

उच्च सतही ओज़ोन एवं कार्बन डाइऑक्साइड का चने की
सूक्ष्म मौसमी तथा जैवभौतिकी मापदण्डों पर परस्पर प्रभाव

**Micrometeorological and biophysical parameters of
chick pea under the interaction of elevated surface
ozone and carbon dioxide**

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Micrometeorological and biophysical parameters of chick pea under the interaction of elevated surface ozone and carbon dioxide

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By

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CERTIFICATE

This is to certify that the thesis entitled, “**Micrometeorological and biophysical parameters of chick pea under the interaction of elevated surface ozone and carbon dioxide.**”, submitted to the Faculty of Post Graduate School, Indian Agricultural Research Institute, New Delhi, by **Mr. Ram Narayan Singh**, Roll No. **20649** in partial fulfillment of the requirements for the award of the degree of **Master of Science in Agricultural Physics**, is a record of bona fide research work carried out by him under my guidance and supervision and that no part of the thesis has been submitted anywhere for the publication or for any other degree or diploma.

I further certify that the assistance and help received during the course of this investigation has been duly acknowledged.

Place: New Delhi

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Date:

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*Dedicated
to my
beloved
parents...*



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ABBREVIATIONS

Abbreviations	Expansion
AMB	Ambient treatment
BSS	Bright sunshine hours
CATD	Canopy air temperature difference
CGR	Crop growth rate
DAS	Days after sowing
EC	Elevated Carbon dioxide treatment
ECO	Elevated Carbon dioxide and Ozone treatment
EO	Elevated Ozone
EP	Pan evaporation
FAOCE	Free air CO ₂ and O ₃ enrichment
FC	Field capacity
fIPAR	Fractional intercepted photosynthetically active radiation
HI	Harvest index
IPAR	Intercepted photosynthetically active radiation
LAI	Leaf area index
LSD at 5%	Least significance difference at 5 % level
PAR	Photosynthetically active radiation
PPFD	Photosynthetic photon flux density
PWP	Permanent wilting point
RGR	Relative growth rate
RH	Relative humidity
RLWC	Relative leaf Water content
RUE	Radiation use efficiency
SMW	Standard meteorological week
T _{max}	Maximum temperature
T _{min}	Minimum temperature

1. INTRODUCTION

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 of effect of the projected climatic conditions on crop growth and production in the future is a major concern for worldwide food security programmes (Parry and Hawkesford, 2010, 2012; Foulkes *et al.*, 2010). This is particularly relevant considering the increasing world population. The world food production needs to be increased 100% by 2050 to meet the demands of the projected growth of population (Nakicenovic *et al.*, 2000). Intergovernmental Panel on Climate Change (IPCC) 2001, assessment report concluded that, human activities are affecting our climate”. They also quote the increase of greenhouse gases, like carbon dioxide (CO₂) and tropospheric ozone (O₃), are important factors affecting the global climate change (IPCC, 2001). Ground level ozone or tropospheric ozone (O₃) is a major pollutant generated by photochemical reactions of volatile organic compounds with nitrogen oxides. The ozone concentration is rising continuously in the atmosphere (IPCC, 2014). In the Asian countries, the emission of ozone precursors is rising and it is expected to increase continuously in the foreseeable future (Kitao *et al.*, 2015). The tropospheric ozone with present concentration of 30 ppb is considered as one of the most serious environmental stresses for agroecosystems. (Matyssek *et al.*, 2012; Agathokleous *et al.*, 2015). On the other hand, atmospheric carbon dioxide (CO₂) concentration is also increasing and has attained a level of nearly 402 ppm during December 2015 (NOAA, 2016). Burning of fossil fuels and anthropogenic interferences are the main reasons for the increase in level of atmospheric carbon dioxide which may lead to significant change in earth’s climate within a century. Currently, terrestrial vegetation is growing in a CO₂ level which is higher than in the past 26 million years. Since the atmosphere is the only source of C for plants, the rise in carbon dioxide concentration in atmosphere have a significant effect as carbon fertilization resulting in major consequences for plant production The elevated CO₂ level is expected to affect the plant growth and development pattern, as it changes photosynthesis, carbon assimilation pathways as well as its resource use efficiency.

Several studies revealed that, for short-term exposures of elevated CO₂ the net photosynthesis is enhanced particularly for C₃ plants (Drake *et al.*, 1997; Ainsworth

and Long, 2005), resulting an increase in yield (Oliveira *et al.*, 2010). Conversely, long-term elevated CO₂ exposure results a reduction in growth due to photosynthetic acclimation (Miller *et al.*, 1997; Erice *et al.*, 2006a; Aranjuelo *et al.*, 2009 and Kimball *et al.*, 2002). This process of photosynthetic “down-regulation” (Saralabai *et al.*, 1997; Ainsworth *et al.*, 2003; Sanz-Sáez *et al.*, 2010) is mainly responsible for the reduction in metabolic activity to a due to reduced carboxylation (Erice *et al.*, 2006b) as well as reduced amount of rubisco under enriched CO₂ condition (Urban, 2003; Aranjuelo *et al.*, 2005).

It is widely accepted that concentrations of both O₃ and CO₂ are simultaneously increased in the troposphere over the past century and are expected to rise at even higher rates to levels where they have a significant impact on crop growth and production (Krupa and Kickert, 1989). Elevated O₃ and elevated CO₂ concentration may have antagonistic effects on the micrometeorological and biophysical parameter of representative crop species. It is opined that negative effect of high O₃ on crop growth is somehow compensated by elevated CO₂ (Koike *et al.*, 2012). It is also well known that increasing O₃ levels at ambient CO₂ causes yield reduction in many crops species (Fuhrer and Booker, 2003). This negative effect of ozone results due to reduced activity of Rubisco associated with accelerated leaf senescence in plants which results in reduced assimilation of photosynthates (Grandjean and Fuhrer, 1989). In addition to its detrimental effect on of O₃ on rubisco, it also impairs the translocation of photosynthates from sources to sinks (Grantz and Yang, 2000). The effect of elevated CO₂ on photosynthesis counteracts the effect of ozone (McKee *et al.*, 1995). Hence, ozone determines the extent of enhancement of yield by elevated CO₂. The relative yield stimulation by elevated carbon dioxide is larger in an atmosphere having elevated levels of ozone, or vice versa. The negative impacts of ozone is less in a carbon dioxide enriched atmosphere as compared to ambient carbon dioxide. The protective effect of carbon dioxide against elevated ozone could be explained by a reduction in leaf conductance which reduces the ozone uptake and by an increase in the activity of anti-oxidant enzymes (Rao *et al.*, 1995). But most of the recent researches concluded that the protective effect of elevated carbon dioxide against ozone is primarily due to ozone exclusion, rather than an increased detoxification capacity (Wang *et al.*, 2014).

Chick pea (*Cicer arietinum* L.) a member of genus *Cicer*, tribe *Cicereae*, family Fabaceae, and subfamily Papilionaceae, is the world's third most important food legume crop (http://www.icrisat.org/what-we-do/crops/Chick_pea/Chick_pea.htm, accessed on 03/06/2017). Chick pea is a major and cheap source of protein compared to animal protein. Origin of chick pea was in south eastern Turkey (Ladizinsky, 1975) but it has been adapted to a wide agro-climatic conditions over the globe (Khanna-Chopra and Sinha, 1987). Currently it is grown on about 11 m ha area out of which 96% of cultivation is in the developing countries. South and south East Asia contributes around 80% of global chick pea production out of which 83% is being produced by India. Currently chick pea is cultivated in 11 Mha with total production of 8.4 million tonnes (average of 2004-06 triennium) and its productivity is 786 kg ha⁻¹ (http://www.icrisat.org/what-we-do/crops/Chick_pea/Chick_pea.htm, accessed on 03/06/2017).

In places like semi-arid tropics where water availability is a major limiting factor in the crop production, chick pea added an advantage of biological nitrogen fixation proved its high commercial potential. A very few studies have been done on chick pea from this perspective and hence it is important to study the impact of elevated carbon dioxide and ozone and their interaction on plant growth, canopy characteristics of the plant system, dry matter partitioning, water and radiation use efficiencies, biophysical and other micrometeorological parameters. This will help us to understand the behaviour of the crop under future scenario of elevated GHG levels.

No study has been conducted on chick pea to investigate the impact of both elevated carbon dioxide and ozone. Only few field scale study has been conducted that is confined to elevated carbon dioxide and to physiological aspects. However, Saha *et al.* (2014) investigated the WUE and RUE of chick pea under the impact of elevated carbon dioxide in open top chambers. Limited information was found about the impact of these interacting gases on survival, growth, and productivity of pulses. So the present study was undertaken to study the impact of elevated ozone (~70 ppb) and CO₂ (~550 ppm) on chick pea in free air ozone and carbon dioxide with the following objectives:

1. To study the micrometeorological parameters under elevated ozone, carbon dioxide and their interactions.
2. To assess the impact of elevated ozone, carbon dioxide and their interactions on growth, development and yield attributes of chick pea.
3. To study the radiation and water use efficiency of chick pea under elevated ozone, carbon dioxide and their interactions.

2. REVIEW OF LITERATURE

Global climate change is expected to affect the carbon assimilation, biomass allocation, growth and nutrient uptake of plants since the atmospheric ozone and carbon dioxide levels were predicted to rise to 550 ppm (RCEP, 2000) from the current 403 ppm. Relative to 1850–1900, global surface temperature change for the end of the 21st century (2081–2100) is projected to *likely* exceed 1.5°C (IPCC 2014). The global surface temperature change at the end of the 21 century (2081-2100) relative to 1850-1900 is projected to likely exceed 1.5°C (IPCC 2014).

The photosynthetic processes are influenced by elevated carbon dioxide concentration and the simultaneous increase in temperature influences the crop growth and development, energy, water and nutrient availability and their use. Similarly, elevated CO₂ concentration causes higher biomass production which implies more carbon input into the soil which in turns alters soil physical properties. On the other hand tropospheric ozone which is also an important atmospheric GHG as well as an air pollutant also affects the crop growth and metabolism chiefly because of its oxidising nature affects the plants.

Chick pea (*Cicer arietinum* L.) is one of the most important winter season pulse crop as well as the cheapest source of protein for millions of peoples in developing countries (Joshi *et al.*, 2002). Chick pea is the third most important food legume crop contributing a share of 14.6% to the global pulse production (FAOSTAT, 2010), worldwide chick pea is grown on 11 million ha (15.3% of the total pulses area). In Asia chick pea accounts for 89.7% of global production. India is the largest producer of chick pea among Asian countries and accounts 64% of the global chick pea production (Gaur *et al.*, 2010). Some literatures are available on effect of ozone and carbon dioxide investigating the biophysical and micrometeorological parameters for chick pea, but not even a single one is available on the interaction of elevated surface ozone and carbon dioxide condition so far. Therefore, it is important to study the possible changes in response of chick pea and the changes in microclimate of plant canopy brought by the interaction of elevated surface ozone and carbon dioxide environment in subtropical India. The relevant literature for this present study has been given below under the following headings:

2.1.1 Increase in CO₂ concentration in earth's atmosphere

Agricultural productivity is challenged by the rising atmospheric CO₂ which is changing global climate patterns. On the other hand, increasing CO₂ concentration gives a unique chance to increase the productivity of crops specially C₃ crops. The average rate of increase of carbon dioxide has been 1.9 $\mu\text{l l}^{-1} \text{yr}^{-1}$ during the last 12 years and the carbon dioxide is predicted to cross 570 $\mu\text{l l}^{-1}$ by the middle of this century. Krull *et al.* (2005) reported that an increase of 64 ppm in CO₂ during the last fifty years (1953 to 2003). According to different scenarios of CO₂ emissions of Intergovernmental Panel on Climate Change (IPCC), the ranges for atmospheric carbon dioxide concentration will be 463–623 and 478–1099 ppm 2050 and 2100 respectively (McCarthy *et al.*, 2001). As a consequence of this rise in CO₂, the earth's average temperature is expected to rise from 2.0 to 4.5 °C (IPCC, 2007).

