

# Response of $C_4$ (maize) and $C_3$ (sunflower) crop plants to drought stress and enhanced carbon dioxide concentration

M. Vanaja, S.K. Yadav, G. Archana, N. Jyothi Lakshmi, P.R. Ram Reddy,  
P. Vagheera, S.K. Abdul Razak, M. Maheswari, B. Venkateswarlu

*Central Research Institute for Dryland Agriculture, Santoshnagar, India*

## ABSTRACT

Sunflower (*Helianthus annuus* L.) and maize (*Zea mays* L.) were chosen as  $C_3$  and  $C_4$  crop plants and assessed for the impact of enhanced  $CO_2$  (700 ppm) and its interaction with drought stress in open top chambers (OTCs). The ameliorative effect of higher  $CO_2$  concentration ( $eCO_2$ ) under drought stress was quantified. It is interesting to note that the  $C_3$  crop responded significantly and positively with  $eCO_2$  under both well-watered and drought stress treatments for root: shoot ratio while  $C_4$  crop showed a better response only with the drought stress environment. Root volume showed a positive significant response with  $CO_2$  concentration enhanced over ambient level and the increment in root volume was 146% and 340% in sunflower and maize crops, respectively. The leaf water potential, stomatal conductance and transpiration showed a decreasing trend in both the crops with drought stress and  $eCO_2$  showed an ameliorative effect leading to higher  $P_n$  rates in sunflower crop under drought stress treatment. The findings reveal that improvement of root traits is worth attempting for the future crop behavioral responses under  $eCO_2$  and drought stress environments. The study confirmed the beneficial effect of  $eCO_2$  in maize and sunflower by ameliorating the adverse affects of drought stress.

**Keywords:** leaf area; root and shoot characteristics; leaf water potential; gas exchange

The rising atmospheric  $CO_2$  may cause global warming as well as alterations in precipitation patterns. Rising temperature and altered soil moisture due to climate change is believed to decrease the yield of food crops over next 50 years and elevated  $CO_2$  concentration is expected to enhance the crop yield and mitigate the detrimental effects of climate change. Controlled environment studies revealed that  $CO_2$  fertilization factors simulate the enhancements of net  $CO_2$  assimilation rate and yield in both  $C_3$  and  $C_4$  crops (Kimball et al. 2002, Reddy et al. 2010). Drought is the main environmental factor limiting plant growth and the productivity of many crops. In most of the tropical and equatorial regions of the world and across large areas outside the tropics, the yield of agricultural crops is limited more with the amount of water received in and stored within the soil than by air temperature.

It is now well known that  $C_3$  and  $C_4$  plants respond differently to atmospheric  $CO_2$  enrichment. Early controlled environment experiments with

plants grown in pots demonstrated that  $C_3$  species would produce more biomass than  $C_4$  species, when grown individually under enhanced  $CO_2$ . The differential response of  $C_3$  and  $C_4$  crops may lead to changes in areas sown under different crops. When atmospheric  $CO_2$  content is increased, one might expect  $C_3$  crops to generally perform better than  $C_4$  crops (Reddy et al. 2010). It may, for example, accelerate the recent trend in India toward wheat, rice and barley and away from maize and millets, a trend that has largely been driven by the promise of greater increases in yield.

Maize is an important staple  $C_4$  food crop in many countries of the world and it accounts for around 712 million metric tones in 2006. Sunflower (*Helianthus annuus* L.) is one of the important oilseed crop grown in the world and the edible oil contains more vitamin E than any other vegetable oil. Sunflower seed production was 33.3 million tons in 2008–2009, and accounts around 8.5% of the total oilseeds production of world.

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Independently, the impact of increased atmospheric CO<sub>2</sub> and drought stress on crop growth and productivity was well documented, however the interaction between these two are not well understood. The present study was aimed at assessing the influence of enhanced CO<sub>2</sub> under both well watered and drought stress conditions on plant water status, gas exchange and various root and shoot parameters of maize (C<sub>4</sub>) and sunflower (C<sub>3</sub>) crop plants.

