

# Evaluation of certain rainfed food and oil seed crops for their response to elevated CO<sub>2</sub> at vegetative stage

M. Vanaja, P. Vagheera, P. Ratnakumar, N. Jyothi Lakshmi, P. Raghuram Reddy, S.K. Yadav, M. Maheswari, B. Venkateswarlu

Central Research Institute for Dryland Agriculture, Santhoshnagar, Hyderdabad, India

## ABSTRACT

A study was conducted with two important rainfed food crops viz., sorghum (*Sorghum bicolor* L. Moench.) and blackgram (*Vigna mungo* L. Happer) and two oil seed crops viz., sunflower (*Helianthus annuus* L.) and groundnut (*Arachis hypogaea* L.) under two conditions viz., elevated CO<sub>2</sub> (600 ppm) and ambient CO<sub>2</sub> (365 ppm) in open top chambers (OTCs). The observations were recorded at the vegetative stage at 7, 14, 21 and 30 days after sowing (DAS). The results showed significant differences between crops, conditions and time intervals, as well as the single and double order interactions for all the characters studied viz., total dry weight, stem dry weight, root dry weight, leaf dry weight, shoot length, root length and leaf area. Total dry weight and its components viz., stem dry weight, root dry weight and leaf dry weight along with leaf area showed a significant increase under enhanced CO<sub>2</sub> conditions. Among the four crops studied the overall results showed the highest response to elevated CO<sub>2</sub> by blackgram while the lowest response by sorghum.

**Keywords:** elevated carbon dioxide; food crops; oilseeds; total biomass; root/shoot ratio

Under the present global scenario of CO<sub>2</sub> increase (IPCC 1996), it has become pertinent for researchers all over the world to find solutions for future. Firstly, research can help to identify the crops which respond to the above situation and those which do not. Secondly, among the crops which respond, those with relatively a higher magnitude are to be identified initially to address the food and feed self-sufficiency followed by the soil improvement.

Various reviews on the response of different crops revealed that an increase in CO<sub>2</sub> has a positive effect on the plant biomass. Kimball (1986) obtained an average increase of 21% in biomass in response to elevated CO<sub>2</sub> when he analyzed 94 observations of different plants. Cure (1985) and Cure and Acock (1986) reported that sorghum showed a stimulation of 5% increase in biomass with elevated CO<sub>2</sub> levels (scaled to 550 µmol/mol). Venkteshwara Rao (1999) observed that in groundnut cv. TMV-2 biomass production was 29% higher in elevated CO<sub>2</sub> (660 ppm) than in ambient CO<sub>2</sub>. In sunflower the growth was affected at elevated CO<sub>2</sub> by increasing net CO<sub>2</sub> assimilation rate (Tezara et al. 2002). It was observed that with elevated levels of CO<sub>2</sub> (using the FACE technology) there was a greater

stimulation of belowground than aboveground biomass (Kimball et al. 2002). Under ample water and nutrients the root growth of C<sub>3</sub> grasses was stimulated by about 47% as compared with the 12% of shoots whereas in clover (C<sub>3</sub> legume) the root growth stimulation (25%) was nearly same as that of shoots (24%).

In this paper an attempt was made to present the response of certain rainfed crops up to vegetative stage to enhanced levels of CO<sub>2</sub> and were compared with chamber control at ambient level CO<sub>2</sub>, which actually takes care of the deviation in temperature and relative humidity due to the OTC. The crops were raised directly in the field to avoid the root restriction in pots. In enhanced CO<sub>2</sub> condition, the CO<sub>2</sub> levels were elevated to set ppm continuously 24 h from the day of sowing to final sampling. The response reported that the actual effect of CO<sub>2</sub> with all other conditions maintained similar for both the treatments.

## MATERIAL AND METHODS

The seeds of sorghum (*Sorghum bicolor* L. Moench.) cv. CSV-15, blackgram (*Vigna mungo* L.

