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Effect of elevated ozone, carbon dioxide and their interaction on growth, biomass and water use efficiency of chickpea (*Cicer arietinum* L.)

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ABSTRACT

Global climate change has a major impact on growth and sustainability of agro-ecosystem. Keeping in view the importance of rising O_3 and CO_2 concentration in atmosphere, a field experiment was conducted on chickpea (variety: Pusa 5023) in the experimental farm in Free Air Ozone and Carbon dioxide Enrichment (FAOCE) facility at ICAR-Indian Agricultural Research Institute (IARI), New Delhi under four ozone and carbon dioxide treatments (ECO: elevated CO_2 (550±10 ppm) +elevated O_3 (70 ±10 ppb); EC: elevated CO_2 (550±10 ppm ppm) + ambient O_3 (30±10 ppb); EO: elevated O_3 (70±10 ppb)+ ambient CO_2 (400±10 ppm) and AMB; ambient CO_2 (400±10 ppm)+ ambient O_3 (30± 10 ppb) during *rabi* season of 2016-17. The results revealed that the plant height, above ground biomass, CGR and RGR and seed yield of chickpea was significantly highest in elevated CO_2 (EC) treatment followed by ECO treatment and lowest in elevated O_3 (EO) treatment. Elevated ozone had negative impact whereas elevated carbon dioxide had positive impact on growth, biomass and WUE of chickpea and when both are combined the negative impact of elevated ozone were counteracted by elevated carbon dioxide.

Keywords: Elevated CO_2, elevated O_3, RUE, CGR, RGR, chickpea

The impact of global climate change is rising concomitantly and is going to have a major impact on growth and sustainability of the agro ecosystems in the next hundred years. Understanding the effect of projected climatic conditions on crop growth and production in future is a major concern for worldwide food security programmes. The increase of greenhouse gases, like carbon dioxide (CO_2) and tropospheric ozone (O_3) are important factors affecting the global climate change (IPCC, 2014). The ozone with present concentration of 30 ppb is considered as one of the most serious environmental stresses for agro ecosystems (Agathokleous *et al*., 2015). On the other hand, atmospheric carbon dioxide (CO_2) concentration is also increasing and has attained a level of nearly 402 ppm during December 2015 (NOAA, 2016). Short term exposures of elevated CO_2 the net photosynthesis is enhanced particularly for C_3 plants resulting an increase in yield. Conversely, long-term elevated CO_2 exposure results a reduction in growth due to photosynthetic acclimation. This process of photosynthetic “down-regulation” is mainly responsible for the reduction in metabolic activity due to reduced carboxylation as well as reduced amount of rubisco under enriched CO_2 condition (Aranjuelo *et al.,* 2009).

Chickpea (*Cicer arietinumL.*) a member of genus *Cicer*, tribe *Cicereae*, is third most important food legume of the world. Currently it is grown on about 11.5 m ha area out of which 96% of cultivation is in the developing countries. South and south east Asia contributes around 80% of global chickpea production out of which 83% is being produced by India with total production of 9.6 million tonnes (average of 2007-09 triennium) and its productivity is 850 kg ha^{-1} India is the world’s largest consumer of chickpea and it produces nearly 70% of all global production.There are very few studies, mostly on simulation analysis on effect of elevated CO_2 on chickpea growth and yield (Srivastava *et al.* 2016; Saha *et al.* 2015). Keeping in view the importance of impact of elevated ozone and CO_2 on crop, the present experiment was undertaken to study the combined impact of elevated ozone and CO_2 on growth and WUE of chickpea.

MATERIAL AND METHODS

Experimental details

A field experimentwas conducted on chickpea (*C. arietinum L.*;cv. Pusa 5023-kabuli type) inside Free Air

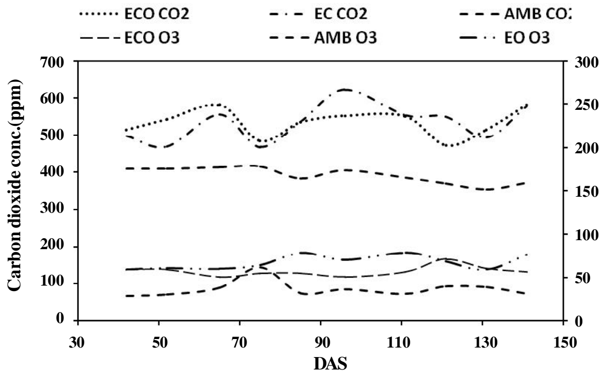

Fig 1: Variation in ozone and carbon dioxide concentrations over the growth period of the crop

Ozone and Carbon dioxide Enrichment (FAOCE) ring installed in experimental farm of ICAR- Indian Agricultural Research Institute (ICAR- IARI), New Delhi (28°35' N latitude, 77°12' E longitude and at an altitude of 228.16 m above mean sea level). Crop was grown under elevated ozone, elevated carbon dioxide and in one ring crop was exposed to combination of both gases.

