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Effect of CO_2 on growth, seed yield and nitrogen uptake in sunflower

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ABSTRACT

Sunflower Hybrid (KBSH-1) was cultivated in Open Top Chambers (OTCs) at ambient (380 ppm) and elevated CO_2 (550 and 700ppm) conditions. Biomass accumulation in root, stem, head and seed was significantly greater at elevated CO_2 (550 ppm and 700ppm) compared with ambient (380 ppm).The improvement in total biomass with 550 and 700 ppm $CO_2$was 18.7 per cent and 40.5 percent and seed yield was 21.0 per cent and 45.9 per cent respectively compared to ambient. The positive growth response to increased atmospheric CO_2 resulted in N and C concentrations. Although elevated CO_2 levels tended to lower N concentration in some plant parts compared to ambient, elevated CO_2 enhanced total N accumulation in each plant component via an increase in biomass.Elevated CO_2 decreased the N per cent compared to ambient in seed meal, leaf and stem. At the recommended dose of nutrients, the total N uptake was high in plants grown at 700 ppm (1.25 g per plant), followed by 550 ppm (1.11g per plant) and ambient (0.96 11 g per plant). At the recommended dose of nutrients, physiological N use efficiency (PE) and grain N use efficiency (NUEg) was also high in plants grown at elevated CO_2 in OTCs and nitrogen harvest index (NHI) was similar for ambient (70.3%) and elevated CO_2 conditions (70.4 and 70.2 per cent at 550 ppm and 700 ppm).The total carbon accumulation was high in plants grown at 700 ppm, followed by 550 ppm and ambient.The C/N ratio of plants was high at elevated CO_2 conditions being 21.2, 20.0 and 19.0 at 700, 550ppm and ambient control respectively.

Keywords: Sunflower, elevated CO_2, open-top chambers, yield, nitrogen harvest index (NHI).

Atmospheric CO_2 concentration has increased from 280ppm to the 380ppm after industrial revolution. The rate of increase is currently 1.9 ppm per year and CO_2 at the end of this century may reach 500 – 1000ppm (IPCC, 2007). This increased atmosphere CO_2 concentration is likely to influence growth, development and productivity of crop plants. Earlier studies have shown that elevated CO_2 concentration increased photosynthesis rates, biomass accumulation and seed production in C_3 plants (Jablonski *et al.*, 2002). Positive physiological responses have been reported in pulse crops like blackgram (Vanaja *et al.*,2007) and redgram (Vanaja *et al.*,2010) under elevated CO_2 conditions. A CO_2 stimulation of plant growth requires a corresponding increase in nutrient acquisition to maintain the plant carbon to nutrient balance. Nitrogen is one of the most important nutrients that limit plant growth and seed production in natural and agricultural ecosystems (Aerts and Chapin, 2000).The impact of N dynamics is especially important since it has been commonly reported that N concentration is reduced in plants grown under elevated CO_2 (Kimball *et al.*, 2002). The impact of elevated atmospheric CO_2 on N fertilizer utilization is not only important because of its potential impact on crop productivity but also because soil fertility changes and nutrient additions especially N is inextricably link to environmental quality.

The present study is an attempt to quantify the effects of elevated CO_2 (550 and 700ppm) on growth, yield andits components, oil content,C and N concentration in root, stem, leaf, head and seeds at harvest as well as nitrogen uptake by whole plant, physiological N use efficiency (PE), grain N use efficiency (NUEg) and nitrogen harvest index (NHI).

MATERIAL AND METHODS

Experimental conditions and plant material

Sunflower plants (*Helianthus annus* L. Hybrid KBSH-1) were grown from seed in pots filled with 18 kg of red loamy soil in Open Top Chambers (OTCs) at Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, during October 2009 to January 2010. Plants were fertilized with 75:90:30 kg of $N:P_2O_5:K_2O$ kg ha^{-1}. Full dose of phosphorus and potash along with half of the nitrogen was applied at the time of sowing while rest of N was applied as top dressing in two splits at 25 and 45 days of planting.

Table 1: Mean *per se* values of traits for sunflower grown under elevated (550 ppm and 700 ppm) and ambient (380 ppm) CO_2 conditions.