Happer) cv. T-9, sunflower (*Helianthus annuus* L.) cv. MSFH-8, and groundnut (*Arachis hypogaea* L.) cv. JL-24 were grown in OTCs of 3 m × 3 m diameter, lined with a transparent PVC sheet. The seeds were sown directly in the soil (Alfisol) to study the effect of elevated CO<sub>2</sub> level (600 ± 50 ppm) on initial plant growth up to 30 DAS. Plants were maintained stress-free by irrigation and application of recommended doses of fertilizers. There were two chambers for each treatment. Each chamber had four 1 m × 1 m plots with five rows of each crop and a minimum of ten plants in each row was maintained.

The experimental site was sandy loam in texture, neutral in pH (6.8), low in available nitrogen (225 kg/ha), phosphorus (10 kg/ha) and medium to high in available potassium (300 kg K<sub>2</sub>O/ha). Two OTCs were maintained at 600 ± 50 ppm to have the elevated levels of CO<sub>2</sub> at crop canopy level by continuously injecting 100% CO<sub>2</sub> into plenum where it was mixed with ambient air from air compressor before entering into the chamber. Other two OTCs were maintained at ambient CO<sub>2</sub> level (365 ppm) without any external CO<sub>2</sub> supply and served as control chambers. The air sample from each chamber was drawn at 3 minutes interval into non-dispersive infrared (NDIR) CO<sub>2</sub> analyzer (California Analytical) and the set ppm of CO<sub>2</sub> concentration (600 ± 50 ppm) was maintained with the help of solenoid valves, roto meters, PCs, Program Logic Control (PLC) and Supervisory Control and Data Acquisition (SCADA) software. Throughout the experimental period, continuous measurements of relative humidity and temperature of all the OTCs were possible with the sensors fitted inside the chambers. The temperature of chambers with elevated levels of CO<sub>2</sub> remained nearly same as in the control chambers that were maintained at ambient CO<sub>2</sub> level (Figure 1). The light intensity in chambers was 80–95% of the outside field. However, gentle washing of polythene cover was frequently required to maintain transparency.

The observations were recorded at weekly intervals up to a one month period on total dry weight, stem dry weight, root dry weight, leaf dry weight, shoot length, root length and leaf area in all the treatments and root:shoot ratio and specific leaf weight (leaf weight/leaf area) were derived from the above observations. Three replications with ten plants for a replication of each crop were harvested at weekly interval, i.e. thirty plants of each crop for elevated CO<sub>2</sub> and a chamber control treatment. The measurements were recorded on lengths of shoot and root for individual plants, i.e.

10 × 3 observations for each parameter, whereas leaf area, stem dry weight, root dry weight and leaf dry weight were recorded for 10 plants/replication, i.e. 2 × 3 observations for each parameter. The root length was recorded on main root of each plant. At different time intervals the leaf area was measured with leaf area meter (LI-3100) and expressed as cm<sup>2</sup>/10 plants. The dry weights of shoot, root and leaf were recorded after a thorough drying of the plant material in hot air oven at 65°C and expressed as g/10 plants. All the data was statistically analyzed using a two-way analysis of variance (ANOVA) to test the significance of treatment and their interactions.

## RESULTS AND DISCUSSION

The mean *per se* values of characters studied at 30 DAS under elevated CO<sub>2</sub> (600 ± 50 ppm) and chamber control (365 ppm) for four crops are presented in Table 1. The response of elevated CO<sub>2</sub> as compared to chamber control are given in Table 2, while the ANOVA in Table 3.

The response was positive for total dry weight under elevated CO<sub>2</sub> (600 ppm) for all four crops tested. Blackgram showed a more significant response under elevated CO<sub>2</sub> when compared with other three crops. The increment in total dry weight under elevated CO<sub>2</sub> at 30 DAS was 80% in blackgram compared to chamber control. In sunflower it was 32%, in groundnut 14%, and in sorghum 9% compared to chamber control (Table 2). Krizek et al. (1984) reported the increase in biomass production in pulses as a result of elevated CO<sub>2</sub> but the relative increase in dry mass varies with plant species (Strain and Cure 1986). Trischle et al. (2000) reported an increase in total biomass in five crops in three days of emergence. Devakumar et al. (1996), Ratnakumar and Swamy (2003) found increased initial growth rates by exposing seedlings to elevated CO<sub>2</sub>.