## MATERIALS AND METHODS

Sunflower (*Helianthus annuus* L.) cv. KBSH-1 and maize (*Zea mays* L.) cv. Harsha were chosen as C<sub>3</sub> and C<sub>4</sub> crops to evaluate their response to enhanced CO<sub>2</sub> (eCO<sub>2</sub>) and its interaction with moisture stress. The plants were raised in open top chambers (OTCs) having 3 m × 3 m × 3 m dimensions lined with transparent PVC (polyvinyl chloride) sheet having 90% transmittance of light. The eCO<sub>2</sub> of 700 ppm was maintained in two OTCs throughout the study and other two OTCs without any additional CO<sub>2</sub> supply which served as ambient control with 380 ppm (aCO<sub>2</sub>). The desired CO<sub>2</sub> concentrations within the OTCs were maintained and monitored continuously throughout the experimental period as illustrated by Vanaja et al. (2006).

The plants were raised in 5 liter capacity pots filled with approximately 6.5 kg of red soil (Alfisol) having 16% moisture content at field capacity. The soil was sandy loam in texture, neutral in pH (6.8), low in available N (210 kg/ha), P (10 kg/ha) and medium to high in available K (170 kg/ha). The recommended dose of fertilizers was applied and the plants were maintained free from pests and diseases.

Each OTC contained 48 pots with each pot containing one plant. The pots were spaced 20 cm apart in all directions in order to minimize competition for light and rows were oriented in a north-south direction. After raising the plants for 21 days in OTCs, half of them were subjected to moisture stress by withholding the irrigation. The two water regimes 80% and 50% of soil water content at field capacity served as well watered (WW) and drought stressed (DS) conditions, respectively. The soil water content was determined by weighing the pots daily and calculated based on the pot weight, soil dry weight and the expected soil water content. Water was added at the time of weighing to maintain the predetermined water content in each pot. Additionally in the last stage

of the experiment, the wet weight per seedling was estimated and added to the pot weight. Each treatment i.e. elevated CO<sub>2</sub> + WW (EW); elevated CO<sub>2</sub> + DS (ED); ambient CO<sub>2</sub> + WW (AW); ambient CO<sub>2</sub> + DS (AD) have 12 pots in each OTC and total 24 pots per treatment. The effect of moisture stress on gas exchange and growth components was analyzed at the end of the stress period of five days in each treatment.

## Plant water and gas exchange measurements

Plant water status was assessed at the end of the stress period by measuring the leaf water potential ( $\Psi_w$ ) of the youngest fully expanded leaf using the Scholander pressure chamber (PMS Instruments, Model 600, Corvallis, USA). The net photosynthetic rate ( $P_n$ ), stomatal conductance ( $g_s$ ) and transpiration rate ( $T_r$ ) were measured using LI-COR-6400 photosynthesis system (LI-COR, Lincoln, USA) under field condition. A CO<sub>2</sub> cartridge was used in order to get stable CO<sub>2</sub> concentrations and to maintain CO<sub>2</sub> concentration of the growth conditions into the leaf chamber.

## Growth measurements

Plants were harvested at the end of the stress period and plant parts were separated into leaves, stem, and roots. The leaf area was measured with LI-3100 leaf area meter (LI-COR, Lincoln, USA) and expressed as cm<sup>2</sup>/plant. Root length was recorded on the main root of each plant and root volume was measured as mL of water displaced and expressed as mL/plant. After thorough drying of the plant material in hot air oven at 65°C till constant weights were obtained, the dry weights of stem, root and leaf were recorded and expressed as g/plant.

The data were analyzed statistically using a two-way analysis of variance (ANOVA) to test the significance of treatments namely crops, CO<sub>2</sub> levels, moisture levels and their interactions.