The experiment was laid out in CRD (factorial) with four replications**.** Elevated carbon dioxide (ECO: 550±10 ppm), elevated ozone (EO: 70 ±10 ppb) and combination both gases (ECO: elevated carbon dioxide (550±10 ppm) + elevated ozone (70 ±10 ppb)) was supplied in three different FAOCE rings (6m diameter), adjacent to these rings another ring was prepared where crop was grown without any external supply of ozone and carbon dioxide (AMB). The elevated concentrations were maintained inside the rings between 7.00 h to 18.00 h throughout the crop growth season starting from 40 days after sowing using high pressurized cylinders by an automatic monitoring system. Air was sampled automatically from the middle of each ring at canopy level and fed to an ozone and carbon dioxide analysers which measure the ozone concentrations. The sensors installed reads and maintains the elevated concentrations of elevated carbon dioxide and ozone (Fig. 1).

Foundation seeds of chickpea namely, Pusa-5023 (Kabuli type), were prepared treating the seeds with fungicide Captan @ 2 g kg^{-1} seed and then with Rhizobium @ $12gkg^{-1}$ seed and were sown on 16th Nov, 2016 in well prepared soil of the FAOCE rings with a row to distance of 45 cm and plant to plant distance of 20 cm. A basal dose of NPK @ 20:50:20 kg ha^{-1} was incorporated prior to sowing.

Biometric observations

Crop phenology was monitored twice in a week, by

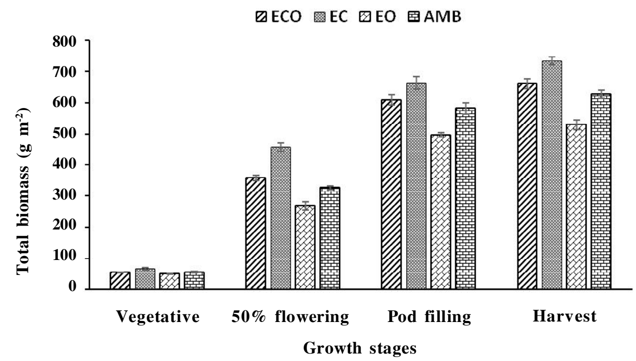

Fig 2: Total crop biomass production in chickpea leaves at different growth stages as influenced by different treatments of ozone and carbon dioxide.

observing the plants in the field and the following phenological events were observed: 50% germination, flowering, pod development and physiological maturity. The plant height was measured from the ground level to the topmost portion of the plant with the help of meter scale at 10 days intervals. Plant biomass was measured from four plants randomly selected from each quadrant of the ring and the stem is cut at ground level. Plants were oven dried at 60°± 5°C for 48 hours and weighed by using digital balance.

Crop growth rate (CGR) and relative growth rate (RGR)

Plant dry matter was calculated at different time interval using digital balance. Then CGR (g $m^{-2} day^{-1}$) was calculated for each treatment using the following formula;

$CGR = W_2 - W_1 / SA\ (t_2 - t_1)$

where, W_1 and W_2 represents the total dry matter production (g) at time t_1 and t_2, respectively and SA is the land area occupied by plants at the time of sampling.

RGR was calculated by using the following formula:

$RGR = (\ln W_2 - \ln W_1) / (t_2 - t_1)$

Water use efficiency (WUE) based on biomass of the crop was calculated from the regression between biomass and amount of water used (mm) whereas on yield basis it is calculated as amount of grain yield produced per mm of water used.

The statistical analysis was performed SAS version 9.2 software package.