The total dry weight was highly significant for conditions, conditions × crops, conditions × time intervals and second order interaction of conditions × crops × time intervals (Table 3). The first order interaction of conditions and time intervals was significant in blackgram and sunflower and non-significant in sorghum and groundnut; this shows that in sorghum and groundnut the response is not same at different time intervals.

The response of stem dry weight was the same as total dry weight and the response of different crops was positive. When compared to other three crops *viz.*, sorghum, sunflower and groundnut, the incre-

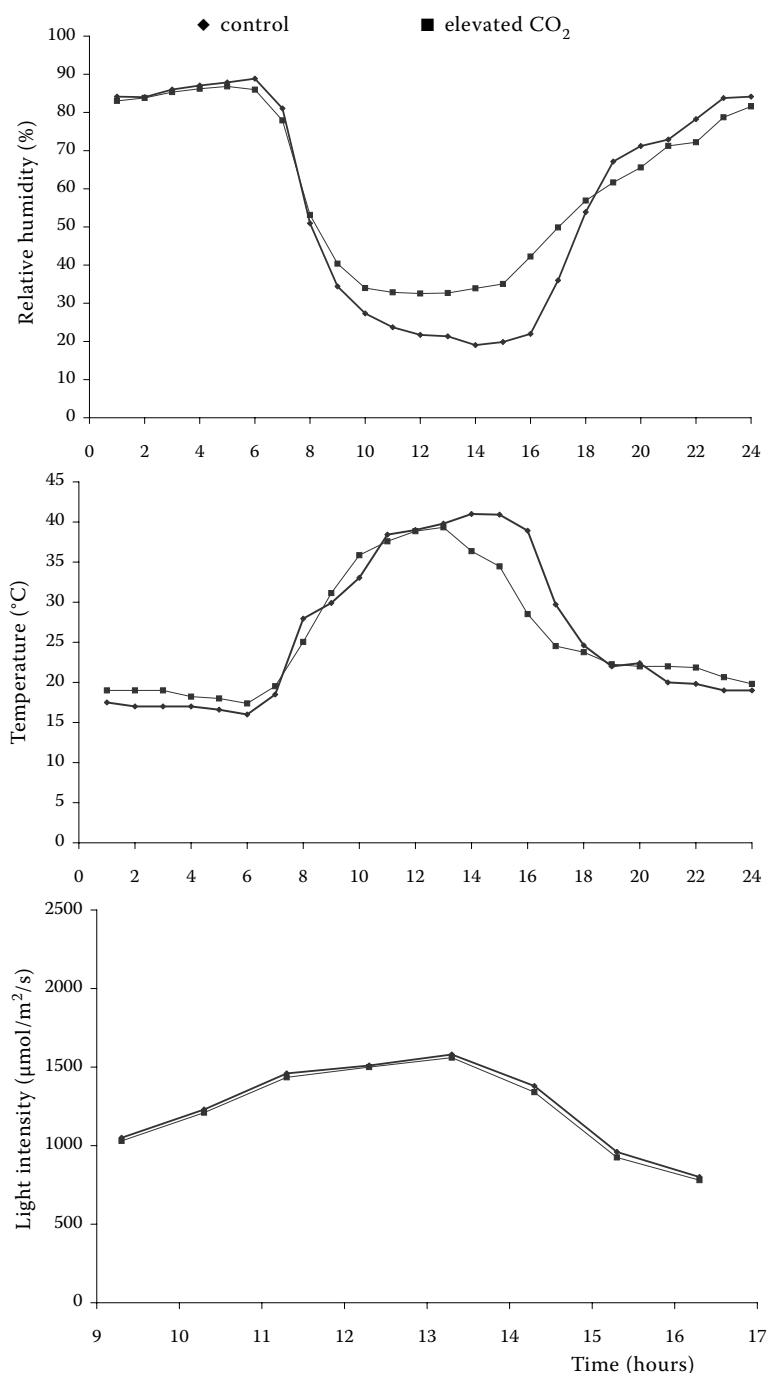


Figure 1. Temperature and relative humidity of OTCs with and without CO<sub>2</sub> and light intensity of OTCs and open field

ment in stem dry weight of blackgram under elevated CO<sub>2</sub> was significantly higher (101%) as compared to chamber control (Table 2). The increment in stem dry weight was 49% in sunflower, 13% in groundnut and sorghum under elevated CO<sub>2</sub>, as compared to chamber control. The analysis for individual crops response showed that conditions and conditions  $\times$  time intervals are highly significant for sorghum, blackgram and sunflower stem dry weight, whereas it was non-significant for groundnut.

