

Fig. 3. Variations in (a) Specific Leaf Area (SLA) (m^2 g^{-1}) and (b) stem dry weight (g m^{-2}) at different crop growth stages in chickpea

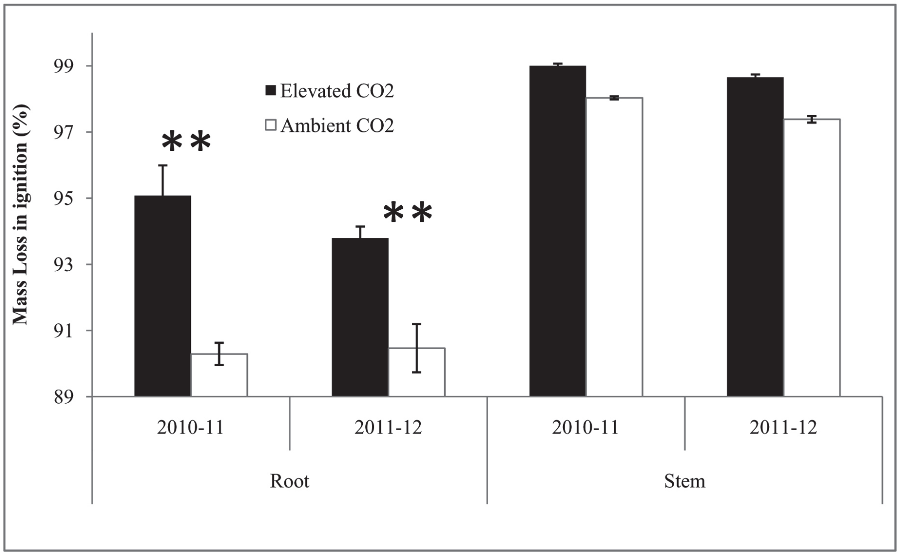

Fig. 4. Variations in mass loss on ignition for root and stem portions of chickpea at 50% flowering under elevated and ambient CO_2 treatments

showed a significant ($p<0.01$) increase in carbon allocation towards roots by 5.3% in 2010-11 and 3.6% in 2011-12, whereas increasing (but non-significant) trend for stem allocation was observed was recorded under elevated CO_2. This signifies the enhanced downward movement of photosynthates resulting from increased photosynthetic assimilation under elevated CO_2. Overall, significant increase in chickpea growth and dry matter allocation was observed due to the photosynthetic enhancement effect of CO_2 enrichment and the partitioning of photosynthates towards different growing plant organs (Pal *et al.,* 2004). The extra carbon fixed by the plants was found to be translocated to growing axis of the plant species (Sharma and Sengupta, 1990).

Significant increase in leaf chlorophyll content (Fig. 5a) along with decreasing leaf carotenoids content (Fig. 5b) under elevated atmospheric CO_2 enrichment were recorded over the entire season in both of the years. Leaf chlorophyll increased by 18.9 to 32.7% ($p<0.01$) under elevated CO_2 during 2010-11, and between 8 to 12% ($p<0.05$) in 2011-12 at different crop growth stages.

Leaf carotenoids content on the other hand decreased by 3-6 % in 2010-11 and 14-30% ($p<0.05$) in 2011-12. Our results are in agreement with Donnelly *et al.* (2000) who reported elevated CO_2 induced protection against leaf chlorophyll damage, ensuring the greenness of the leaves for a longer duration. It might be indicating better nitrogen utilization along with decreasing trend of leaf carotenoids content, and an increasing self-life of leaf chlorophyll in chickpea with enhanced photosynthesis under elevated CO_2 environment. Increased chloroplast number per unit cell area has been reported for *Nicotiana* sp. (Wang *et al.*, 2004). Being a legume, chickpea can fulfill its N requirement through symbiotic nitrogen fixation and therefore, with no limitation in supply of plant available N as in the present study, plant N uptake was accelerated under elevated atmospheric CO_2. It resulted in an increase in the foliar N concentration and leaf chlorophyll content (e.g. Cheng *et al.,* 2010).