The increasing concentrations of greenhouse gases will cause the warming of the globe which is reflecting the multifaceted interactions between microbes, humans and rest of the biosphere. As a result of increasing anthropogenic GHG emission global change factors, predominantly increase in the atmospheric CO₂ concentration and temperature, mean and variance of regional precipitation, land use changes are expected to have profound effects on functioning of the ecosystem in the future (IPCC, 2001). Changes in soil moisture availability mediates the effects of rainfall deficiencies via its impact on LAI, photosynthetic rates, leaf water status, plant growth rate and productivity (Orwig and Abrams, 1997; Allen and Breshears, 1998; Leuzinger *et al.*, 2005; Li *et al.*, 2007). Along with the increasing global atmospheric temperature, soil temperature is also expected to rise concurrently (Schlesinger and Andrews, 2000).

2.1.2 Crop response to elevated carbon dioxide.

2.1.2.1 Biophysical parameters

A number of studies have shown that atmospheric CO₂ concentration directly effects the regulation of stomata by guard cells (Zhu *et al.*, 1998). With limited exceptions, elevated carbon dioxide studies show that in C₃ plants stomatal conductance is initially reduced in response of elevated CO₂ which reduces transpiration and increases the water content. However, in some species the responses are short-lived (Bunce, 1992). Many studies have shown that elevated CO₂ concentrations eventually enhances the

photosynthesis , which increases growth rate and yields of C₃ plants (Centritto *et al.*, 2002; Drake *et al.*, 1997; Kang *et al.*, 2002; Li *et al.*, 2003) and leaf photosynthesis throughout lifecycle of the crop (Garcia *et al.*, 1998).

Saha *et al.* (2015) reported that in C₃ legumes CO₂ enrichment stimulates photosynthesis, due to which the radiation interception and use efficiency is also modified. Elevated CO₂ reduces the stomatal conductance and transpiration combined with increased total biomass and water use efficiency in free air CO₂ enrichment (FACE) in rice (Yoshimoto *et al.*, 2005). This observation is also supported by Medlyn *et al.* (2001) as well as by Ainsworth and Long (2005). But this reduction of transpiration does not always transform to an equivalent reduction in an improved soil-water status (Field *et al.*, 1995; Baker *et al.*, 1997; Wullschleger and Norby, 2001). Because the elevated CO₂ often increases the leaf area index (LAI) (Ainsworth and Long, 2005), which is a primary factor for both water use and productivity (Wullschleger *et al.*, 2002). The effect of enriched atmospheric CO₂ on increase in peak leaf area index (LAI) was reported in soybean (Sun *et al.*, 2009), and pigeon pea (Saha *et al.*, 2012).

Saha *et al.* (2015) in their study of chick pea in OTC reported a higher peak value of LAI as compared to ambient. The LAI profile was reported to be changed under elevated CO₂ due to delay in the senescence in soybean (Dermody *et al.*, 2008a) and by early maturity in pigeon pea crop (Saha *et al.*, 2012). No significant effect of CO₂ enrichment was observed on fIPAR in pigeon pea even though the LAI was significantly increased. Similarly, CO₂ enrichment did not changed the cumulative IPAR over the crop growth period (Saha *et al.*, 2012).

There are many contradictory reports about the effect of elevated atmospheric CO₂ on fIPAR. Some studies shown an increased fIPAR under elevated atmospheric CO₂ environment in wheat (Mulholland *et al.*, 1998), while in rice (De Costa *et al.*, 2006) and barley (Manderscheid *et al.*, 2009) the fIPAR was found to be unaltered by CO₂ enrichment.

Recent studies from FACE experiments suggests that the decrease in stomatal conductance at enriched CO₂ environment often translates to a proportional increase in soil moisture content and decrease in canopy transpiration in soybean (Leakey *et al.*, 2009). A proportional increase in carbon dioxide concentration at leaf level brings

a proportional increase in photosynthetic rate and reduction in stomatal conductance which increases the transpiration efficiency and reduces the anti-transpiration effect of carbon dioxide. A higher assimilation rate and total dry biomass was observed in peach (*Prunus persica* L.). Seedlings grown under enriched CO₂, in OTCs. But total water uptake, stomatal conductance, leaf number leaf and area were unaffected by enriched carbon dioxide throughout the growing season (Centritto *et al.*, 2002). Under elevated CO₂ seedlings shows a dramatic increase in the leaf area (Kellomaki and Wang, 1997; Tissue *et al.*, 1997). McCarthy *et al.* (2007) found that in pines under elevated CO₂ senescence and canopy leaf area remains unaffected, however the leaf area senescence for hardwoods was reduced. On the other hand, Norby *et al.* (2003) reported that the LAI of the forest species remains unaffected by elevated CO₂. Pal *et al.* (2008) in their study conducted on chick pea exposed to elevated CO₂ reported that, CO₂ exposure increases the growth characteristics, viz. total number of branches, leaf area per plant, shoot length, seed yield with a significant increase in the leaf and shoot dry weight. higher biomass and seed yield in growing organs of Berseem (Pal *et al.*, 2004) and pigeon pea (Saha *et al.*, 2011) were reported which is due to enhanced partitioning of photosynthate carbon towards the growing organs. Vanaja *et al.* (2007) found a significant increase in growth parameters of black gram (*Vigna mungo* L.) viz. root : shoot ratio, leaf area, plant weight, length and weight of root and shoot at 700 ppm CO₂ using open-top chambers. Piikki *et al.* (2008) reported that in case of enriched CO₂ the grain yield increases due to increase in grain number per unit ground area. Imai *et al.* (1985) and Allen *et al.* (1998) have reported increase in harvest index (HI) under elevated CO₂, contradictory to that a decreasing trend of HI were reported by Baker *et al.* (1992), Ziska *et al.* (1997) and Kim *et al.* (2001) .

Enriched CO₂ enhances photosynthesis that leads to increase in growth rates and yields of C₃ plants (Centritto *et al.*, 2002; Drake and Gonzalez-meler, 1997; Kang *et al.*, 2002; Li *et al.*, 2003) and a significant increase in leaf photosynthesis throughout the growing season of the crop (Garcia *et al.*, 1998). FACE experiments with clover (*Trifolium repens*) and soybean (*Glycine max*) showed that at elevated CO₂ stimulates leaf carbohydrate content and photosynthetic carbon uptake with increased biomass (Ainsworth *et al.*, 2003; Rogers *et al.*, 2004). However, Cure and Acock (1986) concluded that the changes in harvest index (HI) were inconsistent and non-significant except for soybean, where the HI decreased significantly elevated CO₂. Sun *et al.*

(2009) reported an increase in biomass and seed yield along with a decrease in HI of soybean. Saha *et al.* (2012) reported that due to inability of plant to fully utilize the photosynthetic assimilates harvest index of pigeon pea decreases under elevated atmospheric CO₂ and found no-significant change in HI, in conformity with HI in Lupin (Palta and Ludwig, 2000). Contradictory to this an increase in HI in wheat was reported (Aranjuelo *et al.*, 2013) while a decrease in harvest index has been reported in rice (Kim *et al.*, 2003), soybean (Sun *et al.*, 2009) and pigeon pea (Saha *et al.*, 2012). However, Aranjuelo *et al.* (2013) reported that under elevated CO₂ the increase in wheat yields was not due to increase in total biomass rather due to increase in harvest index of the crop. Saha *et al.* (2015) reported an increase in vegetative and reproductive dry matter of chick pea under CO₂ enrichment. An increase in yield attributes viz. total number of pods, pod dry weight per plant were reported in chick pea (Saha *et al.*, 2015), broad bean (Wu and Wang, 2000), rice (Kim *et al.*, 2003), wheat (Wu *et al.*, 2004; Hogg *et al.*, 2010), rapeseed (Franzaring *et al.*, 2011) and barley (Manderscheid *et al.*, 2009). Similarly, an increase in seed yield, pod weight per plant and seed weight per branch were reported for chick pea (Saha *et al.*, 2015), soybean (Ainsworth *et al.*, 2002; Twine *et al.*, 2013). An increase in seed size was observed through elevated carbon dioxide in soybean (Ziska and Bunce, 2007) and black gram (Vanaja *et al.*, 2007). However no such effect was observed in chick pea (Saha *et al.*, 2015).

As the substrate and the gradient between the ambient air and the mesophylls cell increases the elevated carbon dioxide may have a positive impact on the plant production (Saha *et al.*, 2015). Anda *et al.* (2008) in his work on maize reported that plant responds not only to changes in carbon dioxide concentration, but also to the to the modifications of their microenvironment caused by the elevated carbon dioxide. No significant changes were registered in soil physical parameters due to elevated CO₂ (Saha *et al.*, 2015).

2.1.2.2 Radiation use efficiency (RUE)

Crop productivity is governed by factors like canopy quantum yield, radiation capture, and carbon use efficiency (Bugbee and Monje, 1992) and among these radiation capture is the most important parameter (Monteith, 1981). Pinter *et al.* (1994, 1996) reported that in the elevated CO₂ the radiation capture was increased by 15-20% during first half of the growing season in field grown wheat and cotton. Interception

of the solar radiation by the plant canopy and its utilization for biomass synthesis is the most important factor which determines the biomass accumulation. The effectiveness of radiation interception by a crop canopy of a given LAI is determined by its radiation extinction coefficient (k) and the radiation use efficiency determines the efficiency of conversion of the intercepted radiation to biomass. Both RUE and the extinction coefficient are key parameters in number of crop growth models.

The impact of elevated CO₂ on wheat productivity was studied by analysing the canopy quantum yield, radiation capture canopy and harvest index (Monje and Bugbee, 1998). Radiation use efficiency (RUE) is an effective and efficient approach to quantify the biomass production. RUE may be defined as the increase in above ground dry mass per unit intercepted photosynthetically active radiation (IPAR). De Costa *et al.* (2006) in their study conducted with CO₂ enrichment within OTCs for two seasons reported no change in the seasonal fraction of the intercepted radiation in rice crop, but rice showed significantly greater RUE under enriched CO₂ relative to the ambient conditions. They concluded that in spite of the higher range of growing temperatures rice yields responds positively to enriched CO₂. At crop level greater initiation of grains and greater RUE are the primary causes for this yield stimulation. Manderscheid *et al.* (2003) in their study on the effect of elevated CO₂ in relation to temperature and growth stage on growth and daily RUE of wheat found that when growth depends on source activity the RUE decreases with temperature.

Norby *et al.* (2003) reported that absorbed PAR remains unaffected by elevated CO₂ with increase in the net primary productivity (NPP) with increase in light use efficiency under CO₂ enrichment. A significant increase in leaf area index was recorded through CO₂ enrichment, while no change in fractional intercepted photosynthetically active radiation was observed (Saha *et al.*, 2015). Li *et al.* (2010) found that chick pea cultivar with fern-leaf type gives consistently greater light interception as compared to that that with unifoliate leaf-type cultivar. In pigeon pea higher yields under elevated CO₂ has been reported by Saha *et al.* (2012). They also reported no significant difference in overall periodic fIPAR values between ambient and elevated CO₂ conditions. Saha *et al.* (2015) in their study on chick pea in OTCs showed the possible benefits of elevated atmospheric CO₂ in enhancing RUE. Hui *et al.* (2001) based on intercepted photosynthetic active radiation reported an increase in radiation-use efficiency (RUE) of sunflower grown in ecocells due to elevated CO₂.

One of the traits contributing to differences in species for plant growth rate or RUE is the leaf orientation. It would be interesting to find out how the radiation interception and its utilization changes due to elevated CO₂ by affecting the canopy structure. Also, the calculation RUE values of crop canopy exposed to CO₂ enrichment will be useful in models aimed at predicting crop productivity for future scenario of climate change. (Saha *et al.*, 2015)

2.1.2.3 Water use efficiency (WUE)

It is envisaged that water use efficiency of crop will be altered with climate change (Mo *et al.*, 2007; Thomas, 2008) as influenced by elevated CO₂. Experiments have shown that water use efficiency increases under elevated CO₂ in terms of shoot biomass and grain yield, because under elevated CO₂ conditions increase in the magnitude of the shoot dry weight and grain yield was more than that of the total consumption of water (Wu *et al.*, 2004). In their experiment on wheat crop exposed to enriched CO₂, under high soil moisture, consumed more water during the entire growing period except the dough stage. Hunsaker *et al.* (2000) observed a small decrease in ET of well watered wheat crop grown under high soil N and elevated CO₂ conditions. The higher yields under enriched CO₂ along with small decrease in water consumption (ET) is expected to enhance the WUE of the crop. There is an evidence of reduced growth at elevated CO₂ due to reduced stomatal conductance and this instantaneous response is maintained with time.