In all the crops studied elevated CO<sub>2</sub> showed a positive response for root dry weight and the response ranged from 78 to 6% compared to chamber control (Table 2). Blackgram, a pulse crop showed the highest response (78%) under elevated CO<sub>2</sub> condition, followed by sunflower (49%), groundnut (7%) and sorghum (6%) compared to chamber control. From the FACE experiments, Ottman et al. (2001) observed a small mean response of 3% in sorghum for shoots to elevated CO<sub>2</sub> under well

Table 1. Mean *per se* values of various characters under elevated CO<sub>2</sub> (600 ± 50 ppm) and chamber control (365 ppm) for four crops at 30 DAS

Characteristics	Sorghum		Blackgram		Sunflower		Groundnut	
	elevated CO <sub>2</sub>	chamber control	elevated CO <sub>2</sub>	chamber control	elevated CO <sub>2</sub>	chamber control	elevated CO <sub>2</sub>	chamber control
Root length (cm)	18.00	17.20	10.53	11.93	10.38	9.35	8.90	10.10
Shoot length (cm)	27.65	28.60	14.58	13.58	38.80	38.08	14.45	16.25
Root dry weight (g/10 pl)	5.85	5.52	1.28	0.72	4.13	2.69	1.74	1.63
Shoot dry weight (g/10 pl)	12.80	11.28	5.09	2.53	12.30	8.23	11.18	9.94
Leaf dry weight (g/10 pl)	27.00	25.05	10.62	6.20	26.49	21.68	12.72	10.90
Total dry wt (g/10 pl)	45.65	41.85	16.99	9.45	42.92	32.61	25.65	22.47
Leaf area (cm <sup>2</sup> /10 pl)	7525	7035	2719	1783	7197	6547	2945	2744
Root:shoot ratio	0.46	0.49	0.25	0.29	0.34	0.33	0.16	0.16
Specific leaf weight (g/cm <sup>2</sup> )	0.0036	0.0036	0.0039	0.0035	0.0033	0.0032	0.0043	0.0040

watered conditions, which is consistent with the smaller photosynthetic response of this crop.

The response of root dry weight was also highly significant for conditions and its interaction with crops, time intervals and second order interaction of conditions × crops × time intervals (Table 3). The root dry weight response to elevated CO<sub>2</sub> was positive but not uniform with all the crops tested. In blackgram and sunflower the response was highly significant for both conditions and its interaction with time intervals, except for groundnut where it was non-significant.

With an increase in CO<sub>2</sub> concentration, leaf dry weight increased in all the crops. As it was observed with all the above parameters, blackgram showed the highest response and it was 71% compared to chamber control (Table 2). The next responsive crop was sunflower (22%), followed by groundnut (17%) and sorghum (8%). The leaf dry weight was

highly significant for conditions and its interaction with crops, whereas the second order interaction of crops × conditions × time intervals was non-significant (Table 3). In blackgram and sunflower the leaf dry weight was significant with conditions and its interaction with time intervals, whereas sorghum showed no response.