## RESULTS AND DISCUSSION

### Plant water status and gas exchange

Leaf water potential ( $\Psi_w$ ) decreased significantly ( $P \leq 0.01$ ) with moisture stress in both maize and sunflower crops with ED and AD treatments (Figure 1). The CO<sub>2</sub> levels and their interaction

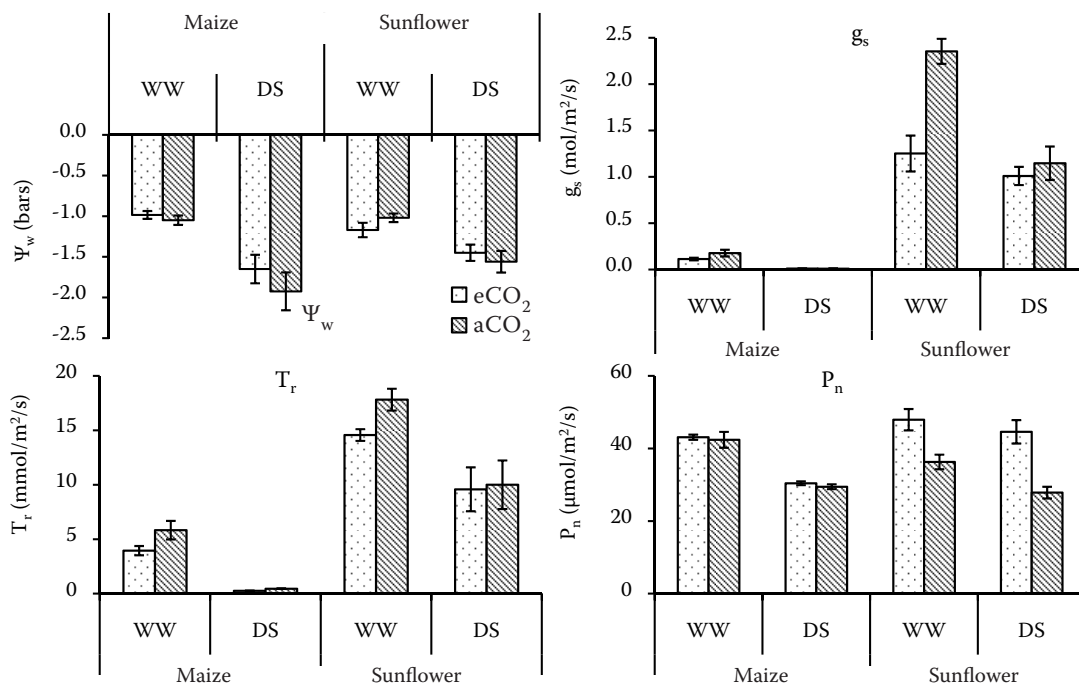


Figure 1. Leaf water potential ( $\Psi_w$ ), stomatal conductance ( $g_s$ ), transpiration rate ( $T_r$ ) and net photosynthetic rate ( $P_n$ ) of maize ( $C_4$ ) and sunflower ( $C_3$ ) under well watered (WW) and drought stress (DS) conditions at elevated CO<sub>2</sub> (eCO<sub>2</sub>) and ambient CO<sub>2</sub> (aCO<sub>2</sub>) concentrations

with moisture status were non-significant in both the crops for change in  $\Psi_w$  response. However, the  $\Psi_w$  decreased slowly under ED conditions which improved  $\Psi_w$  by 7% in sunflower and 14% in maize over ambient. Increased atmospheric CO<sub>2</sub> concentrations ameliorates, mitigates or compensates for the negative impacts of drought on plant growth (Wullschlegel et al. 2002) and enables the plants to remain turgid and functional for longer period (Centrito et al. 1999). Maintenance of better  $\Psi_w$  in plants grown at eCO<sub>2</sub> could be a consequence of stomatal control.

Stomatal conductance ( $g_s$ ) of both ambient and elevated CO<sub>2</sub> grown sunflower and maize plants were influenced by drought stress ( $P \leq 0.01$ ). Stomatal conductance of well watered sunflower (46.8%) and maize (35.6%) plants was significantly reduced by growth under elevated CO<sub>2</sub> conditions ( $P \leq 0.01$ ). There was also a significant difference ( $P \leq 0.01$ ) in  $g_s$  between CO<sub>2</sub> treatments when sunflower plants were subjected to drought. However, under similar situation the response of maize was very small (Figure 1). The reduction of stomatal conductance is the primary impact of increased atmospheric CO<sub>2</sub> concentration on plants (Wall 2001). Considerably lower stomatal conductance at elevated CO<sub>2</sub> was reported in some other crops such as sugarcane (Vu and Allen 2009), barley (Robredo et al. 2007), rice (Upreti et al. 2002) and wheat (Wall 2001).