Polley (2002) opined that with increase in CO₂ concentration the fraction of available water used by crops is likely to increase because of faster canopy closure and greater root growth. However, Kammann *et al.* (2005) reported no significant trend towards the higher soil moisture under CO₂ enrichment since the start of the experiment. However, in the final year they observed a small trend towards water saving and this impact more this became more conspicuous when the upper soil layer dries out. As compared to the ambient soil, the soil under enriched CO₂ was found to be wetter. Many studies has reported that due to the increased soil moisture the plants under enriched CO₂ environment are temporarily free from water stress. (Widodo *et al.*, 2003; Zavaleta *et al.*, 2003; Li *et al.*, 2004). However, Niklaus and Korner (2004) reported that effects of elevated CO₂ may attenuates due to reduction of soil water availability induced by warming effect of carbon dioxide.

The rapid increase in plant growth under elevated CO₂ might cause a depletion of other plant growth resources (Koch and Mooney, 1996; Pospisilova and Catsky, 1999). The warming due to elevated CO₂ may increase the evapotranspiration which in turn depletes the soil moisture. Dermody *et al.* (2008b) found that soil moisture contents were lowest when seasonal temperatures were greatest. Hunsaker *et al.* (1994) in their experiment conducted in FACE measured the ET from cotton crop using three independent approaches: energy balance (Kimball *et al.*, 1994), soil water balance and sap flow gauges (Dugas *et al.*, 1994), they reported that ET did not significantly change with increasing CO₂ concentration to 550 $\mu\text{mol mol}^{-1}$ level. However seasonal ET was found to (estimate using soil water balance) increased by an average of 4.8 and 0.9% under water-stress conditions and reduced by 4.5 and 5.8% in a well-watered treatment for the two years, respectively (Hunsaker *et al.*, 1996). Sarker and Hara (2009) observed that *egg plants* grown in enriched CO₂ and soil water shortage condition environment might be use water efficiently. Schapendonk *et al.* (1997) though the average water use efficiency was augmented at enriched CO₂, but this increased WUE is fully compensated by the higher LAI due to elevated CO₂ that results into equal total transpiration from both the elevated and ambient carbon dioxide concentrations.

Overall, the effects of warming and soil moisture were more influential on species and community-level responses than were the effects of elevated CO₂ (Engel *et al.*, 2009). Saha *et al.* (2011) reported lower soil moisture content for enriched CO₂ as compared to the ambient level and they also found that the difference was prominent at 30–45 cm soil depth in which consistently lower soil moisture content was observed under elevated CO₂ enrichment. Since the pigeon pea under elevated CO₂ extracted more moisture than the ambient treatment, higher transpiration rates were observed elevated CO₂ conditions. Hui *et al.* (2001) also reported 26% increase in water-use efficiency (WUE) in sunflower under elevated CO₂ in ecocells. Overall, depending on the species, temperature and the experimental conditions both increase and decrease in WUE are reported under elevated CO₂ concentrations.

2.2. Increase in Ozone concentration in earth's atmosphere

Ozone (O₃) is an important component of tropospheric and stratospheric layers of the atmosphere. Only 10% of ozone is present in the troposphere and rest of the 90% of total ozone is present in stratosphere (Lelieveld and Dentener, 2000). Ozone present

in the lower 1.5-2 km troposphere is referred as surface ozone. It forms naturally in stratosphere and shields earth from harmful UV radiations. In troposphere ozone is generated via series of photochemical reactions. Surface O₃ is projected to increase to a level of 40 ppb in the Northern Hemisphere (Meinshausen *et al.*, 2006). The projections also suggested an increase of 20-25% of ozone level by 2050 in the northern hemisphere.

2.2.1 Crop response to elevated ozone

There are number of evidences that in many areas of the world current ambient ozone concentrations are sufficiently high to induce significant yield reduction in crops such as soybean (Morgan *et al.*, 2003), wheat (Wang *et al.*, 2007), and rice (Ainsworth *et al.*, 2008).

Ozone produces reactive oxygen species (ROS), that may effects the structure and function of the cell membranes (Gillespie *et al.*, 2011). Prolonged exposure to elevated O₃ of led to development of injury symptoms in crop plants such as interveinal yellowing or chlorotic stippling (Picchi *et al.*, 2010; Sarkar and Agrawal, 2010). Significant reduction is observed, even at low levels of ozone, in the photosynthesis, growth and yield of various species. (Ormrod, Black and Unsworth, 1981; Heck *et al.*, 1982, Reich; 1983; and Reich and Amundson, 1984). Bhatia *et al.* (2013) reported that in maize elevated ozone significantly decreases the LAI, growth attributes, leaf and shoot biomass, and the yield attributes of the crop. Potato plants exposed to elevated ozone showed a faster decrease of chlorophyll content (Bindi *et al.*, 2002) and LAI (Hacour *et al.*, 2002), which has also been confirmed in wheat (Feng *et al.*, 2008). Zhang *et al.* (2014) reported that at both flowering and seed feeling stage of soybean enriched ozone significantly reduces chlorophyll and carotenoid contents, however chlorophyll a/b ratio remains unaffected. Ozone uptake in plants occurs mainly through stomatal openings (Long and Naidu, 2002). Hence the ozone uptake by the plants is chiefly governed by the stomatal conductance. This is shown by number of experiments with crops exposed simultaneously to elevated atmospheric CO₂ and O₃, which showed reduced injury due to ozone, apparently due in large part exposed to lowered Ozone flux (Fiscus *et al.*, 2002; Morgan *et al.*, 2003; Booker *et al.*, 2005).

Major factors controlling Stomatal conductance are vapour pressure deficit between leaf and surrounding air, photosynthetic photon flux density (PPFD), leaf temperature, soil water availability, growth stage of plant and atmospheric CO₂ concentration (Jarvis, 1976). Crop in warm and humid environments have higher conditions stomatal conductance in comparison to crops of hot and dry climate, hence crops of humid environment are likely to have more risk of ozone injury. Massman (2004) reported that some crops having similar stomatal conductance show different tolerance level to similar ozone concentrations. Linear decline in leaf conductance in soybean was observed on frequent exposure of the crop to low levels of O₃ but the effects are not well known on stomata for relatively low concentrations of ozone (Reich and Amundson., 1984). WUE and stomatal conductance were found to decrease by O₃ treatment in hybrid poplar (Reich and Lassoie, 1984).

Elevated ozone is found to have marked impact on various physiological parameters of plants like stomatal function photosynthesis, respiration and carbon allocation. (Darall, 1989). Photosynthesis is extremely sensitive process to elevated ozone stress and found to be suppressed well before the appearance of visible injury symptoms (Furukawa, 1991). The inhibitory effect of ozone on photosynthesis is result of its impact on chlorophyll content and the ETS cycle in PS-I and PS-II (Heath, 1994). Heath (1994) also reported that 20 ppb to 100 ppb of ozone may reduce the photosynthesis by 5% to 80%. The rate of respiration was found to increase in different plants under ozone stress. (Pell and Brenman, 1973). After the visible injury symptoms, excessive energy is required for the repairing of damaged cells which enhances the rate of respiration in plants (Heath, 1994), but enhanced respiration was observed in *Lycopersicon esculentum* even in absence of visible injury (Dugger and Ting, 1970). Elevated ozone causes oxidative damage of biological membranes especially chloroplasts which reduces photosynthesis and decreases the dry matter production. (Karberg *et al.*, 2005). Ozone stress also affects the carbohydrate, lipid metabolism as well as the protein content in plants (Heath, 1994).

Different type of foliar injury symptoms were exhibited by different plants in response of ozone injury. Ashmore and Marshall (1998) opined that sometimes a marked change in various growth and yield parameters may be observed without any visible injury symptom on crops, like Ollerenshaw *et al.* (1999) reported that in oilseed rape and wheat no visible plant injury were found but flowering and seed yield was

found to decrease by 38% and 14% respectively in oilseed rape and, straw and grain yield of winter wheat was dropped by 8% and 13% respectively. The severity of injury caused by enriched ozone depends on a number of factors including ozone concentration, weather conditions, and exposure duration and growth stage of the crop and plant genetics. Plants exposed to ozone experiences an early senescence (Fuhrer *et al.*, 1997). Though under elevated O₃ causes accelerated canopy senescence which reduces radiation interception, however the principal effect of ozone on biomass is due to the reduction in radiation conversion (Dermody *et al.*, 2008b).

Elevated ozone significantly affected the shoot length of wheat (Feng *et al.*, 2007) and maize (Bhatia *et al.*, 2013). Grain yield of maize was also found to reduced significantly under elevated ozone concentration. This results match the findings of Rudorff *et al.* (1996) they reported reduced corn grain yield in response damage caused by ozone during flowering. Elevated ozone causes oxidative damage of biological membranes especially chloroplasts which reduces photosynthesis and decreases the dry matter production (Karberg *et al.*, 2005). Wang *et al.* (2008) reported significant decrease in total dry matter of *Brassica napus* plants with increase in ozone concentration. Sudhakar *et al.* (2008) reported 20% reduction in dry matter in tomato plants when exposed to enriched O₃ environment. Kharel and Amgain (2010) found that seed dry weights, total seeds per plant, test weight, total above-ground biomass, harvest index and shelling percentage in mung bean is reduced under elevated ozone. Sarkar and Agrawal (2010) have shown reductions in total biomass of wheat plants under elevated concentrations of O₃. Agrawal *et al.* (2005) and Rai *et al.* (2007) also observed significant decrease in biomass of mung bean and wheat plants respectively under ambient ozone. Presence of higher ozone levels make the plant weak and susceptible to pest attack which results in a complete loss of yield. growth parameters of wheat were also found to decreased significantly under enriched ozone concentrations (Sarkar and Agrawal, 2010). Avnery *et al.* (2011) estimated the reductions of global yields ranging from, to 3.9-5% for wheat, 2.2-5.5% for maize and 8.5-14% for soybean.

2.2.2 Effect of elevated ozone on RUE and WUE

In soybean plants exposed to elevated O₃ concentration a significant decrease in RUE has been observed (Unsworth *et al.*, 1984 and Leadley *et al.*, 1990). Reich and Lassoie (1984) reported a similar result for poplar plants under low level of ozone enrichment.

Zhang *et al.* (2014) in his study with soybean under elevated ozone also reported a significant decrease in WUE. Radiation use efficiency (RUE) of wheat was found to decrease significantly in response to ozone and increases in response to CO₂ enrichment (Rudorff *et al.*, 1996).

2.3.1 Interaction effect of elevated ozone and carbon dioxide

Limited work has been done on the interactive effects of ozone and carbon dioxide. Mulchi *et al.* (1992) opined that the combined effects of elevated O₃ and CO₂ on soybean yield were largely additive. Rudorff *et al.* (1996) reported reductions in both dry biomass and grain yield were much smaller in response to O₃ exposure when plants were grown under combined ozone and carbon dioxide. The counteracting effect of CO₂ enrichment against O₃ induced stress was also observed in wheat (Rudorff *et al.*, 1996), soybeans (Mulchi *et al.*, 1992) and radish (Barnes and Pfirrmann, 1992). When O₃ and CO₂ were elevated in combination, and the negative impact of O₃ is partially counteracted by the elevated CO₂. Elevated CO₂ was able to counter the negative effect of O₃ on growth and yield parameters of maize to a certain extent (Bhatia *et al.*, 2013). In maize shoot length, grain yield and other yield parameters were found to increase under the combined treatment of ozone and carbon dioxide as compared to enriched ozone alone. Fiscus *et al.* (2002) reported that in soybean the seed yield is significantly increase under elevated CO₂ and a significantly decreased under elevated ozone treatment. All the above studies provides a strong evidence that the negative impact of ozone on crop growth were counteracted by elevated carbon dioxide.

3. MATERIAL AND METHODS

In order to achieve the research objectives, field experiments on chick pea under elevated ozone, carbon dioxide and their interaction were conducted during the *rabi* season (November-April) of 2016-17. The details of the materials used and methods adopted during the course of present investigation are given below.

3.1 Field Experiments

3.1.1 Details of the experimental site

The present study was carried out in the FAOCE (Free Air Ozone and Carbon dioxide Enrichment) facility of CESCRA at ICAR-Indian Agricultural Research Institute, New Delhi, 28°35' N latitude, 77°12' E longitude and at an altitude of 228.16 m above mean sea level.