The response of root and shoot dry weight in all the crops was positive with elevated CO<sub>2</sub> when compared to chamber control. The relative response of roots to shoots differed with different crops. The increment in shoot biomass of sorghum, blackgram and groundnut was higher, as compared to the increment in root biomass; hence the root:shoot ratio values are negative at 30 DAS (Table 2). Sunflower showed a reverse response where the root:shoot ratio was positive but non-significant. Stulen and den Hertog (1993) concluded in their review on dry matter partitioning in response to

Table 2. Increase (%) in different parameters of four crops (sorghum, blackgram, sunflower, groundnut) at 30 DAS under elevated CO<sub>2</sub> (600 ppm) compared to chamber control (365 ppm)

Crops	Weight				Root:shoot ratio	Shoot length	Root length	Leaf area	Specific leaf weight
	total dry	stem dry	root dry	leaf dry					
Sorghum	9.08 <sup>4</sup>	13.47 <sup>3</sup>	6.07 <sup>4</sup>	7.77 <sup>4</sup>	-6.49 <sup>3</sup>	-3.32 <sup>3</sup>	4.65 <sup>2</sup>	6.97 <sup>4</sup>	0.035 <sup>4</sup>
Blackgram	79.70 <sup>1</sup>	100.95 <sup>1</sup>	78.41 <sup>1</sup>	71.18 <sup>1</sup>	-11.95 <sup>4</sup>	7.37 <sup>1</sup>	-11.74 <sup>3</sup>	52.54 <sup>1</sup>	13.45 <sup>1</sup>
Sunflower	31.62 <sup>2</sup>	49.34 <sup>2</sup>	53.28 <sup>2</sup>	22.20 <sup>2</sup>	2.58 <sup>1</sup>	1.90 <sup>2</sup>	10.96 <sup>1</sup>	9.94 <sup>2</sup>	3.62 <sup>3</sup>
Groundnut	14.13 <sup>3</sup>	12.54 <sup>4</sup>	7.03 <sup>3</sup>	16.65 <sup>3</sup>	-3.55 <sup>2</sup>	-11.08 <sup>4</sup>	-11.88 <sup>4</sup>	7.33 <sup>3</sup>	8.86 <sup>2</sup>

Superscript numbers denotes the ranking of the crops for that particular character

Table 3. ANOVA for various characters at 30 DAS for different crops (sorghum, blackgram, sunflower, groundnut) under elevated CO<sub>2</sub> (600 ppm) and chamber control (365 ppm)

Source	DF	Mean sum of squares							
		total dry weight	stem dry weight	root dry weight	leaf dry weight	root: shoot ratio	shoot length	root length	leaf area
Replications	2	6.17	0.76	0.002	3.65*	0.002	1.29	0.031	180096
Crops	3	507.32**	71.80**	14.12 **	262.46**	0.196**	352.14**	100.78**	26141600**
Conditions	1	112.71**	15.21**	1.47**	49.19**	0.001	0.70	0.06	2272032**
Time intervals	3	4002.47**	408.90**	38.81**	1476.13**	0.115**	1636.26**	230.80**	110194600**
Crops × conditions	3	9.64**	1.25**	0.19**	4.48*	0.003	1.41	1.54**	55947
Crops × time intervals	6	286.11**	18.85**	7.50**	142.80**	0.019**	197.59**	15.18**	11781010**
Conditions × time intervals	2	47.76**	9.30**	0.52**	13.51**	0.001	0.47	0.732**	353424*
Crops × conditions × time intervals	6	4.52**	0.685**	0.21**	2.03	0.006	4.02	1.40**	117104
Error	46	1.345	0.211	0.02	1.06	1.672	0.22	95818	0.005

\*\*significance at 1% level, \* at 5% level

elevated CO<sub>2</sub> that there is a wide variability in root:shoot ratio and the observations varied as negative, no change and positive.

The response of shoot length under elevated CO<sub>2</sub> (600 ppm) conditions was positive in blackgram and sunflower, whereas it was negative in sorghum and groundnut when compared to chamber control (Table 2). The response for shoot length was positive and significant in blackgram for conditions and its interaction with time intervals. Bhattacharya et al. (1985) reported a significant increase in plant height, leaf expansion in sweet potato and cowpea under elevated CO<sub>2</sub>. The response of shoot length was non-significant for conditions and its interaction with crops, time intervals and second order interaction of conditions × crops × time intervals (Table 3,) hence the shoot length is the least responsive.