RESULTS AND DISCUSSION

Crop phenology

In all the treatments germination of chickpea crop was

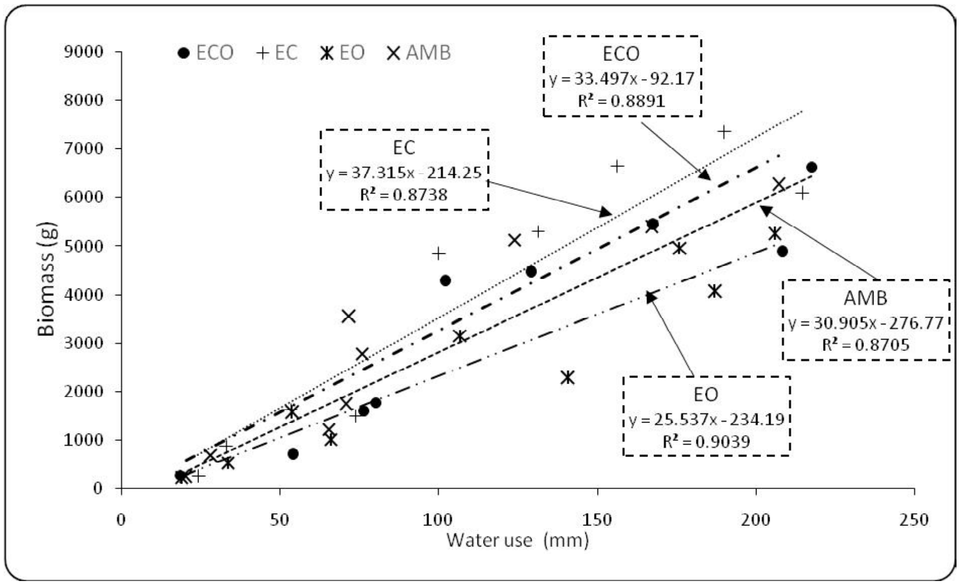

Fig 3: Biomass based water use of efficiency of chickpea crop under elevated surface ozone and carbon dioxide treatments

Table 1: Occurrence of phenological stages (in DAS) of chickpea crop as influenced by different treatments of ozone and carbon dioxide

Treatment	Germination	50 %Flowering	Pod initiation	Maturity
EO	7	85	113	131
EC	6	82	108	135
ECO	6	82	110	128
AMB	7	86	111	145

Table 2: Temporal variation of plant height (cm) in chickpea crop as influenced by different treatments of ozone and carbon dioxide

Treatments	Days after sowing (DAS)						
	52	65	75	85	96	121	131
ECO	23.75	31.00^{B}	44.25^{AB}	47.75^{B}	63.00^{AB}	78.75^{AB}	93.00^{A}
EC	24.75	33.25^{A}	48.50^{A}	52.25^{A}	65.75^{A}	82.75^{A}	95.25^{A}
EO	22.25	26.75^{C}	37.75^{C}	42.50^{D}	59.25^{C}	68.38^{C}	71.50^{B}
AMB	23.25	29.25^{B}	41.00^{BC}	45.25^{C}	61.00^{BC}	72.13^{BC}	76.25^{B}
CV %	10.05	4.53	7.01	2.55	2.99	6.02	6.72
LSD at 5%	NS	2.09	4.63	1.84	2.87	7.00	8.70

observed in 6-7 DAS (Table 1). Initially, there was no variation in phenological stages, but it was visible after 42 DAS when treatments (elevated CO_2 and O_3) given inside the ring. The growth period shortened by about 10 days due to the elevated CO_2 effect and 14 days due to elevated O_3 treatment. Both elevated CO_2 and elevated O_3 advanced all phenological stages of the crop by different mechanism. Other researchers (Saha *et al.,* 2015) also reported the early senescence in elevated CO_2 treatment. Elevated O_3 typically damage chlorophyll content of leaves and nutrient status thus enhance senescence of crops (Zhang *et al.*, 2014).

Plant height

Plant height differed significantly due to treatments (Table 2). The highest plant height (95.2 cm) was observed in EC at 131 DAS followed by 93.0 cm in ECO, 76.25 cm in AMB, 71.5 cm in EO treatments. Plant height was significantly higher under elevated CO_2 condition than elevated O_3 and their interaction. The effect was more prominent at 65 DAS and 85 DAS which was coinciding with

Table 3: Crop growth rate (g m^{-2} day^{-1}) and relative growth rate (mg g^{-1} day^{-1}) of chickpea crop as influenced by different treatments of ozone and carbon dioxide