3.1.2 Climate

The climate of ICAR-IARI is sub-tropical to semi-arid with hot and dry summer and colder winter seasons. Summers are long (early April-August) with monsoon setting in between (July-September). It included under agro climatic zone 'Trans-Gangetic plains'. May and June are the warmest months for the period of summer and diurnal temperature ranges from 40°C - 46°C. Highest daily maximum temperature (46.8°C) was recorded on 29th May, 1998. In winter season, coldest month is January where mean daily minimum temperature ranges about 6°C to 8°C. Lowest daily minimum temperature (-1.4°C) was recorded on 9th January, 2006. Annual mean rainfall is 710 mm and July-August are the wettest months during entire year. 80% of the annual rainfall is received from south-west monsoon during July to September (common date of onset of monsoon at Delhi is 29th June). The rest amount of rainfall is obtained from "Western Disturbances" during winter seasons (December to February). Mean values of meteorological parameters (except rainfall) recorded at the ICAR-IARI agro meteorological observatory during the *rabi* season 2016-17 are presented in the Table 1.

Table 3.1: Weekly weather data during *rabi* season 2016-17 recorded at agromet observatory of ICAR-IARI, New Delhi

SMW	Date	Tmax	Tmin	EP	RAINFALL	AWS	BSS	RH(M)	RH(E)
		°C	°C	mm	mm	km h ⁻¹	hrs	%	%
46	12-18 Nov	28.2	8.5	3.3	0.0	2.5	0.9	90.7	35.4
47	19-25 Nov	28.6	7.3	3.9	0.0	2.7	4.5	87.4	32.3
48	26-02 Dec	28.2	8.8	4.8	0.0	5.1	5.8	82.1	45.9
49	03-09 Dec	24.4	5.1	3.0	0.0	1.9	4.6	96.7	50.1
50	10-16 Dec	24.4	6.3	2.8	0.0	2.9	5.4	95.0	51.1
51	17-23 Dec	23.0	4.3	3.1	0.0	4.3	5.9	90.6	40.6
52	24-31 Dec	20.7	5.4	2.3	0.0	3.8	3.2	92.3	56.4
1	01-07 Jan	22.9	9.2	2.1	0.7	2.8	4.7	96.6	58.1
2	08-14 Jan	17.6	4.2	2.0	0.0	3.6	4.7	92.4	46.9
3	15-21 Jan	18.7	6.2	2.4	0.0	4.9	4.3	91.4	54.7
4	22-28 Jan	21.5	10.6	2.1	8.5	4.3	2.8	95.0	67.9
5	29-04 Feb	21.5	8.6	2.8	0.0	3.3	5.6	96.6	61.6
6	05-11 Feb	21.6	9.1	3.5	0.0	5.2	5.7	94.1	50.9
7	12-18 Feb	22.8	9.5	4.0	0.0	4.1	6.8	92.6	54.9
8	19-25 Feb	26.9	12.2	4.7	0.0	6.0	8.2	85.6	39.4
9	26-04 Mar	27.5	11.0	4.8	0.0	4.9	7.5	83.7	41.6
10	05-11 Mar	26.7	12.1	4.8	2.1	6.3	7.5	82.7	49.6
11	12-18 Mar	25.4	9.6	4.7	0.7	4.3	8.4	93.1	47.3
12	19-25 Mar	32.4	16.3	5.8	0.0	4.6	8.3	85.6	40.0
13	26-01 Apr	36.4	20.4	6.4	0.0	7.3	9.3	75.7	40.3
14	02-08 Apr	35.3	19.5	6.6	1.1	7.7	7.4	76.3	42.7
15	09-25 Apr	36.7	18.8	7.6	0.0	7.3	9.8	64.1	41.1

3.1.3 Soil

Soil physico-chemical properties

3.1 Mechanical composition of soil

The sand, silt and clay percentage were estimated using hydrometer method (Bouyoucos, 1962), and texture was determined using the textural triangle proposed by USDA.

Bulk density (BD)

Core sampler was used to collect undisturbed soil samples from desired depths (0-15 and 15-30 cm). The soil samples were dried in hot air oven at 105 °C for 48 hrs. Bulk density (Mg m^{-3}) was calculated using the following formula (Veihmeyer and Hendrickson, 1948):

$$\text{BD} = (X - Y) / V$$

Where, X = weight of core with oven dry soil

Y = weight of core

V = volume of core.

Soil reaction (pH) and electrical conductivity (EC)

For determination of soil pH was 1:2.5 (w/v) soil-water suspensions is prepared and pH was measured using combined electrode. The supernatant was used for estimation of EC using a conductivity bridge (Jackson, 1973) and expressed in dSm^{-1} .

The soil of the experimental site belongs to of Indo-Gangetic alluvium. The Surface and subsoil texture ranges from sandy loam to loam. A representative soil samples were collected from this site and analyzed for physico-chemical properties (Table. 2). The soil is poor in available nitrogen and medium in organic carbon content and available P.

Table 3.2: Soil physico-chemical properties of the experimental site

S. No.	Particulars	Content
Physical characteristics		
A)	Sand (%)	62.5
	Silt (%)	25.8
	Clay (%)	11.7
	Textural class	Sandy loam
	Bulk density(0-15 cm soil) (g cc ⁻¹)	1.58
Chemical characteristics		
B)	Organic carbon (%) (Walkley and Black,1934)	0.52
	Available nitrogen (N kg ha ⁻¹) (Subbiah and Asija, 1956)	179.6
	Available phosphorus (P kg ha ⁻¹) (Olsen <i>et al.</i> , 1954)	21.6
	Available potassium (K kg ha ⁻¹) (Flame photometer method, Hanway and Heidel, 1952)	275.0
	pH (1:2.5 soil: water)	8.2

Experimental details

The circular rings of Free Air Ozone and Carbon dioxide Enrichment (FAOCE rings) fixed in the field were used for the experiment. Ozone ring are equipped with sensor module, duct line to discharge ozone into ozone rings in line data monitoring facilities for CO₂, ozone, wind speed, wind direction, temperature and humidity and computerize data logging facilities. Horizontal SS pipes or ducts are used in hexagonal structure for ozone release in rings. Ozone sampling tube is placed at three different locations in ozone ring to pull air sample through air pump for determination of ozone concentration in each ring on real time basis. High volume air blower (5000 cfm) is used to discharge ozone through ozone generator inside ring



Plate 1. Experimental site (FAOCE facility at CESCRA, ICAR-IARI)

3.2 Crop

The circular rings of FAOCE fixed in the field used for the experiment and foundation seeds of chick pea namely, Pusa-5023 (Kabuli type), are procured from National Seed Corporation, New Delhi, the seeds treated with the fungicide captan @ 2g kg⁻¹ seed and then with Rhizobium @ 12g kg⁻¹ seed and were sown on 16th Nov, 2016 in well prepared soil of the FAOCE rings with a row to row 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. Weeding was done manually in each plot as and when needed. Moderate irrigation (20 mm) was given to avoid drought stress on the crop. The brief characteristics of the variety is given below.

Pusa 5023 (Pusa Shaktimaan) is a *kabuli* chick pea variety developed at ICAR-IARI, New Delhi and release for Delhi NCR region, it is moderately resistant against fusarium wilt and dry root rot, it has an excellent cooking quality, attractive and extra-bold seeded size with average yield of 25.30 q ha⁻¹ in Delhi.

3.5 Experimental Layout

• Cultivar	Pusa 5023
• Date of sowing	16 th November, 2016
• Design	CRD
• Ring size	6 m diameter
• Number of treatments	4
• Number of replications	4

Treatments:

• ECO	Elevated CO ₂ (550 ppm) + elevated O ₃ (70 ppb)
• EC	Elevated CO ₂ (550 ppm) + ambient O ₃ (30 ppb)
• EO	Elevated O ₃ (70 ppb) + ambient CO ₂ (400 ppm)
• AMB	Ambient CO ₂ (400 ppm) + ambient O ₃ (30 ppb)

Carbon dioxide and Ozone: Generation and measurement

The elevated CO₂ concentrations were maintained inside the rings using high pressurized cylinders containing CO₂ with the help of ducts around the rings using an automatic monitoring system, ozone was also supplied using highly pressurized ozone cylinder using pressure pipes and ducts around the rings. Air was sampled automatically from the middle of each ring at canopy level and fed to an ozone and carbon dioxide analyzers which measure the ozone concentrations daily from 0700 to 1830 hours. The sensors installed reads and maintains the elevated concentrations of elevated carbon dioxide and ozone.

3.7 Observations schedule

The observations were recorded and measured for different micrometeorological and biophysical at 10 days interval.

3.7.1 Weather parameters

Different weather data parameters like minimum and maximum temperatures, morning and evening relative humidity (RH), wind speed, bright sunshine hours (BSS), evaporation and rainfall were collected from the agro meteorological observatory of the Division of Agricultural Physics, ICAR-IARI, New Delhi.

3.7.2 Crop parameters

3.7.2.1 Crop phenology

Crop phenology was monitored twice in a week, by observing the plants in the field and the following phenological events were observed:

- a) 50% germination (50% seedlings emerged).
- b) Flowering
- c) Pod development
- d) Physiological maturity- when all leaves senesced

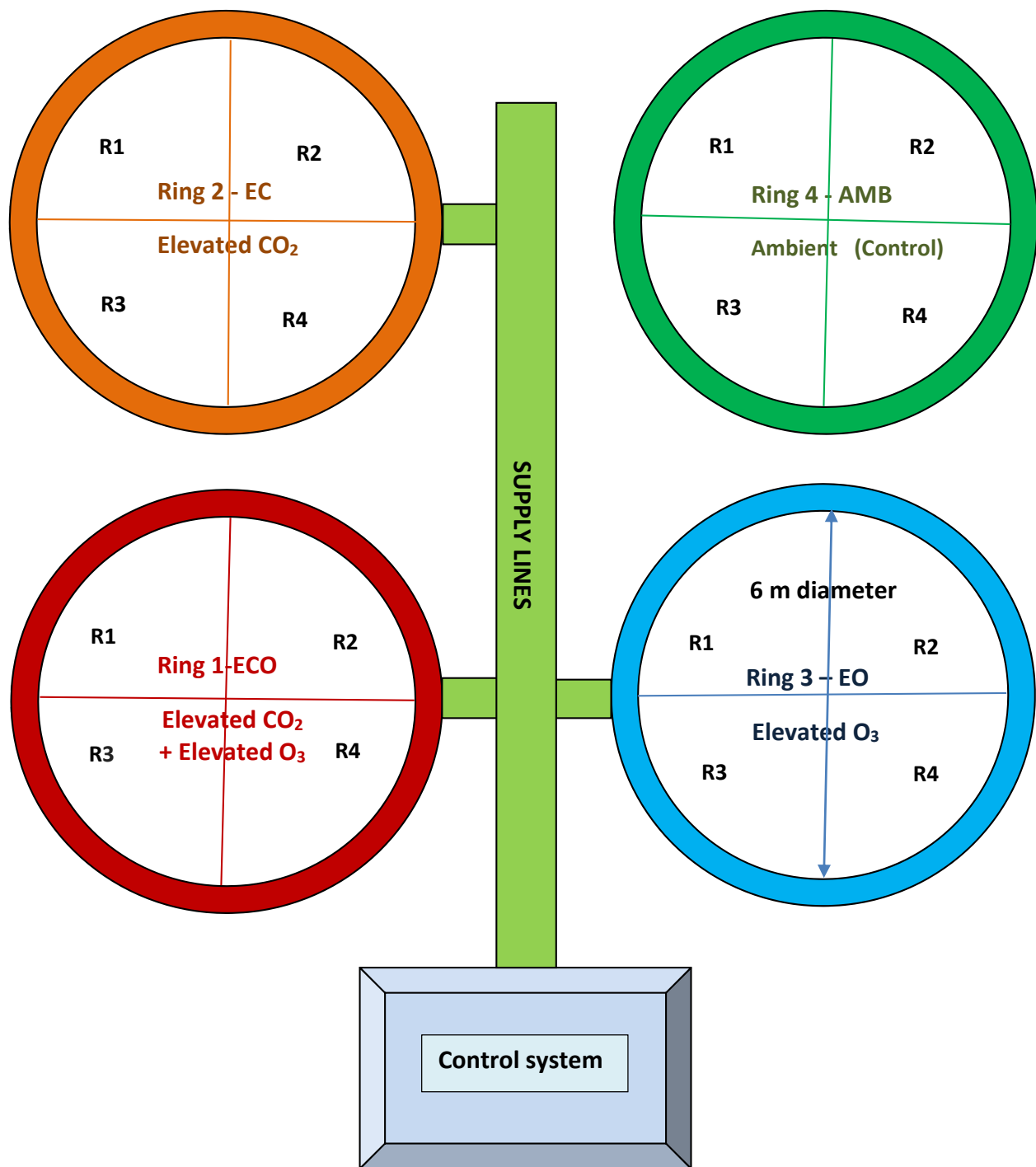


Figure 3.1. Layout of experiment for chick pea crop under elevated O_3 and CO_2

3.7.2 Plant bio-physical parameters

Different biophysical parameters like leaf area index (LAI), biomass were recorded at 10 days intervals.