Transpiration was significantly ( $P \leq 0.01$ ) influenced by water availability in both maize and sunflower. Elevated CO<sub>2</sub> reduced transpiration by 18% and 32% in sunflower and maize under well watered condition. The reduction in transpiration due to increased CO<sub>2</sub> under drought stress was at higher magnitude in maize (42%) than sunflower (4%). Reduction in stomatal conductance under eCO<sub>2</sub> decreased transpirational water losses through plant stomata. It appears eCO<sub>2</sub> exposure tends to enhance soil moisture conservation, which can improve overall plant water relations and facilitate higher biomass production.

Elevated CO<sub>2</sub> significantly ( $P \leq 0.01$ ) improved the  $P_n$  in both well watered and moisture stressed sunflower plants. Under drought stress the sunflower  $P_n$  values were significantly ( $P \leq 0.01$ ) higher (60%) in elevated compared with ambient CO<sub>2</sub> (32%). In contrast, the impact of elevated CO<sub>2</sub> on  $P_n$  in maize was not significant in both well watered and moisture stress conditions, though significant ( $P \leq 0.01$ ) reduction in  $P_n$  with drought stress was observed under both elevated and ambient CO<sub>2</sub>. As per Ward et al. (1999), the reduction in the rates of net photosynthesis under water stressed conditions was less in  $C_4$  plants as compared with greater reduction in  $P_n$  values and leaf area for  $C_3$  plants resulting in higher reduction in biomass production. Relatively less negative effect of soil drying on  $P_n$  under eCO<sub>2</sub> was observed in  $C_4$  maize

as compared with  $C_3$  sunflower and it could be due to better  $\Psi_w$  and the photosynthesis more readily saturated even at normal atmospheric conditions.

### Growth measurements

The growth response of both maize ( $C_4$ ) and sunflower ( $C_3$ ) crops to  $eCO_2$  and its interaction with moisture stress was categorized as (i). The improvement of different biomass components due to  $eCO_2$  in which the most responsive growth parameter to  $eCO_2$  in each crop was identified under both irrigated and stress conditions. (ii) The reduction due to moisture stress and its interaction with  $eCO_2$  in which the most affected growth parameter due to moisture stress at  $eCO_2$  and  $aCO_2$  and the range of ameliorating capability of  $eCO_2$  in each crop was identified. The per se values of different growth parameters of both maize and sunflower crops at  $eCO_2$  and  $aCO_2$  were presented in Figure 2.

The ANOVA results for different growth characters indicated that  $CO_2$  levels and moisture levels are significant for leaf area, total biomass and its components such as leaf, stem and root biomass of both crops; however the interaction of  $CO_2$  and moisture levels were non-significant (Table 1). The response of shoot length was significant in sunflower for both  $CO_2$  levels as well as moisture levels whereas in maize it was significant only with moisture levels. The root length in sunflower and root volume in maize was significant for  $CO_2$  levels. Highly significant response was observed for maize with the interaction of  $CO_2$  and moisture levels. The root: shoot weight ratio response was highly significant in maize with moisture levels.