Plant trait	CO_2 (ppm)			CD(5%)
	380	550	700	
Leaf dry wt. (g per plant)	9.3	9.9	11.5	1.37
Stem dry wt. (g per plant)	22	27.4	31.2	3.27
Root dry wt. (g per plant)	5.2	6.8	7.8	1.27
Head dry wt. (g per plant)	9.8	10.3	13.3	1.45
Seed wt. (g per plant)	23.3	28.2	34.0	2.30
Total dry wt. (g per plant)	69.9	82.6	97.8	6.97
Harvest Index (Percent)	36.2	37.1	37.8	NS
Hundred seed wt. (g)	4.3	5.0	4.8	NS
Oil content (Percent)	46.2	46.4	47.8	NS
Oil Yield (g per plant)	10.8	13.1	16.3	
Total N uptake (g per plant)	0.96	1.11	1.25	
Seed N yield (g per plant)	0.67	0.79	0.88	
Physiological N use efficiency (PE)(g biomass /g N uptake)	73.0	74.7	78.1	
Grain nitrogen use efficiency (NUEg)(g grain /g N uptake)	24.3	25.5	27.2	
Nitrogen harvest index (NHI)	70.3	70.4	70.2	

Desired CO_2 concentration of 550ppm and 700ppm were maintained and monitored continuously through the experimental period as illustrated by Vanaja *et al*., (2006). Elevated CO_2 levels of 550 and 700 ppm were maintained in two OTCs throughout this study. The third OTC without any additional CO_2 supply served as a control chamber (ambient level, 380ppm).

Final harvest, yield, C and N per cent

Six plants were maintained in each OTC (one plant per pot). The plants were harvested and representative plant samples of 6 replicates of each nitrogen and CO_2 treatment were randomly chosen to determine the biomass and yield characters. On the same day of sampling, roots were washed carefully to remove the soil adhere to them and plants were separated into roots, stem, leaves and capitulum. The flower heads were dried in sun light and seeds were separated. The harvested plant parts *viz*; leaves, stems, roots and head (de-seeded) were dried at 60^0C till constant weights were attained to determine the dry weights.

The total dry weight and hundred seed weight, harvest index (%) were derived from the recorded observations.Oven dried plant samples and seeds were ground to fine powder and used to analyze carbon (C) and nitrogen (N) content (%). N concentration was determined by Kjeldhal digestion method (Nelson and Somers, 1972) and carbon was analyzed by following the Walkey and Black rapid titration method as described by Jackson (1973).The seed oil content was extracted by sox-let apparatus using petroleum ether as solvent. The meal after oil extraction was used for carbon and nitrogen analysis.

Nitrogen mass and carbon mass in root, stem, leaf, head and seed tissues was obtained by multiplying tissue sample N or C concentration by biomass values for the respective plant components. Total plant nitrogen mass (total N uptake) and carbon mass was determined by summing nitrogen or carbon mass per plant component (leaf, stem, head, seed and root).Carbon and nitrogen ratios were calculated by dividing the total C by total N. The nitrogen harvest index (NHI), measure show efficiently the plant utilizes acquired nitrogen for the production of grain protein. The N harvest index (NHI: grain N uptake (g per plant)/total N uptake(g per plant)),

Physiological N use efficiency (PE: dry matter(g per plant)/ Total N uptake (g per plant), and

Grain N use efficiency (NUEg: grain yield (g per plant)/Total N uptake (g per plant)

were calculated as per Jackson (1973) and Moll *et al*. (1982).

The data were statistically analyzed using a one-way analysis of variance (ANOVA) to test the significance of CO_2

Table 2: Analysis of variance of carbon (%) and nitrogen (Per cent) observed under different CO_2 levels in sunflower

	CO_2 (ppm)			CD(5%)
	380	550	700	
Carbon (%)				
Leaf	25.2	25.1	25.5	NS
Stem	34.7	34.0	34.1	NS
Root	27.6	27.4	28.8	NS
Head	23.8	25.8	29.5	1.09
Seed	35.8	38.1	38.4	1.55
Nitrogen (%)				
Leaf	0.95	0.90	0.86	NS
Stem	0.27	0.27	0.26	NS
Root	1.02	1.01	0.89	0.34
Head	0.85	0.93	0.94	NS
Seed	5.37	5.15	4.95	NS

conditions.

RESULTS AND DISCUSSION

The plant traits of leaf, stem, head, seed, root and total dry weight performed better at 700ppm and had a significantly higher mean value compared to 550ppm which in turn had a significantly higher mean value compared to 380ppm level of CO_2 (Table 1).

Biomass, grain yield and HI

Elevated CO_2 generally resulted in increased biomass production in sunflower plants. Biomass accumulation in root, stem, head and seed was significantly greater at elevated CO_2 (550 and 700 ppm) compared with ambient (380 ppm). The total biomass (g per plant) improved from 69.6 g per plant at ambient to 82.6 and 97.8 g per plant under 550 and 700ppm respectively there by showing an improvement of 18.7 per cent (at 550ppm) and 40.5 per cent (at 700ppm) over ambient (Table1). This increase in biomass under elevated CO_2 was due to increase in leaf, stem, root, head andseed biomass (Fig.1).