3.7.2.1 Biomass accumulation

Plant biomass was measured at regular intervals of 10 days. Randomly four plants were selected from each quadrant of the ring and the stem is cut at ground level. Plants were oven dried at $60^{\circ} \pm 5^{\circ}$ C for 48 hours and weighted by using digital balance.

3.7.2.2 Leaf Area Index (LAI)

LAI was measured at 10 days interval by using LAI- 2000 Plant Canopy (LAI-2000, Li-COR, and Lincoln, NE, USA). The canopy analyzer estimates LAI indirectly by measuring radiation above and below the canopy. Its optical system measures the blue light interception (below 490 nm) using five detectors at 5 zenith angles ($0-13^{\circ}$, $16-28^{\circ}$, $32-43^{\circ}$, $47-58^{\circ}$, $61-74^{\circ}$) simultaneously. The instrument takes one above and four beneath plant canopy measurements to estimate the LAI. Three LAI readings were averaged for each replication.

3.7.2.3 Plant height

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 sampling at different crop growth stages

To determine the resource use efficiency (radiation and water use efficiency) and for calculating the dry matter partitioning, from each ring above ground plant parts were harvested randomly in triplicate from each quadrant at every 10 days interval (three distinct crop growth stages, viz. initial vegetative, 50% flowering and pod maturity stage).

3.7.3 Leaf chlorophyll determination

For chlorophyll determination fresh leaf samples were collected from different treatments and 100 mg of fresh leaf was weighed accurately using an analytical balance and chlorophyll was extracted by equilibrating it with 10 ml Dimethyl Sulphoxide (DMSO) in a capped vial and keeping at 65 °C in an oven for 3 hours (Hiscox and Israelstam, 1979).the decanted solution is used to obtain the absorbance at 645 and 663 nm wavelength in a Spectronic-20 Spectrophotometer. Absorbance was also taken at 480 nm wavelength for estimating carotenoids content from the equations given by Kirk and Allen (1965). The chlorophyll content of the leaf was calculated using the modified formula given by Arnon (1949). Chlorophyll and carotenoids contents were expressed on leaf weight basis (mg of chl g⁻¹ of leaf fresh weight).

$$\text{Total Chlorophyll} = (8.02A_{645} + 20.2A_{663}) (V/1000 \times W) \quad \dots\dots (4)$$

$$\text{Chlorophyll a} = (12.7A_{663} - 2.69A_{645}) (V/1000 \times W) \quad \dots\dots (5)$$

$$\text{Chlorophyll b} = (22.9A_{645} - 4.68A_{663}) (V/1000 \times W) \quad \dots\dots (6)$$

$$\text{Total carotenoids} = (A_{480} + 0.114A_{645} - 0.638A_{663}) (V/1000 \times W) \quad \dots\dots (7)$$

Where, A₄₈₀, A₆₄₅ and A₆₆₃ are the absorbance at 480, 645 and 663 nm, respectively.

W is the weight fresh leaf sample.

V is the final volume (ml) of the extract.

3.7.4 Relative Leaf Water Content (RLWC)

For estimating the Relative leaf water content was calculated according to the method given by Barrs and Weatherley (1962). For relative leaf water content measurement, the second leaflet from top of the plant (four leaflet from each quadrant of the ring) was taken carefully to avoid any damage. To prevent any moisture loss from the leaves the fresh weight of the leaves were taken as quickly as possible after detaching the leaves from the leaflet. Subsequently, the leaves are saturated by adding enough water and kept for 24 hours for attaining a content



Plate 2. Measurement of Leaf Area Index using Canopy analyser



Plate 6. Measurement of PAR using line quantum sensor



Plate 10. Measurement of profile soil moisture variation using neutron moisture meter

weight by absorbing water. Afterwards saturated leaf weight was recorded and the leaves were dried in the oven at 65 °C and finally dry weight was recorded. The RLWC was recorded at 10 days interval during the growing period. The RLWC was calculated by using the following formula:

$$RLWC = (F - D) \div (S - D) \quad \dots\dots\dots (8)$$

Where, F = weight of fresh leaf (mg)

S = weight of saturated leaf (mg)

D = weight of dry leaf (mg)

3.7.5 Crop Growth Rate (CGR) and Relative Growth Rate (RGR)

The rate of dry matter accumulation per unit land area is called crop growth rate (CGR), which was calculated for chick pea crop at different growth stages at regular time interval. Plant dry matter was calculated at different time interval using electrical balance. After, then CGR (g m⁻² day⁻¹) was estimated for each treatment using the following formula:

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

Where, W₁ and W₂ represents the total dry matter production (g) at time t₁ and t₂, respectively and SA is the land area occupied by plants at the time of sampling.

Relative growth rate (RGR) is defined as the rate of increase of plant dry matter per unit plant material per unit time. Its dimension are expressed as mass mass⁻¹ time⁻¹ and its unit is g g⁻¹ day⁻¹. Biomass was recorded using an electrical digital balance for each ring over a time interval. Averaged over the time interval t₁ to t₂ during which the biomass increases from W₁ to W₂. RGR can be calculated by using the following formula:

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

Where, W₁ and W₂ are total dry weight at the time t₁ and t₂, respectively.

3.7.2.5 Crop Yield and Harvest Index

Yield component analysis

The experiment was completed at the harvesting maturity of the crop when the entire crop was dried and turned yellowish brown at 151 days after sowing. Final biomass, grain yield and other yield parameters viz. pod number, seed number, and number of seeds per pod were recorded on per plant basis. Leaves, stem and pods were separated and their dry weights were recorded using a precise digital balance.

An area of 1 m² was harvested manually from each ring after maturity of the crop and weighed to obtain the final above ground biomass (g m⁻²). Finally, average yield g m⁻² was calculated and converted to kg ha⁻¹. Harvest index (HI) was also calculated by using following formula:

$$\text{HI (\%)} = (\text{Grain yield} / \text{Final above ground biomass}) \times 100$$

3.7.2.6 Hundred seed weight

Hundred seeds were counted for each quadrant by a seed counter in biophysical laboratory. Then seeds were weighed separately for each quadrant on digital balance to obtain the test weight (g).

3.7.2.7 Grain protein content

Crude protein content in the seed flour was calculated using a factor of 6.25 (Clemente *et al.*, 1999) with the N content determined by micro-Kjeldahl method (Bremner, 1960).

3.7.3 Plant photosynthesis, Stomatal conductance and Transpiration

Photosynthesis was measured on the mature leaflets from the top by giving a constant light of 1000 $\mu\text{mol m}^{-2} \text{s}^{-1}$ using LI-6400 system (LICOR, USA). LICOR (LI-6400) system employs the gas exchange principle for the measurement of the plant photosynthesis rate. It consists of a system console, CO₂ analyzer and an interchangeable leaf chambers.

The observations were taken between 10:00 AM to 11:30 AM in the morning.



Plate 5. Measurement of photosynthesis and transpiration rate using IR gas analyser

The leaflet was enclosed in the chamber and the net exchange of CO₂ ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) between the leaf and the atmosphere was measured. Four measurements were taken in each ring at regular time intervals. Internal CO₂ concentration, stomatal conductance (cm s^{-1}) and transpiration ($\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$) were also recorded.

3.7.4 Crop Micrometeorological Parameters

3.7.3.1 Photo synthetically Active Radiation (PAR)

Line quantum sensor (LICOR- 3000, U.S.A.) was used for the measurement of the incoming photo-synthetically active radiation (PAR). It is recorded at the top and bottom of the canopy and reflected PAR from plant canopy as well as from soil was also measured. PAR measurements were taken above the canopy by facing the line quantum sensor towards the sky to obtain incident radiation (I_o) and the sensor was held in inverted position to obtain the radiation reflected from the crop canopy (I_r). Afterwards, transmitted radiation (I_t) was taken at the bottom of the plant canopy by placing the sensor just above the ground level and also another measurement was taken by inverting the sensor at the same position to obtain the reflected radiation from the soil (I_e). These measurements were recorded on clear days around local solar noon (12:00 and 13:00 hours IST) for each ring at 10 days time interval. Different fractions of PAR viz., absorbed PAR (APAR), intercepted photosynthetically active radiation (IPAR) and fraction IPAR (fIPAR) and were calculated using the following formulas:

$$\text{IPAR} = I_o - I_t$$

$$\text{APAR} = (I_o + I_e) - (I_r + I_t)$$

$$\text{fIPAR} = (I_o - I_t) / I_o$$

Where, I_o = Incident PAR at the top of the canopy

I_t = Transmitted PAR at the bottom of the canopy

I_r = Reflected energy flux from plant canopy

I_e = Reflected energy flux from soil surface

3.7.3.3 Canopy temperature

The canopy temperature was measured using a hand-held IR thermometer (AG-42, Telatemp Crop. USA). It is a non-contact method used for measuring canopy temperature as well as canopy air temperature difference (CATD). Data were recorded from an angle of approximately 45° to the horizontal. Care was taken during the measurement to avoid direct view of the instrument towards sun. Data were recorded at 10 days interval at 14.00 hours during the experiments.

3.7.3.4 Air temperature and relative humidity within crop canopy

Air temperature and relative humidity were measured continuously within plant canopy by ATRH sensors installed in the rings.

Study of soil characteristics

3.7.3.5 Soil moisture

Soil moisture at the depth of 0-15 cm was estimated using gravimetric method. It estimates the moisture content on the basis of mass wetness. Soil samples were taken by screw-auger in aluminum cans and fresh weight is recorded immediately. Then the samples were dried in hot air oven at 105°C for 24 hours. The weight of dried samples were recorded along with the can weight to obtain the soil moisture content using the following formula:

$$W (\%) = \{(M_w - M_d) / M_d\} * 100$$

Where, W is percent soil moisture, M_w weight of moist soil before drying and M_d is weight of dry soil after drying in oven.

Soil moisture (v/v) monitoring and WUE

Neutron probe access tube were installed to a depth of 1.5 m in each of the four rings at the centre for monitoring soil moisture. The soil moisture content was monitored at 10 days interval for each 15-cm layer increments (15-30, 30-45, 45-60, 60-75 and 75-90 cm depth) using the neutron moisture meter (CPN 503 DR hydro probe moisture gauge, International INC. USA.). Gravimetric soil moisture content for



Plate 6. Measurement of PAR using line quantum sensor



Plate 7. Measurement of canopy temperature using IR thermometer.



Plate 8. Measurement of surface moisture using screw auger



Plate 9. Bulk density measurement of soil profile for calibration of neutron moisture meter



Plate 10. Measurement of profile soil moisture variation using neutron moisture meter

surface soil (0-15 cm) was also determined at 10 days interval and at harvest by drying moist soil in hot air oven to constant mass at 105°C. All the measurements were carried out in triplicate. For the standard curve a plot of 4 m x 4 m was made near the main rings and is subjected to profile saturation prior to subsequent measurements. The depleting soil moisture content was measured gravimetrically at the specified depths with a screw auger and the neutron probe was calibrated against soil water content determined gravimetrically and bulk density of the soil at the experimental site (Zhang *et al.*, 2000).

Soil moisture depletion rates were calculated and reported as mm day⁻¹. The cumulated depletion was calculated during entire crop growth period. The crop water use was then computed using soil water balance equation. Assuming no drainage occurred as the soil moisture was very less during this period. Water use efficiency (WUE) of the crop was calculated from the regression between biomass and Amount of water used (cm).