Conclusions

A significant positive growth response of chickpea to the elevated atmospheric CO_2 enrichment was recorded. In spite of increase in individual plant height, LAI, leaf chlorophyll content and dry matter yield, leaf carotenoids content decreased along with a decreasing trend in SLA. This suggests the occurrence of less expanded thick green leaves for a longer duration

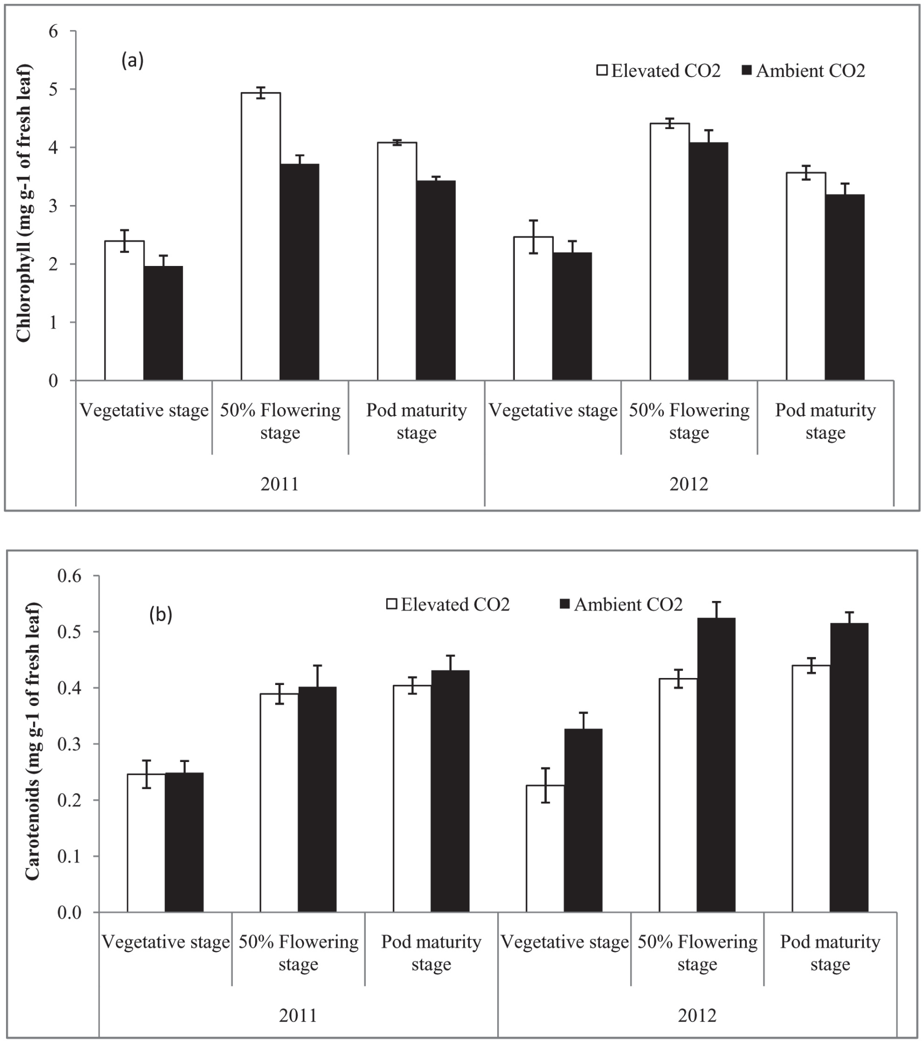

Fig. 5. Variations in leaf pigmentation (a) total chlorophyll (mg of Chl / gm of leaf fresh wt) and (b) total carotenoids (mg of Carotenoids/ gm of leaf fresh wt) at different crop growth stages in chickpea

under elevated CO_2 condition. Regarding the dry matter allocation, more partitioning towards the stem and the roots was obtained under the elevated CO_2 condition.

Acknowledgements

First author acknowledges Dr Raveender Singh, Head, Division of Agricultural Physics and Dr Anjali Anand, Senior Scientist, Division of Plant Physiology for their constructive support and valuable suggestions for conducting the research work and the fellowship received from CSIR, New Delhi, India to undertake this research work as part of PhD.

References

Arnon, D.I. 1949. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. *Plant Physiol.* **24**: 1-15.

Bhatt, R.K., Baig, M.J. and Tiwari, H.S. 2007. Growth, biomass production, and assimilatory characters in *Cenchrus ciliaris* L. under elevated CO_2 condition. *Photosynthetica* **45** (2): 296-298.

Cheng, Z.X., Suo, Z.F., Feng, Y.X. and Ping, C.X. 2010. Effect of nitrogen nutrition on photosynthetic function of wheat leaf under elevated atmospheric CO_2 concentration. *Acta Agron. Sin.* **36** (8): 1362-1370.

Das, R. 2003. Characterization of response of *Brassica* cultivars to elevated carbon dioxide under moisture stress. Ph. D. Thesis. Indian Agricultural Research Institute, New Delhi.

Demothes, M.A.G. and Knoppik, D. 1994. Effects of long-term enhanced CO_2 partial pressure on gas exchange parameters and saccharide pools of wheat leaves. *Photosynthetica* **30**: 435-445.