### (i) Response of biomass components to $eCO_2$ in sunflower and maize

**Leaf characters.** An increase in the leaf area in response to  $eCO_2$  ranged from 7% and 86% in

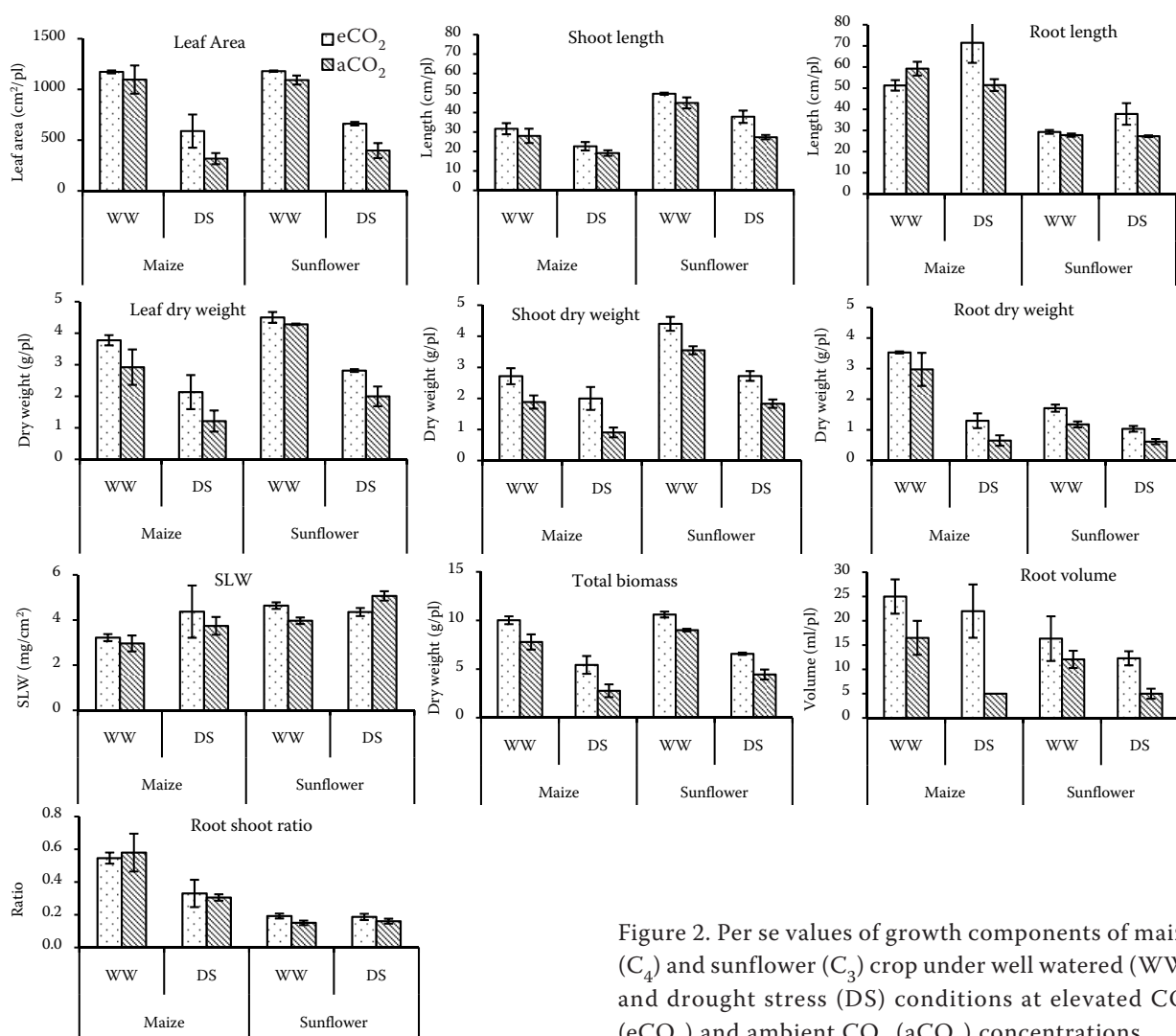


Figure 2. Per se values of growth components of maize ( $C_4$ ) and sunflower ( $C_3$ ) crop under well watered (WW) and drought stress (DS) conditions at elevated  $CO_2$  ( $eCO_2$ ) and ambient  $CO_2$  ( $aCO_2$ ) concentrations

Table 1. ANOVA of root and shoot characters with (aCO<sub>2</sub>) and (eCO<sub>2</sub>) under well-watered and drought stressed conditions in maize and sunflower