3.7.3.7 Radiation Use Efficiency

Angstrom formula ($a=0.32$ and $b=0.46$) was used to estimate the global solar radiation, the bright sunshine hours (BSS) data required was obtained from agro meteorological observatory (ICAR-IARI, New Delhi). The global radiation values multiplying with a factor of 0.48 (Monteith, 1972) gives the daily of incident PAR. Subsequently the daily incident PAR is multiplied with corresponding fIPAR to obtain the daily intercepted PAR (IPAR). The daily IPAR obtained is integrated over the entire growth period total IPAR (TIPAR). Finally, the RUE was calculated for yield and biomass separately using following formula:

$$\text{RUE}_b (\text{g MJ}^{-1}) = \text{Biomass} / \text{TIPAR}$$

$$\text{RUE}_y (\text{g MJ}^{-1}) = \text{Grain yield} / \text{TIPAR}$$

Where, TIPAR – Total intercepted PAR

3.8 Statistical Analysis

The measured data sets were processed for analysis of variance as applicable to completely randomized design, to test differences among the various treatments and their interactions using Statistical Analysis System (SAS).

4. RESULT

4.1. Weather conditions during growth period of chick pea

Chick pea crop was grown during *rabi* season (November-April) of 2016-17. Daily weather data during the growing season, were collected from the ICAR-IARI agro meteorological observatory. Weekly mean values of weather parameters were calculated and analyzed according to standard meteorological weeks (SMW).

4.1.1. Weekly mean maximum and minimum temperatures

During *rabi* season of 2016-17, weekly mean maximum temperature ranged between 17.6°C and 36.7°C (Fig. 4.1). High temperature (36.7°C) was recorded during 15th SMW. Sudden increase in weekly mean maximum temperature was observed in 12th SMW (32.4°C) and in 8th SMW (26.8°C). Lowest mean maximum temperature was observed in 2nd SMW (17.6°C). Initially, at the time of sowing mean maximum temperature was also higher in 46th SMW (28.6°C) during *rabi* season (2016-17).

Weekly mean minimum temperature during *rabi* season 2016-17 (Fig. 1A) followed the different trend and ranged 4.2°C (2nd SMW) and 20.4°C (16th SMW). It was observed that weekly mean maximum temperature was increased in 1st SMW (9.1°C) and 12th SMW (16.2°C) during the crop growth.

4.1.2. Weekly cumulative rainfall

During the growth period, a total rainfall of 92.7 mm was received (Fig. 4.1). A maximum rainfall of 59.8 mm was recorded in 4th SMW and many SMW were rainfall deficit. Moderate rainfall was received in 10th (14.9 mm), 14th (8 mm) SMW. Rainfall was also occurred in 11th (5.0 mm) and 1st (5.0 mm) SMW.

4.1.3. Weekly mean pan evaporation

During the growing season initially the evaporation rate 3.3 mm in the 46th SMW and increases up to 4.8 mm in the 50th SMW and then decreases to 2.10 mm in 1st SMW, after this the weakly pan evaporation follows a linearly increasing trend and attains the highest value of 7.55 mm during the 15th SMW. Total pan evaporation was observed 87.6 mm during entire growing season (Fig. 4.1).

4.1.4. Weekly mean bright sunshine hours

Bright sunshine hours data were recorded and it was observed that during *rabi* season of 2014-15 (Fig. 4.2), weekly mean bright sunshine hours ranged between 0.87 hours (46th SMW) to 9.84 hours (15th SMW). Up to 6th SMW the trend is irregular, however, an increasing trend was observed from 6th SMW to the harvest of the crop. The major drops in bright sunshine hours were recorded in 52nd (3.2 hours) and 4th (2.8 hours) SMW. Two peaks were observed in 13th SMW (9.2 hours) and 15th SMW (9.8 hours).

4.1.5. Weekly mean morning and evening relative humidity (RH)

Weekly mean morning relative humidity (RH) varied to a great extent, during the growing season it ranges from 64.1% to 96.7%, a sudden drop was observed after 12th SMW. Initially it was around 90.7%, but there after certain up and down it reached peak of 96.6% in 5th SMW and thereafter, it decreased till 15th SMW with a peak at 11th SMW (Fig. 4.2). Weekly mean evening RH ranged between 32.2% (47th SMW) and 67.8% (4th SMW) during the growing season. There were peaks on 51th, 4th, 8th, 11th and 14th SMW and continuous increasing trend was noticed between 48th to 1st SMW. After 4th SMW RH decreases up to 41% in 15th SMW, with some peaks in between.

4.1.6. Weekly mean wind speed

Weekly mean wind speed during *rabi* season (2016-17) varied between 1.9 to 7.68 km h⁻¹ (Fig. 4.2). The highest wind speed of 7.68 km h⁻¹ was recorded in 14th SMW and the lowest (1.9 km h⁻¹) in 49th SMW. Three low weekly mean wind speeds (3.3, 3.6 and 3.8 km h⁻¹) were recorded in 5th, 2nd and 52nd SMWs respectively.

4.1.7. CO₂ and O₃ concentration inside FAOCE ring

Daily data of variation of concentration of O₃ and CO₂ are presented in Fig. 4.3. From the data it is revealed 30 ± 10 ppb O₃ and 400 ± 10 ppm CO₂ was there inside AMB treatment (concentration of ambient O₃ and CO₂). Inside the EC treatment ring CO₂ concentration was varying 550 ± 20 ppm and inside EO treatment ring O₃ was varying 70 ± 10 ppb. ECO treatment ring had 550 ± 20 ppm CO₂ and 70 ± 10 ppb O₃.

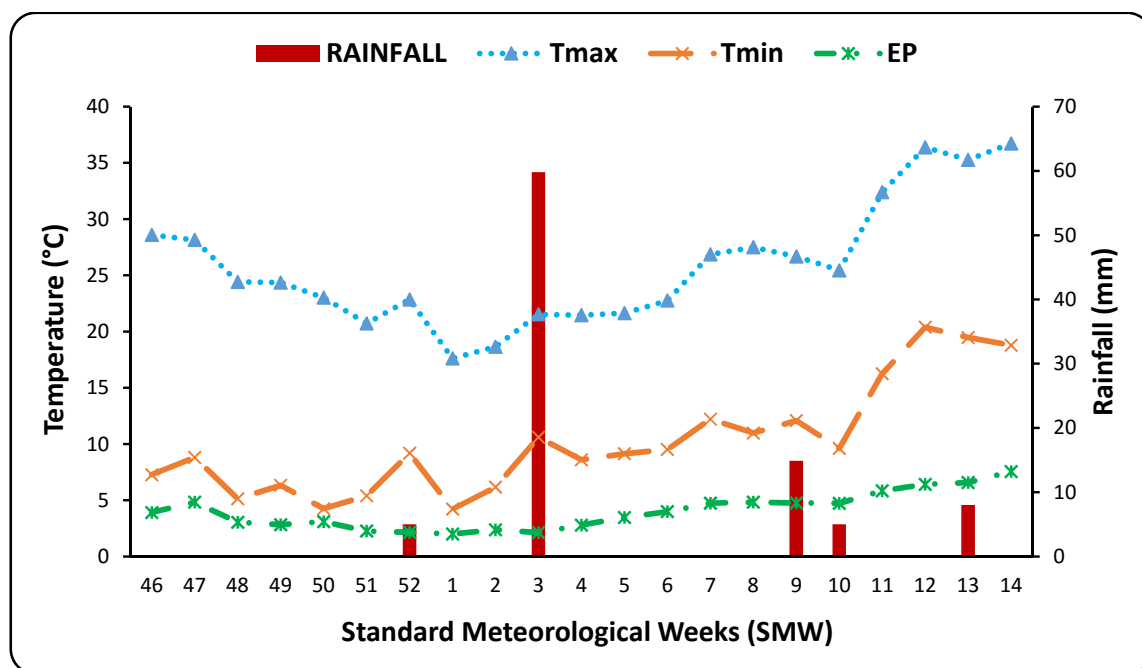


Fig 4.1. Weekly mean maximum temperature, minimum temperature, evaporation and rainfall at ICAR- IARI farm during *rabi* season 2016-2017

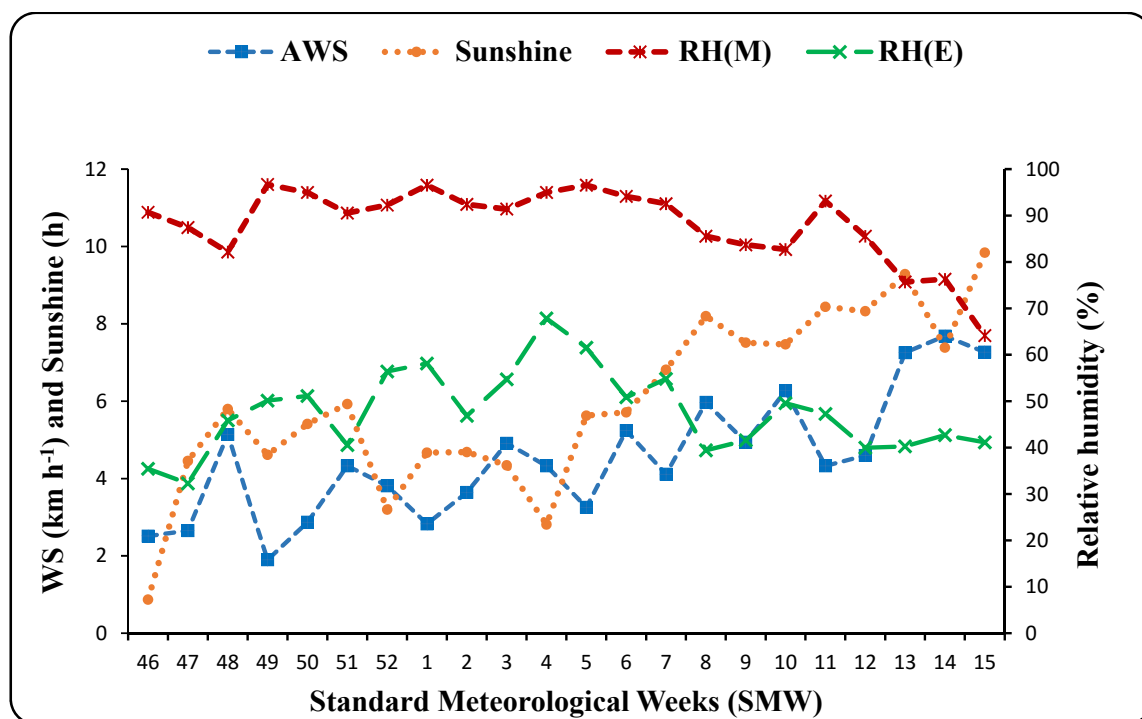


Fig 4.2. Weekly mean wind speed, sunshine hours, morning relative humidity and evening relative humidity at IARI farm during *rabi* season 2016-2017

4.2. Crop micrometeorological and bio-physical parameters

4.2.3. Canopy temperature

Canopy temperature was measured in different treatments during entire crop growth period. Canopy temperature varied among different treatments (Fig 4.4). Only three dates (41, 75 and 85 DAS) are showing significance at $p \leq 0.5$ level of significance. At 75 DAS, it was maximum (21.50°C) in ECO (combination of elevated CO_2 and O_3), followed 20.39°C in EC, 19.20°C in EO and minimum (18.99°C) for ambient condition (Table 4.1). It was continuously increased up to crop maturity. At maturity (around 141 DAS), it was maximum for ECO (36.61°C), followed by EO (33.65°C), AMB (28.24°C), and lowest for EC (33.46°C) though the variation is non-significant.

Canopy Air Temperature Difference (CATD) were also measured in all the treatments (Fig. 4.5). It varied significantly throughout the crop growing season. CATD was lowest in AMB treatment (-1.43 to 2.91°C), followed by EO treatment (-0.01 to 2.90°C), followed by ECO treatment (-0.46 to 2.99°C) and EC treatment (-0.14 to 2.98°C). Initially CATD was negative as crops were exposed in cool temperature and at vegetative stage soils were covered with leaves.