Treatments	Days after sowing (DAS)							
	30-60		60-90		90-120		120-141	
	CGR	RGR	CGR	RGR	CGR	RGR	CGR	RGR
ECO	2.42^{B}	216.25^{B}	6.23^{B}	328.50^{B}	6.94^{B}	388.50^{B}	5.49^{B}	291.25^{B}
EC	3.54^{A}	288.25^{A}	7.50^{A}	396.50^{A}	8.30^{A}	443.50^{A}	6.34^{A}	356.25^{A}
EO	2.01^{B}	152.75^{C}	4.36^{D}	268.75^{C}	5.36^{C}	312.00^{C}	4.37^{D}	206.50^{D}
AMB	2.40^{B}	187.50^{B}	5.65^{C}	326.00^{B}	6.69^{B}	359.50^{B}	4.97^{C}	252.00^{C}
CV %	10.29	10.14	5.87	7.22	3.84	6.45	5.40	7.02
LSD at 5%	0.41	33.00	0.53	36.70	0.40	37.33	0.44	29.92

Table 4: Yield water use of efficiency (WUE) of chickpea crop under elevated surface ozone and carbon dioxide treatments

Treatments	Seed yield (gm^{-2})	Water use (mm)	WUE (kg ha - mm^{-1})
ECO	270.40^{B}	217.50^{A}	12.46^{B}
EC	324.33^{A}	190.03^{C}	17.07^{A}
EO	191.50^{C}	206.98^{B}	9.26^{C}
AMB	245.88^{B}	207.30^{B}	11.86^{B}
CV%	8.56	2.48	9.29
LSD at 5%	34.04	7.84	1.81

50% flowering and pod filling stage. The plant height at harvest was more in EC treatment than in ECO (combined treatment) which was due to positive effect of CO_2 fertilization and negative effect of O_3 on plant growth.

As chickpea is a leguminous crop with nitrogen fixing nodules, more nodulation is possible under elevated CO_2 condition to support the mechanism of growth enhancement (Gamper *et al.,* 2005). The entry of ozone through stomata reduces the growth rate due the disruption of cellular process (Bhatia *et al.*, 2013).

Biomass accumulation

The accumulated biomass was highest under elevated CO_2 condition in comparison to all other treatments (Fig.2) at all the growth stages. Biomass accumulation in ECO and AMB treatments were statistically at par. The lowest biomass accumulation reduction was observed in EO treatment. The increase of above ground biomass accumulation is due to more photosynthates partitioned towards above ground parts by CO_2 enriched crop. Reduction of stomatal aperture also decrease the entry of O_3 inside leaves in elevated CO_2 treatment which is a detoxifying process of O_3 and ultimately increase the availability of substrates (Pearson *et al.,* 1995).

CGR and RGR

The highest CGR and RGR was observed in EC treatment, followed by ECO and AMB treatments and the lowest in EO treatment (Table 3). Among all the treatments highest CGR and RGR was observed during 90-120 DAS after that it decreased. Both CGR and RGR significantly increased under elevated CO_2 and in combination treatments but significantly decreased under elevated O_3 treatment. Elevated CO_2 treatment recorded an increase of 24.0 to 47.5% in CGR and 21.6 to 53.7% in RGR over ambient condition respectively.

Water use efficiency (WUE)

Water use efficiency on account of biomass accumulation significantly differed dute to different CO_2 and O_3 treatments (Fig.3). Total water use was 217.5 mm and 206.9 mm for ECO and EO, respectively which was significantly higher than EC (190.0 mm) and AMB (207.3 mm) treatments. Whereas the WUE was significantly higher under EC (37.32 kg ha-mm^{-1}) than other treatments. Similar trend was also observed in WUE on seed yield basis (Table 4). The WUE for yield was significantly lower under EO (9.26 kg ha-mm^{-1}) in comparison to other treatments. It was highest under EC treatment (17.07 kg ha-mm^{-1}), followed by ECO (12.46 kg ha-mm^{-1}) and AMB (11.86 kg ha-mm^{-1}). The reduction of WUE was due reduction of yield and biomass under elevated O_3 as compared to crop exposed to elevated CO_2 and ambient condition.

CONCLUSION

Elevated ozone has negative impact whereas elevated carbon dioxide has positive impact on growth, biomass and WUE of chickpea and when both are combined the negative impact of elevated ozone were counteracted by elevated carbon dioxide. WUE was significantly increased in EC and reduced in EO, ECO values are higher than AMB. During crop growing season both CGR and RGR was significantly increased under elevated CO_2 and in combination treatments but significantly decreased under elevated O_3 treatment.

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