Characters	Mean sum square					
	CO <sub>2</sub> levels		moisture levels		CO <sub>2</sub> × moisture levels	
	maize	sunflower	maize	sunflower	maize	sunflower
Shoot length	ns	174.04*	238.52*	649.74**	ns	ns
Root length	ns	105.02*	ns	ns	584.50**	ns
Root volume	487.69*	ns	ns	ns	ns	ns
Leaf area	90584*	93810**	1394432**	1105954**	ns	ns
Leaf dry weight	2.36*	0.805*	8.44**	11.84**	ns	ns
Stem dry weight	2.78**	2.28**	2.15*	8.65**	ns	ns
Root dry weight	1.07*	0.678**	15.57**	1.152**	ns	ns
Total dry weight	18.00**	10.43**	69.23**	55.56**	ns	ns
Root shoot weight ratio	ns	ns	0.137**	ns	ns	ns
Photosynthesis	ns	806.557**	656.643**	139.234**	ns	26.016*
Stomatal conductance	ns	1.538**	0.033**	2.103**	0.024**	0.931**
Transpiration	ns	ns	82.174**	163.904	ns	ns
Leaf water potential	ns	ns	2.372**	0.672**	ns	ns

\*\**P* < 1%, \**P* < 5%; ns – not significant

maize and 8% and 67% in sunflower under EW and ED conditions, respectively (Table 2). The leaf dry weight improved by 29% in maize and 5% in sunflower with elevated CO<sub>2</sub> under well watered condition and 76% and 41% under drought stress for maize and sunflower, respectively. The eCO<sub>2</sub> conditions improved the specific leaf dry weight (SLW) of maize under both irrigated (9%) and moisture stressed (17%) conditions. Sunflower showed a different trend as eCO<sub>2</sub> improved the SLW under irrigated condition (17%) and decreased under moisture stress condition (–14%). This clearly indicates that in sunflower crop, eCO<sub>2</sub> facilitated more in maintenance of leaf area under moisture stress than leaf dry weight.

Plasticity in leaf area is an important means by which a drought stressed crop maintains control over water use (Blum 1996). Leaf area averaged slightly more per plant of sorghum and soybean under elevated CO<sub>2</sub> (Dugas et al. 1997). Increased CO<sub>2</sub> tends to accelerate the growth and leaf area per plant, which may increase the total transpiration. Upreti et al. (2000) reported that the leaf area increased by 46% compared to ambient grown rice plants. Rogers et al. (1992) reported that there was about 56% increase in the leaf area of soybeans (*Glycine max* L.) at 700 ppm of CO<sub>2</sub>. The maintenance of leaf area under drought stress is

crucial to sustain the photosynthesis and thereby crop productivity (Wu et al. 2004).

**Stem characters.** The improvement in shoot length of maize with elevated CO<sub>2</sub> was 13% under well watered conditions which increased to 18% under drought stress. The response of sunflower was 11% and 38% under similar conditions. The increase in dry weight of stem was 44% and 121% under EW and ED in maize while in sunflower it was 24% and 49%, respectively. This clearly indicates that maize stem dry weight response at eCO<sub>2</sub> was higher as compared with that of sunflower under both irrigated and moisture stress conditions. Zhao et al. (2006) observed a positive effect of high CO<sub>2</sub> concentration on shoot biomass growth of *Cinnamomum camphora* under three soil water levels. Higher shoot growth and stem dry weight were observed in *Phaseolus acutifolius* at 700 ppm than at ambient CO<sub>2</sub> (Salsman et al. 1999). Similarly, increased shoot length and dry weight were recorded with enhanced level of CO<sub>2</sub> in *Ricinus communis* (Vanaja et al. 2008). The plant height was unaffected in *Commelina benghalensis*; however leaf, stem and shoot dry weight tended to increased when exposed to enhanced level of CO<sub>2</sub> (Price et al. 2009).

**Root characters.** The response of root characters such as root length, root volume and root



Table 2. Increase (%) of root and shoot characters due to (eCO<sub>2</sub>) over (aCO<sub>2</sub>) in maize and sunflower under well-watered (WW) and drought stressed (DS) conditions