Table 4.1. Temporal variation of canopy temperature ($^{\circ}\text{C}$) in chick pea crop as influenced by different treatments of ozone and carbon dioxide

Treatments	Days after sowing (DAS)									
	41	52	65	75	85	96	111	121	131	141
ECO	20.70 ^A	17.29	22.59	21.50 ^A	20.01 ^A	23.81	25.21	25.24	32.00	36.61
EC	20.26 ^A	17.39	20.56	20.39 ^B	18.54 ^B	23.25	24.13	23.34	29.59	33.46
EO	20.21 ^{AB}	17.04	20.06	19.20 ^C	18.23 ^{BC}	22.78	23.35	24.09	29.50	33.65
AMB	19.66 ^B	16.05	19.39	18.99 ^C	17.69 ^C	22.11	22.41	23.61	28.24	33.81
CV %	1.79	1.49	1.46	1.08	1.97	1.30	0.96	0.85	2.02	1.14
LSD at 5%	0.55	NS	NS	0.33	0.56	NS	NS	NS	NS	NS

4.3. Crop biophysical parameters

4.3.1. Crop phenology

Phenology of the chick pea crop grown in different treatments is presented in table 4.2. During *rabi* 2016-17 sowing was done on 16th November for all treatments in FAOCE ring. Cultivar Pusa 5023 was germinated in 6 - 7 DAS for all treatments. The difference in phenology was observed at 50% flowering stage. There is no variation in phenological stages initially but variation was visible after 42 DAS when treatment (elevated CO₂ and O₃) given inside the ring.

The growth period shortened by about 10 days due to the elevated CO₂ effect and 14 days due to elevated O₃ treatment. The main differentiation was occurred after pod initiation to maturity.

Table 4.2. Chick pea phenology (DAS) of chick pea 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

4.3.2. Leaf Area Index (LAI)

Leaf area index (LAI) of chick pea crop was varied significantly among all treatments at $p \leq 0.5$ level of significance (Fig. 4.6). Initial stages LAI increased during vegetative phase, then reached a peak around 111 DAS and decreased thereafter due to senescence of the crop at maturity. No significant differences among the treatments were observed during initial vegetative (up to 52 DAS) as well as at harvesting stage (141 DAS) of the crop but showed significant variation thereafter (Table 4.3). Highest LAI was recorded is 5.42 in EC (550 ppm CO₂), 5.00 in ECO (550 ppm CO₂ + 70 ppb O₃), 4.57 in EO (70 ppb O₃) and 5.18 for the AMB treatment at 111 DAS. Subsequently, it decreased with crop maturity. The LAI of EC remains significantly higher than all other treatments while EO remains lowest. An increase of 4 to 28 % in LAI of EC and a simultaneous decrease of 7.3 to 23.8 % was recorded in EO, as

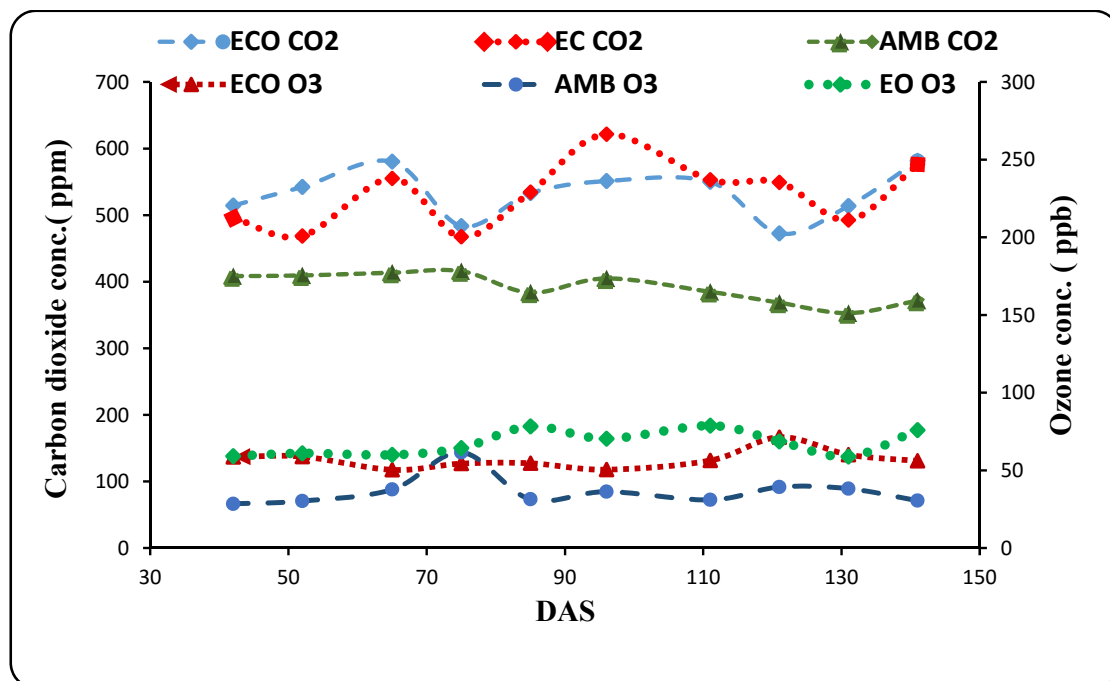


Fig 4.3. Variation in ozone and carbon dioxide concentrations over the growth period of the crop

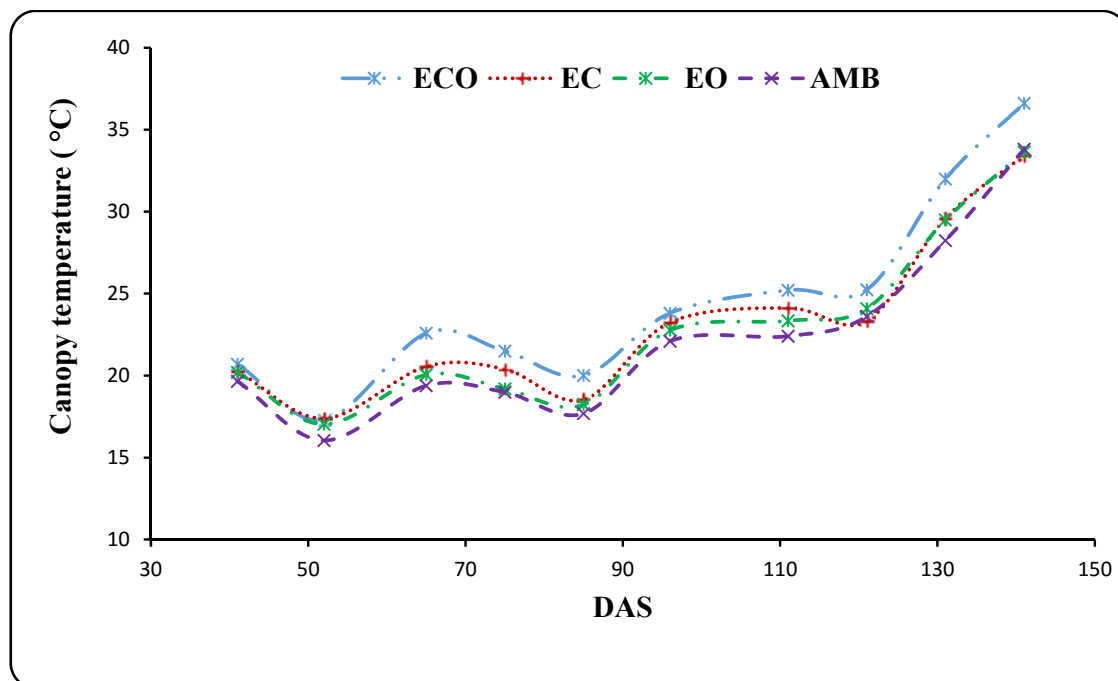


Fig 4.4. Variation of canopy temperature in chick pea under different treatments of ozone and carbon dioxide for the entire growth period

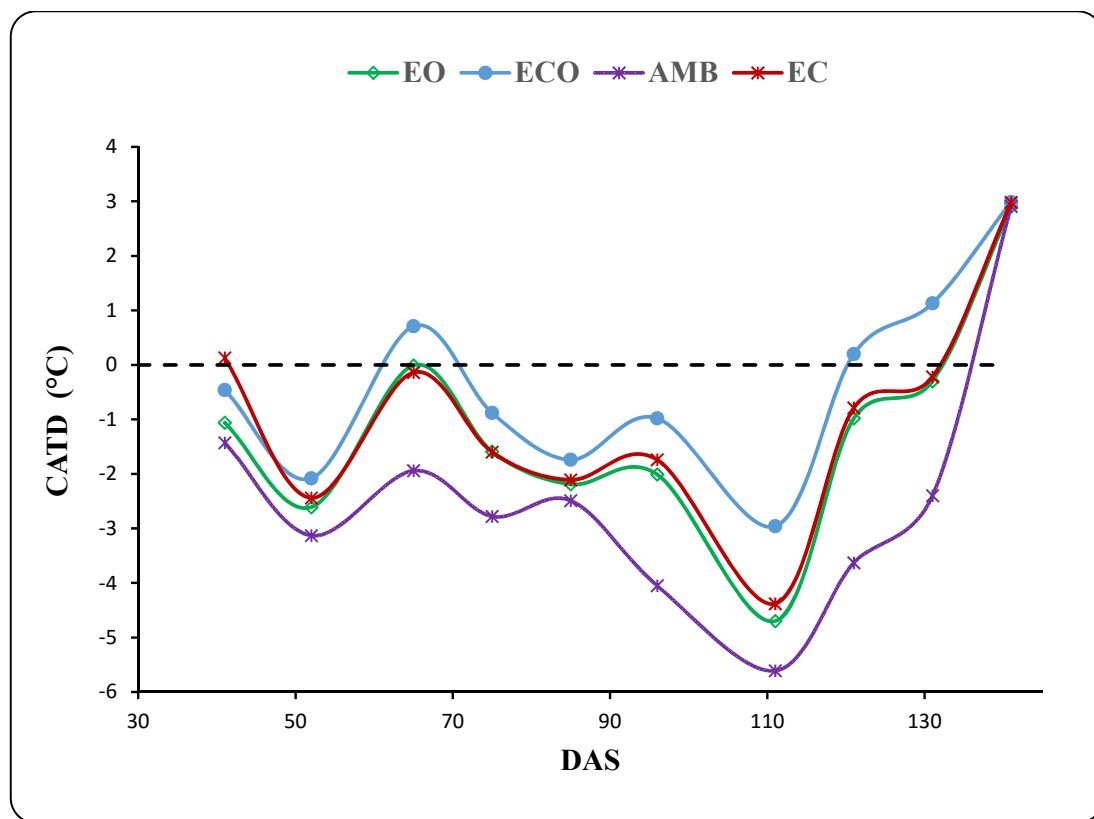


Fig 4.5. Canopy Air Temperature Difference (CATD) in chick pea under different treatments of ozone and carbon dioxide



A. Chick pea crop during initial vegetative growth period



B. Chick pea crop at 50% flowering stage

Plate 11.1. Phenological stages of chick pea



A. Flowering



B. Pod filling



C. Chick pea crop at harvesting stages

Plate 11.2. Phenological stages of chick pea

compared to the AMB treatment. No significant differences were observed between AMB and ECO throughout the growing season of the crop.

Table 4.3. Temporal variation of LAI in chick pea crop as influenced by different treatments of ozone and carbon dioxide

Treatments	Days after sowing (DAS)									
	41	52	65	75	85	96	111	121	131	141
ECO	0.99	1.32	1.94 ^B	2.19 ^B	3.08 ^C	3.99 ^B	5.00 ^B	4.49 ^B	4.07 ^B	2.33
EC	1.23	1.42	2.45 ^A	2.92 ^A	3.80 ^A	4.54 ^A	5.42 ^A	4.87 ^A	4.37 ^A	2.57
EO	0.72	1.28	1.80 ^B	1.83 ^C	2.56 ^D	3.53 ^C	4.57 ^C	3.81 ^C	3.28 ^D	1.81
AMB	0.97	1.45	1.99 ^B	2.27 ^B	3.36 ^B	3.81 ^B	5.18 ^{AB}	4.46 ^B	3.66 ^C	2.29
CV %	8.44	9.84	10.08	4.01	4.15	4.03	3.90	3.08	4.92	7.83
LSD at 5%	NS	NS	0.31	0.14	0.20	0.25	0.30	0.21	0.29	NS

4.3.4. Relative Leaf Water Content (RLWC)

The effect of different treatment of O₃ and CO₂ on RLWC was highly significant for all treatments in *rabi* 2016 -17 (Table 4.4). Crop exposed to ECO (550 ppm CO₂ + 70 ppb O₃) treatment produced significantly highest RLWC (0.77 - 0.99) followed by crops of ambient treatment (0.73 - 0.94), followed by crop exposed to elevated O₃ (0.73-0.90) and followed by EC treatment (0.72 - 0.82). Lowest RLWC measured in crop exposed to elevated CO₂. RLWC was highest at around 85 DAS in all the treatments which coincides with pod formation stage. Afterwards RLWC was decreased with crop maturity and attained the lowest value in all the four treatments (Fig. 4.7).