The grain yield improved from 23.3 g per plant at ambient to 28.2 and 34.0 g per plant under 550 and 700ppm CO_2 there by showing an increment of 21.0 and 45.9 per cent. In mungbean a significant increase in pod number, pod weight and total seed weight were reported at elevated CO_2 conditions (Vanaja *et al*.,2007). In pigeon pea the significant

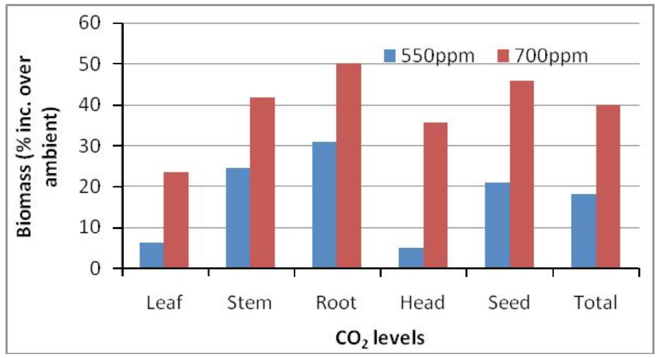

Fig. 1: Per cent increase in leaf, stem, root, head, seed and total biomass of sunflower grown at elevated CO_2 conditions over ambient.

increase in grain yield (150.1 per cent) at 700ppm CO_2 was reported which was due to increase in pod number, number of seeds and hundred seed weight (Vanaja *et al*., 2010). Elevated CO_2 also increased the hundred seed weight and HI in sunflower but not significantly.

Oil content and oil yield per plant

Elevated CO_2(700ppm) increased the oil content but not significantly. There was 3.5 per cent increase in oil content at 700ppm compared to ambient. Although high CO_2 levels tended to increase oil content non significantly, elevated CO_2 enhanced oil yield per plant significantly via an increase in seed yield (Table 1).

Nitrogen (%) and Carbon (%)

Nitrogen (%) in root, stem, leaf, head of elevated CO_2 (550 and 700ppm) grown plants was not significantly different from the ambient. The root,stem,leaf and seed nitrogen per cent decreased while that of head increased with the increase in atmospheric CO_2 from ambient to 550 and 700 ppm (Table 2). N per cent in seed meal was 5.37, 5.15 and 4.95 under ambient, 550 ppm and 700 ppm respectively (Table 2).Jablonski *et al*., (2002) demonstrated a significant decrease in seed N in wheat and barley but not in soybean. They argued that seed N decreased at elevated CO_2 in non legumes but not in legume species because of nitrogen fixation. Miyagi *et al.* (2007) reported 2.98 per cent seed N and 3.10 per cent seed yield at elevated CO_2 (700 ppm) and 3.11 per cent N and 2.25 g per plant seed yield under 370 ppm CO_2 in wild sunflower. In the present study there was decrease in seed N and increase in seed yield under elevated CO_2 conditions as reported by Miyagi *et al.* (2007). Under elevated CO_2 conditions sunflower increased the seed production, N uptake and biomass allocation to root and decreased the seed N. The enhancement of seed production