	Maize		Sunflower	
	WW	DS	WW	DS
Root characters				
Root length	-13.4	38.8	5	54
Root volume	51.5	340	35	146
Root dry weight	18.6	98.6	45	68
Shoot characters				
Shoot length	13.1	18.3	11	38
Stem dry weight	44.3	120.5	24	49
Leaf area	6.9	85.8	8	67
Leaf dry weight	29.2	75.6	5	41
Root and shoot characters				
Total dry weight	28.8	95.8	18	48
Root shoot ratio	0.58	8.2	28	16

dry weight with ED recorded higher values as compared with EW in both the crops. In maize the response was -13%, 52% and 19% for root length, root volume and root dry weight, respectively for EW when compared with AW and the values for the same parameters under AD were 39%, 340% and 99% (Table 2). In sunflower the response was 5.4% and 38% for root length, 35% and 146% for root volume and 45% and 68% for root dry weight under EW and ED, respectively. A significant improvement in root volume with eCO<sub>2</sub> was evident with both the crops under both conditions. The response of these root characters was more prominent with maize under stressed condition. Under ED the response of root length was significantly higher in sunflower whereas the response of root volume was higher in maize. Elevated CO<sub>2</sub> concentration significantly increased the soybean root volume and root: shoot ratio (Rogers et al. 1994) as a result of increase in root diameter, length, volume and weight.

**Total biomass.** Total dry weights of both maize (C<sub>4</sub>) and sunflower (C<sub>3</sub>) crops showed a significant positive response under both EW and ED conditions. Increase in the total biomass of maize was 29% under EW and 96% under ED and the response was 18% and 48% in sunflower, respectively. Earlier studies on a number of crop plants at eCO<sub>2</sub> revealed a positive response in biomass of C<sub>4</sub> crops, although to a smaller extent as compared with C<sub>3</sub> plants (Kimball 1993). In potato an increase in biomass was observed with irriga-

tion at enhanced CO<sub>2</sub> (Fleisher et al. 2008) and even under severe water stress it led to increased dry matter production in groundnut (Clifford et al. 1993). A significant and positive response in total biomass was observed in *Vigna radiata* L. (Srivastava et al. 2001) and in *Vigna mungo* L. (Vanaja et al. 2007) under enhanced levels of CO<sub>2</sub> at vegetative, reproductive and harvest stages. At early vegetative growth stage in *Vigna mungo* L. and sunflower the total biomass increased with elevated CO<sub>2</sub> with concomitant increase in stem, root and leaf biomass. The root: shoot ratio depends upon the partitioning of photosynthates which may be influenced by environmental stimuli. Rogers et al. (2006) observed large variability in root: shoot ratio regardless of photosynthetic pathway.

#### (ii) Drought stress and its interaction with eCO<sub>2</sub> in maize and sunflower

The reduction of total biomass due to drought stress in maize was lower under eCO<sub>2</sub> (46%) compared to aCO<sub>2</sub> (64%) (Table 3) and similar trend was observed with sunflower and the values were 38% (eCO<sub>2</sub>) and 51% (aCO<sub>2</sub>).

The extent of reduction in different total plant biomass components namely leaf, stem and root biomass due to moisture stress differed significantly ( $P \leq 0.01$ ) with CO<sub>2</sub> levels and the range of reduction was also found to be dissimilar in maize (C<sub>4</sub>) and sunflower (C<sub>3</sub>) crops. At aCO<sub>2</sub> the maximum

Table 3. Decrease (%) in root and shoot characters under drought stressed (DS) conditions at (eCO<sub>2</sub>) and (aCO<sub>2</sub>) in maize and sunflower

	Maize		Sunflower	
	aCO <sub>2</sub>	eCO <sub>2</sub>	aCO <sub>2</sub>	eCO <sub>2</sub>
Root characters				
Root length	13.1	−39.3 (400)	30.5	−1.16 (104)
Root volume	69.7	12.0 (83)	58.6	24.7 (58)
Root dry weight	78.2	63.2 (19)	47.8	39.5 (17)
Shoot characters				
Shoot length	31.5	28.4 (10)	39.2	23.8 (39)
Stem dry weight	50.4	26.5 (47)	48.4	38.1 (21)
Leaf area	71.1	49.8 (30)	63.6	44.0 (31)
Leaf dry weight	58.3	43.4 (26)	53.4	37.4 (30)
Root and shoot characters				
Total dry weight	64.3	45.9 (29)	50.7	38.1 (25)
Root shoot ratio	39.9	39.6 (1)	−6.6	3.1 (147)

The values in parenthesis are the % improvement due to (eCO<sub>2</sub>) under moisture stress

impact of moisture stress was observed with root volume, root dry weight, leaf area and leaf dry weight in both maize and sunflower though the extent of reduction varied between these parameters. However, eCO<sub>2</sub> helped in amelioration of adverse effects to a larger extent in both the crops.