The four crops tested showed different responses for root length under elevated CO<sub>2</sub>. The length of the roots showed a positive increase in sunflower (10.96%) and sorghum (4.65%) after 30 days of growth under elevated CO<sub>2</sub> (600 ppm), when compared to chamber control (Table 2), whereas it was negative in blackgram (−11.74%) and groundnut (−11.88%). Baker et al. (1990) recorded around 65%

more actively growing roots in rice at 800 ppm, whereas the elongation rate of individual root axes was not affected. However the spread of the roots with more root hairs resulted in increased root biomass in all the crops tested.

The leaf area of all the crops showed a positive response under elevated CO<sub>2</sub> condition compared to chamber control. Blackgram showed the highest and significant response (52.54%) among the four crops evaluated. Sunflower, groundnut and sorghum are next in this order with 9.94, 7.33 and 6.97% increase in leaf area (Table 2). The response of leaf area for conditions and its interaction with time intervals was significant, whereas conditions × crops and second order interaction of conditions × crops × time intervals was non-significant (Table 3). Conditions are significant for blackgram, sunflower and groundnut, whereas interactions between conditions and time intervals were significant only for blackgram. The response of leaf area in sorghum was positive but non-significant. Several studies showed that the extra C in plant leaves induced by elevated CO<sub>2</sub> resulted in an increase in leaf size, number of branches or tillers and number of nodes along the branches which support leaves, and hence greater leaf area (Allen 1990).

The specific leaf weight (leaf weight/leaf area) increased in all the crops under elevated CO<sub>2</sub> condition when compared to chamber control. Compared to chamber control the increase in specific leaf weight was higher in blackgram (13.45%) under elevated CO<sub>2</sub> followed by groundnut (8.86%) and sunflower (3.62%), whereas sorghum showed least response (0.035%) for specific leaf weight (Table 2). This shows that the response of leaf weight was relatively higher than the expansion of the leaves and thereby leaves are thicker under elevated CO<sub>2</sub>. Huber et al. (1984) concluded that the increase in specific leaf mass (leaf weight/leaf area) was presumably due mostly to the increase in starch content but the leaves of soybean are also thicker under enhanced CO<sub>2</sub> condition, due to the increase in palisade cells, which was not observed in maize (Thomas and Harvey 1983, Lawlor and Mitchell 1991).

Among four dry weight characteristics, sorghum showed the least response under elevated CO<sub>2</sub>, as compared to chamber control, except for shoot dry weight whereas groundnut was on par with sorghum. This might be due to sorghum being a C<sub>4</sub> crop. Kimball et al. (2002) reviewed that C<sub>4</sub> crops in general respond less, compared to C<sub>3</sub> crops under elevated CO<sub>2</sub>.

To conclude, overall results of all the characters studied, the highest response was shown by blackgram (a pulse crop), while the lowest response was given by sorghum (a C<sub>4</sub> crop). Sunflower and groundnut were found to place between these two. Among the four crops studied only sorghum is C<sub>4</sub> and its response to elevated CO<sub>2</sub> was lower than C<sub>3</sub> crops, specifically for total biomass and its components *viz.*, root dry weight and leaf dry weight along with leaf area and specific leaf weight. As for the increment in stem dry weight, sorghum was on par with groundnut.