Donnelly, A., Jones, M.B., Burke, J.I. and Schnieders, B. 2000. Elevated CO_2 provides protection from O_3 induced photosynthetic damage and chlorophyll loss in flag leaves of spring wheat (*Triticum aestivum* L., cv. 'Minaret'). *Agri. Ecosyst. Environ.* **80**: 159-168.

Gamper, H., Hartwig, U.A. and Leuchtmann, A. 2005. Mycorrhizas improve nitrogen nutrition of *Trifolium repens* after 8 yr of selection under elevated atmospheric CO_2 partial pressure. *New Phytologist* **167**(2): 531-542.

Hiscox, J.D. and Israelstam, G.F. 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. *Can. J. Bot*. **57**: 1332-1334.

IPCC, 2007, *The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

Keeling, R.F., Piper, S.C., Bollenbacher, A.F. and Walker, S.J. 2008. Atmospheric CO_2-curve values (ppmv) derived from flask air samples collected at Cape Kumukahi, Hawaii. http://cdiac.ornl.gov/ftp/trends/co2/kumsio.co2

Kim, S. Gitz, D.C., Sicher, R.C., Baker, J.T., Timlin, D.J. and Reddy, V. R. 2007. Temperature dependence of growth, development, and photosynthesis in maize under elevated CO_2. *Environmental and Experimental Botany* **61**: 224-236.

Kirk, J.T. and Allen, R.L. 1965. Dependence of pigment synthesis on protein synthesis. *Biochem. Biophys. Res. Commun*. **21**: 523-530.

Liu, L., King, J.S. and Giardina, C.P. 2005. Effects of elevated concentrations of atmospheric CO_2 and tropospheric O_3 on leaf litter production and chemistry in trembling aspen and paper birch communities. *Tree Physiol.* **25**: 1511-1522.

Morison, J. I. L. and Gifford, R.M. 1984. Plant growth and water use with limited water supply in high CO_2 concentrations. i. leaf area, water use and transpiration. *Aust. J. Plant Physiol.* **11**: 361-374.

Pal, M., Karthikeyapandian, V., Jain, V., Srivastava, A.C., Raj, A. and Sengupta, U.K. 2004. Biomass production and nutritional levels of berseem (*Trifolium alexandrium*) grown under elevated CO_2. *Agri. Ecosyst. Environ.* **101**: 31-38.

Pal, M., Rao, L.S., Jain, V., Srivastava, A.C., Pandey, R., Raj, A. and Singh, K.P. 2005. Effects of elevated CO_2 and nitrogen on wheat growth and photosynthesis. *Biologia Plantarum* **49** (3): 467-470.

Qiao, Y., Zhang, H., Dong, B., Shi, C., Li , Y., Zhai, H. and Liu, M. 2010. Effects of elevated CO_2 concentration on growth and water use efficiency of winter wheat under two soil water regimes. *Agric. Water Manage.* **97**: 1742-1748.

Rao, P.P., Birthal, P.S., Bhagavatula, S. and Bantilan, M.C.S. 2010. *Chickpea and Pigeonpea Economies in Asia: Facts, Trends and Outlook.* Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. pp.76. ISBN: 978-92-9066-530-534.

Saha, S., Chakraborty, D., Lata, Pal, M. and 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.

Saha, S., Sehgal, V.K., Nagarajan, S. and Pal, M. 2012. Impact of elevated atmospheric CO_2 on radiation utilization and related plant biophysical properties in pigeon pea (*Cajanus cajan* L.). *Agric. For. Meteorol.* **158**: 63-70.

Singh, F. and Diwakar, B. 1995. Chickpea Botany and Production Practices, Skill Development Series no. 16. International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.

Sharma, A. and Sengupta, U.K. 1990. Carbon dioxide enrichment effect on photosynthesis and related enzymes in *Vigna radiata* (Wilczek). *Indian J. Plant Physiol*. **33**: 340-346.

Tausz-Posch, S., Seneweeraa, S., Norton, R.M., Fitzgerald, G.J. and Tauszd, M. 2012. Can a wheat cultivar with high transpiration efficiency maintain its yield advantage over a near-isogenic cultivar under elevated CO_2? *Field Crops Res.* **133**: 160-166.

Wang, X., Anderson, R., Kelvin, O. and Griffin, L. 2004. Chloroplast numbers, mitochondrion number and carbon assimilation physiology of *Nicotiana sylvestris* as affected by CO_2 concentration. *Environ. Exp. Bot.* **51**: 21-31.

Received: 2 November 2012; Accepted: 13 March 2013