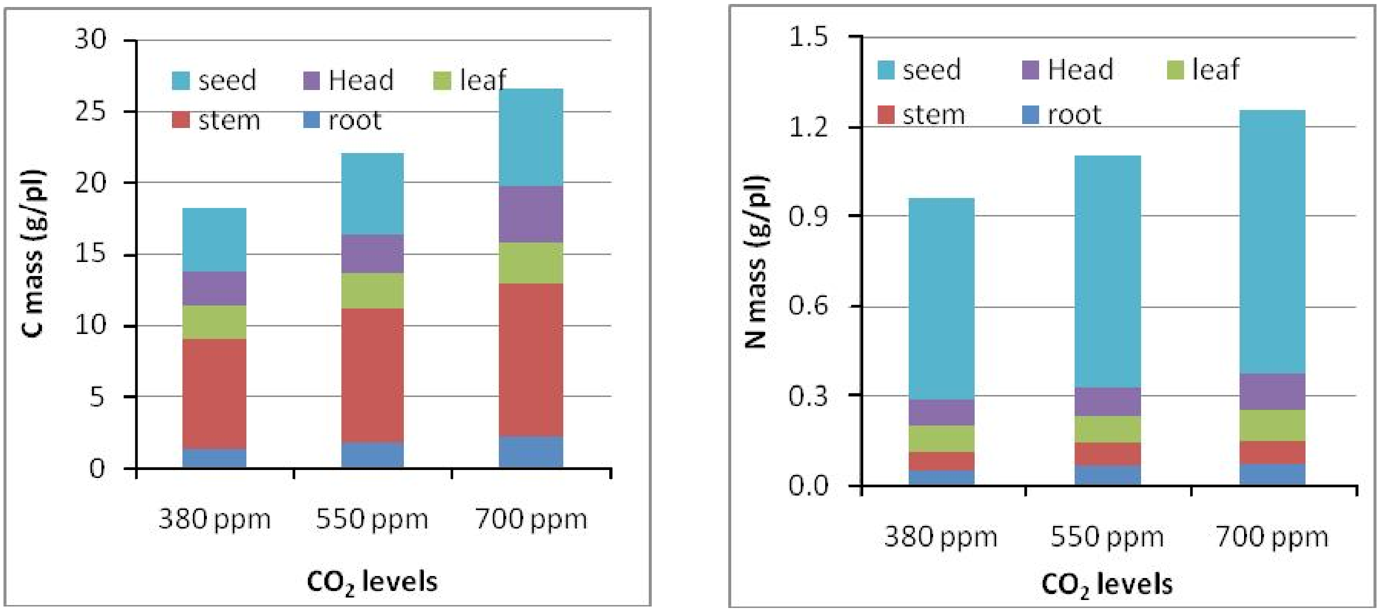

Fig.2: Carbon and nitrogen mass in sunflower root, stem, leaf, head and seed of plants grown in ambient and elevated CO_2 (550 and 700 ppm) conditions.

was strongly correlated with the enhancement of seed nitrogen per plant under elevated CO_2 which was caused by increased N acquisition during the reproductive period.

Although high CO_2 levels tended to lower N concentration in some plant parts, elevated CO_2 enhanced total N accumulation in each plant component via an increase in biomass (Fig.2). The N mass was significantly higher than ambient at 550 ppm and 700 ppm. The total N accumulation was highest in plants grown at 700 ppm (1.26 g per plant) followed by 550 ppm (1.11 g per plant) and ambient (0.97 g per plant). The seed nitrogen was also the highest at 700 ppm (0.88g per plant) followed by 550 ppm (0.79 g per plant) and ambient (0.67 g per plant).Hikosaka *et al.*, (2011) concluded that seed production is limited primarily by nitrogen availability and will be enhanced by elevated CO_2 only when the plant is able to increase nitrogen acquisition or decrease seed N. The different nitrogen uptake rate may be ascribed to differences in root size or kinetics of nitrogen uptake. In the present study, the root mass was 5.2 g per plant at ambient and increased to 6.8 g per plant at 550 ppm and 7.8 g per plant at 700 ppm. This enhanced root size (biomass) may have increased the plant N uptake under elevated CO_2 conditions (Table 1).

Physiological N use efficiency (PE) and grain N use efficiency (NUEg) was higher under elevated CO_2 compared to ambient.PE was 73.0, 74.7 and 78.1 and NUE_g was 24.3, 25.5 and 27.2in plants grown in OTCs at ambient, 550ppm and 700ppm CO_2respectively. The nitrogen harvest index (NHI), considered to be a measure of how efficiently the plant utilizes acquired nitrogen for the production of grain protein (seed nitrogen to total shoot nitrogen) was similar for ambient and elevated CO_2conditions. NHI was 70.3, 70.4 and 70.2 per cent at ambient, 550 ppm and 700 ppm respectively (Table 1).

The changes in carbon content in leaf, stem and root were not significant with elevated CO_2 while significantly higher values were recorded for head and seed (Table 2). The carbon mass (g per plant) was significantly higher than ambient at 550 ppm and 700 ppm. The total carbon accumulation was highest in plants grown at 700 ppm (32.7g per plant) followed by 550 ppm (27.0 g per plant) and ambient (22.1 g per plant). The seed carbon was also the highest at 700 ppm (12.9 g per plant) followed by 550 ppm (10.7g per plant) and ambient (8.3g per plant).The effect of elevated CO_2 (550 and 700ppm) on carbon mass in root, stem, leaf, head, seed and total plant was significantly higher over ambient which lead to an alteration in C/N ratio. The C/N ratio of plants was higher at elevated CO_2 conditions being 21.2, 20.0 and 19.0 at 700, 550ppm and ambient control respectively.This is also consistent with published report for plants grown under elevated CO_2 (Torbert *et al.*, 2004).

CONCLUSIONS

Hence, it may be concluded that sunflower responds positively to increasing CO_2, in terms of biomass,seed and oil yield. Though elevated CO_2 decreased the leaf, stem and seed N per cent, elevated CO_2 increased the total nitrogen uptake per plant through increase in biomass and seed yield. At the recommended dose of nutrients, the nitrogen uptake, physiological N use efficiency and grain N use efficiency was high under elevated CO_2 conditions. Since the uptake is more for plants grown at elevated CO_2 conditions at the recommended dose of nutrients, there will be decrease in available N in soil. Nitrogen harvest index was same for ambient and elevated CO_2 conditions indicating redistribution of acquired N from leaves and stems to the grains was similar.

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