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## REFERENCES

- Allen L.H. (1990): Plant responses to rising carbon dioxide and potential interactions with air pollution. *J. Environ. Qual.*, 19: 15–34.
- Baker J.T., Allen L.H., Boote K.J. (1990): Growth and yield responses of rice to carbon dioxide concentration. *J. Agr. Sci.*, 115: 313–320.
- Bhattacharya N.C., Biswas P.K., Bhattacharya S., Sionit N., Strain B.R. (1985): Growth and yield response of sweet potato to atmospheric CO<sub>2</sub> enrichment. *Crop Sci.*, 25: 975–981.
- Cure J.D. (1985): Carbon Dioxide Doubling Responses: a Crop Survey. In: Strain B.R., Cure J.D. (eds.): *Direct Effects of Increasing Carbon Dioxide on Vegetation*, DOE/ER-0238. United States Department of Energy, Washington, DC: 99–116.
- Cure J.D., Acocck B. (1986): Crop responses to carbon dioxide doubling: a literature survey. *Agric. Meteorol.*, 38: 127–145.
- Devakumar A.S., Udayakumar M., Prasad T.G. (1996): A simple technique to expose seedlings to elevated CO<sub>2</sub> for increased initial growth rates. *Curr. Sci.*, 71: 469–472.
- Huber S.C., Rogers H.H., Mowry F.L. (1984): Effect of water stress on photosynthesis and carbon partitioning in soybean (*Glycine max* L. Merr.) plants grown in the field at different CO<sub>2</sub> levels. *Plant Physiol.*, 76: 244–249.
- IPCC (1996): *Climate change 1995: Summary for policy makers and technical summary of the working group I*. In: Houghton J.T., Meria Filho L.G., Callander B.A., Harris N., Kattenburg A., Maskell K. (eds): *Intergovernmental Panel on Climate Change*. Cambridge Univ. Press, Cambridge, UK.
- Kimball B.A. (1986): Ecology of crops in changing CO<sub>2</sub> concentration. *J. Agric. Meteorol.*, 48: 559–566.
- Kimball B.A., Kobayashi K., Bindi M. (2002): Responses of agricultural crops to free-air CO<sub>2</sub> enrichment. *Adv. Agron.*, 77: 293–368.
- Krizek D.T., Sward R.J., Downton W.J.S. (1984): *Cotton Physiology – A Treatise – SOA Monograph*. DOE, Washington.
- Lawlor D.W., Mitchell R.A.C. (1991): The effect of increasing CO<sub>2</sub> on crop photosynthesis and productivity: a review of field studies. *Plant Cell Environ.*, 14: 807–818.
- Ottman M.J., Kimball B.A., Pinter P.J. Jr., Wall G.W., Vanderlip R.L., Leavitt S.W., LaMorte R.L., Matthias A.D., Brooks T.J. (2001): Elevated CO<sub>2</sub> effects on sorghum growth and yield at high and low soil water content. *New Phytol.*, 150: 261–273.
- Ratnakumar P., Swamy P.M. (2003): Effect of elevated CO<sub>2</sub> on seedling growth and photosynthesis in tropical species, *Syzygium cumini* (L.) Skeel. In: *Proc. Nat. Semin. Physiological Interventions for Improved Crop Productivity and Quality: Opportunities and Constraints*, New Delhi: 92–98.
- Stulen I., den Hertog J. (1993): Root growth and functioning under atmospheric CO<sub>2</sub> enrichment. In: Rozema J.,

- Lambers H., Van de Geijn S.C., Cambrige M.L. (eds): CO<sub>2</sub> and Biosphere. Kluwer Acad. Publ., Dordrecht, Netherlands: 99–115.
- Strain B.R., Cure J.D. (1986): Direct effects of atmospheric CO<sub>2</sub> enrichment on plants and ecosystems: A bibliography with abstracts. Rep. ORNL/ CDIC, 13: 1–199.
- Tezara W., Mitchell V., Driscoll S.P., Lawlor D.W. (2002): Effect of water deficit and its interaction with CO<sub>2</sub> supply on the biochemistry and physiology of photosynthesis in sunflower. J. Exp. Bot., 53: 1781–1791.
- Thomas J.F., Harvey C.N. (1983): Leaf anatomy of four species grown under continuous CO<sub>2</sub> enrichment. Bot. Gaz., 144: 303–330.
- Trischle C.R., Polley H.W., Johnson H.B., Pennington R.E. (2000): Seedling response to elevated CO<sub>2</sub> in five epigeal species. Int. J. Plant Sci., 161: 779–783.
- Venkteshwara Rao K. (1999): The combined effect of elevated CO<sub>2</sub> levels and temperature on growth characteristics of groundnut (*Arachis hypogaea* L.). Indian J. Plant Physiol., 4: 297–301.

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*Corresponding author:*

Dr. M. Vanaja, Crop Science Division, Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, 500 059 India  
phone: 91 040 24530161, fax: 91 040 24531802, e-mail: mvanaja@crida.ernet.in

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