Leaf, stem, root dry weights of maize decreased due to moisture stress by 58%, 50% and 78% under aCO<sub>2</sub>; however, eCO<sub>2</sub> helped the plants to ameliorate the adverse affects by improving them to the extent of 26%, 47% and 19%, respectively over aCO<sub>2</sub> (Table 3). The decrease in these parameters due to moisture stress in sunflower was 53%, 48% and 48% under aCO<sub>2</sub>; however, eCO<sub>2</sub> improved leaf, stem, root dry weights to the extent of 30%, 21% and 17%, respectively. In both crops the impact of eCO<sub>2</sub> was found to be highest under drought stress for root length followed by root volume. The improvement in root length was 400% in maize and 104% in sunflower under the ED over AD. The root volume decreased by 70% in maize and 59% in sunflower under AD, which was ameliorated to the extent of 83% and 58%, respectively, by eCO<sub>2</sub>. This enhancement in root length and root volume under ED in both crops makes the plants to explore soil moisture more efficiently and maintain growth under drought stress.

Drought stress led to a decrease in leaf area by 71% and 64% in maize and sunflower, respectively under aCO<sub>2</sub>, and the detrimental effects were ameliorated to the tune of around 30% in both crops

when subjected to eCO<sub>2</sub> condition. Elevated CO<sub>2</sub> also induces other changes in plant development besides enhancing dry matter production. In the present study it was observed that eCO<sub>2</sub> did not influence the P<sub>n</sub> rates of maize crop both under WW and DS conditions as compared with sunflower where this condition led to improvement in the P<sub>n</sub> rates under both WW and DS conditions. In contrast to this the g<sub>s</sub> and T<sub>r</sub> were very low in maize under WW condition as compared to sunflower and they further declined under DS condition. An increase in atmosphere CO<sub>2</sub> concentration mitigates drought stress directly by reducing stomatal conductance which reduces transpiration enabling the plant to avoid drought (Wall 2001). Investigations have revealed that elevated CO<sub>2</sub> reduces the rate of drying of plants as water is withheld, consistent with their lower stomatal conductance and lower transpiration rate (Bunce 1998). Elevated CO<sub>2</sub> might enhance the drought tolerance of plant by lowering osmotic potential (Tyree and Alexander 1993).

The study confirmed the beneficial effects eCO<sub>2</sub> in both maize (C<sub>4</sub>) and sunflower (C<sub>3</sub>) crops more so under drought stress conditions. The root: shoot ratio in sunflower improved under EW and ED conditions by 28% and 16%, respectively over AW and AD. Nevertheless, in maize the response was 8% under ED compared to AD and it was not substantial under irrigated conditions. The higher root: shoot ratio indicates higher partitioning of

photosynthates to below-ground parts with enhanced root length and root volume which helps the plants to thrive better under limited moisture environments.

It is interesting to note that the quantum of response of maize ( $C_4$ ) to  $eCO_2$  was better under both irrigated and moisture stress as compared with sunflower ( $C_3$ ) crop. This could be due to the responses to  $eCO_2$  that are genotype dependent rather than photosynthetic pathway. However, to conclude the findings, a higher number of representative genotypes from each group of these crops need to be evaluated.

The results of the present study suggest that elevated  $CO_2$  may mitigate drought impact and improve water relations thus abating the ill effects of drought stress on growth of both maize and sunflower. These findings would facilitate the comprehension of how the crop plants would respond to  $eCO_2$  and how would change precipitation patterns in future with changed climatic conditions.

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*Corresponding author:*

Dr. Maddi Vanaja, M.Sc., Ph.D., Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad-500 059, India  
phone: +91 040 2453 0161, fax: +91 040 2453 1802, e-mail: mvanaja@crida.ernet.in

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