Table 4.4. Temporal variation (DAS) of Relative Leaf Water Content (RLWC) in chick pea crop as influenced by different treatments of ozone and carbon dioxide

Treatments	Days after sowing (DAS)						
	52	65	75	85	96	111	121
ECO	0.77 ^A	0.85 ^A	0.78 ^A	0.99 ^A	0.99 ^A	0.84 ^A	0.78 ^A
EC	0.73 ^B	0.82 ^B	0.75 ^B	0.94 ^B	0.88 ^B	0.83 ^B	0.76 ^B
EO	0.73 ^B	0.76 ^C	0.74 ^C	0.90 ^C	0.78 ^C	0.79 ^C	0.71 ^C
AMB	0.72 ^B	0.72 ^D	0.63 ^D	0.82 ^D	0.73 ^D	0.76 ^D	0.68 ^D
CV %	6.1	5.0	6.44	7.26	7.79	5.47	5.61
LSD at 5%	0.015	0.01	0.004	0.018	0.01	0.006	0.007

4.3.4. Chlorophyll and carotenoid

Chlorophyll content of leaf was varied significantly ($p \leq 0.5$) in all the four (ECO, EO, EC and AMB) treatments (Table 4.5). The highest chlorophyll (mg chl g⁻¹ of fresh weight) was recorded in crop with elevated CO₂ (1.20 to 3.76 mg chl g⁻¹ of fresh weight) and lowest in crop treated with elevated O₃ (0.87-3.12 mg chl g⁻¹ of fresh weight). Combined treatment of elevated CO₂ and O₃ recorded 0.92-3.72 mg chl g⁻¹ of fresh weight. Highest chlorophyll was measured at 111 DAS in all the four treatments. After 111 DAS chlorophyll content of decreased towards maturity.

At initial stages (75 and 85 DAS) carotenoid content was non-significant after that it varied significantly among different treatments (Table 4.6). As elevated CO₂ and O₃ has negative effect on production of carotenoid, AMB treatment recorded highest (0.05-0.16 mg of carotenoid g⁻¹ of leaf fresh weight) and EO treatment recorded lowest 0.03-0.15 mg of carotenoid g⁻¹ of leaf fresh weight). The carotenoid content was more in 75 DAS and decreased afterward.

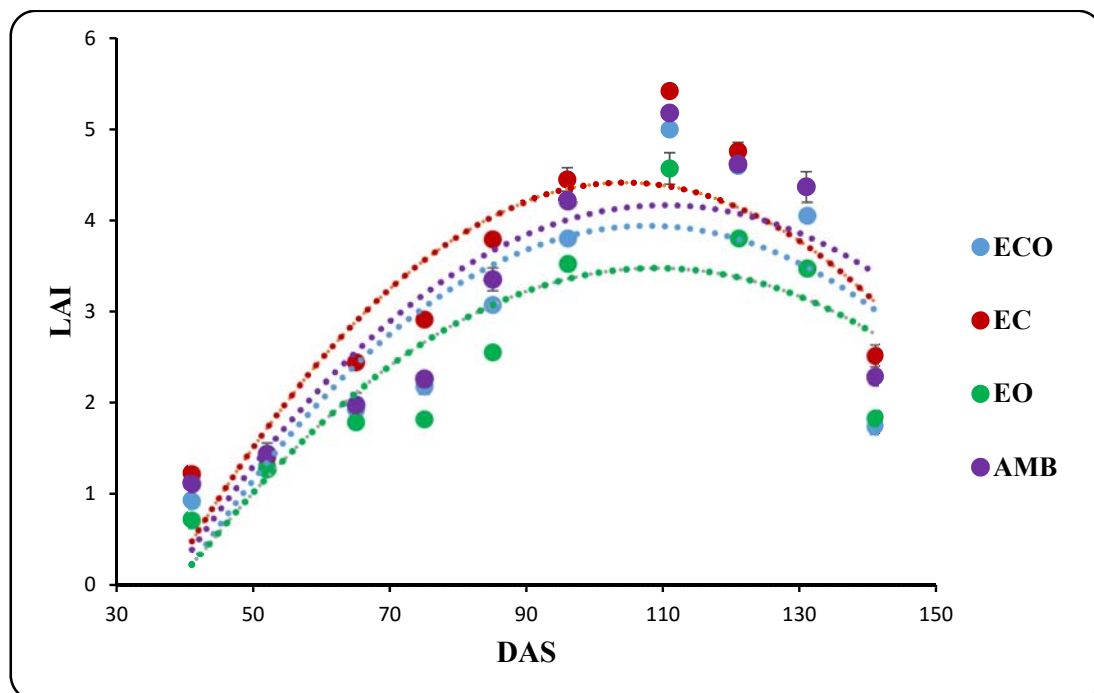


Fig 4.6. Variation in LAI of chick pea under different treatments of ozone and carbon dioxide during the entire growth period

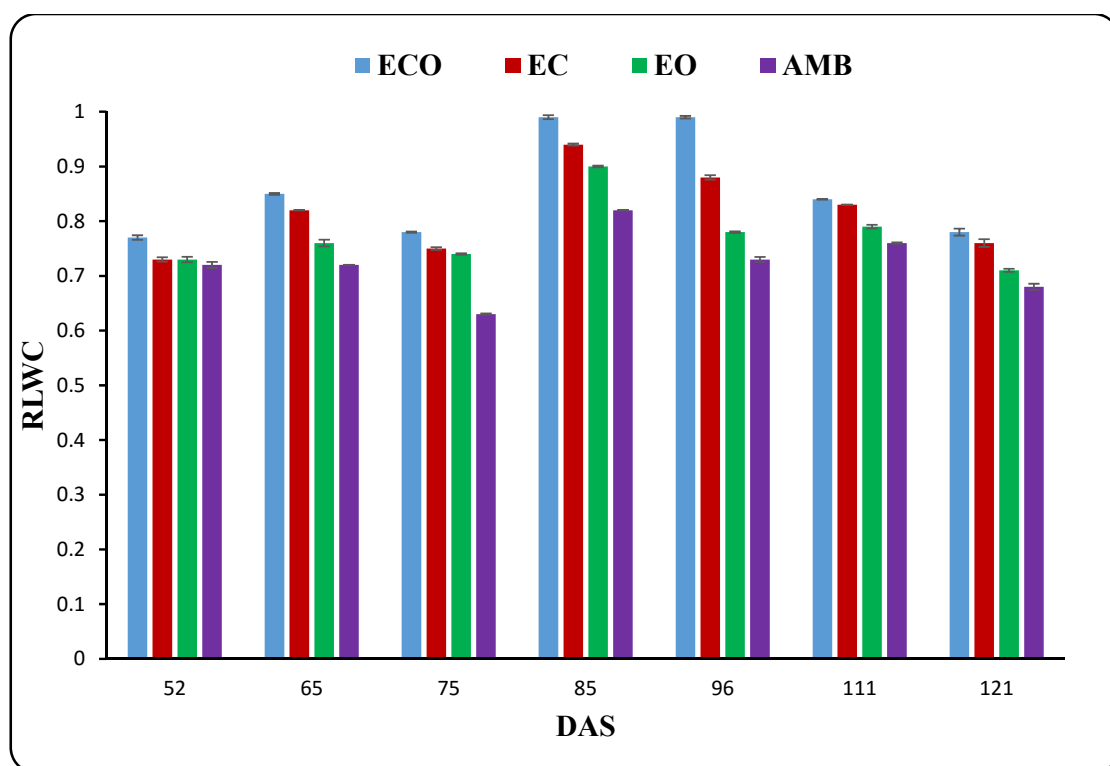


Fig 4.7. Variation in Relative Leaf Water Content (RLWC) of chick pea leaves during the entire growth period

Table 4.5. Temporal variation of chlorophyll (mg of chl g⁻¹ of leaf fresh weight) in chick pea crop as influenced by different treatments of ozone and carbon dioxide

Treatments	Days after sowing (DAS)					
	75	85	96	111	121	131
ECO	0.92 ^C	0.85 ^A	1.38 ^B	3.72 ^A	2.36 ^A	2.21 ^{AB}
EC	1.20 ^A	0.86 ^A	1.54 ^A	3.76 ^A	2.45 ^A	2.52 ^A
EO	0.87 ^C	0.68 ^B	1.00 ^D	3.12 ^B	1.85 ^B	1.64 ^C
AMB	1.03 ^B	0.71 ^B	1.19 ^C	3.54 ^A	2.37 ^A	2.11 ^B
CV %	4.20	6.68	3.24	7.07	8.35	7.17
LSD at 5%	0.065	0.08	0.06	0.38	0.29	0.42

Table 4.6. Temporal variation of carotenoid (mg of carotenoid g⁻¹ of leaf fresh weight) content in chick pea crop as influenced by different treatments of ozone and carbon dioxide

Treatments	Days after sowing (DAS)					
	75	85	96	111	121	131
ECO	0.16	0.07	0.04 ^C	0.03 ^C	0.05 ^B	0.04 ^C
EC	0.15	0.07	0.06 ^B	0.04 ^B	0.05 ^B	0.05 ^B
EO	0.15	0.06	0.03 ^D	0.03 ^C	0.04 ^C	0.03 ^D
AMB	0.16	0.08	0.07 ^A	0.05 ^A	0.06 ^A	0.07 ^A
CV %	4.55	10.42	6.39	9.13	6.82	7.55
LSD at 5%	NS	NS	0.0051	0.0053	0.005	0.0058

4.3.5. Photosynthetic rate, stomatal conductance, intercellular CO₂ concentration, transpiration rate

Different level of CO₂ and O₃ treatment affected significantly photosynthetic rate in chick pea crop in *rabi* 2016-17 (Table 4.7). Highest photosynthetic rate recorded in EC treatment (20.13 – 41.81 μ mol CO₂ m⁻² s⁻¹) and lowest in EO treatment (6.90 – 19.66 μ mol CO₂ m⁻² s⁻¹). The photosynthetic was more at 112 DAS in all the

treatments (except EC treatment where highest photosynthetic rate was recorded at 86 DAS.

During *rabi* 2016-17, stomatal conductance was lowest ($0.15-0.22 \text{ mol m}^{-2} \text{ s}^{-1}$) in ECO ($560 \text{ ppm CO}_2 + 70 \text{ ppb O}_3$) and highest ($0.29 - 0.38 \text{ mol m}^{-2} \text{ s}^{-1}$) in AMB treatment (Table 4.8). Stomatal conductance reached maximum at 65-86 DAS among all the four treatments. EC and EO treatments were recorded in between values $0.25-0.32$ and $0.23-0.28 \text{ mol m}^{-2} \text{ s}^{-1}$.

Intercellular CO_2 concentration was also varied significantly among all the treatments (Table 4.9). The Intercellular CO_2 concentration was more in EO treatment ($266.0 - 442.38 \text{ ppm}$) and lowest in EC treatment ($214.00 - 325.63 \text{ ppm}$) in different growth stages. At 112 DAS intercellular CO_2 concentration was less compare to earlier stages. Highest intercellular CO_2 concentration observed at 65 DAS in EO treatment.

Transpiration rate was significantly varied among all the four treatments (Table 4.10). Highest transpiration rate observed in case of AMB treatment ($2.98 - 5.63 \text{ mmol m}^{-2} \text{ s}^{-1}$) and lowest in case of ECO treatment ($2.19 - 3.06 \text{ mmol m}^{-2} \text{ s}^{-1}$). Transpiration rate was reached at maximum at 86 DAS and decreased at 112 DAS.

Table 4.7. Temporal variation of photosynthetic rate ($\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) in chick pea crop as influenced by different treatments of ozone and carbon dioxide

Treatments	Days after sowing (DAS)			
	55	65	86	112
ECO	14.87 ^B	15.93 ^B	20.54 ^B	23.41 ^B
EC	20.13 ^A	17.91 ^A	41.81 ^A	26.98 ^A
EO	11.89 ^C	12.93 ^C	6.90 ^C	19.66 ^C
AMB	14.71 ^B	15.84 ^B	18.50 ^B	21.20 ^{BC}
CV %	10.12	7.42	10.21	7.03
LSD at 5%	2.40	1.78	3.45	2.47

Table 4.8. Temporal variation of stomatal conductance ($\text{mmol m}^{-2} \text{s}^{-1}$) in chick pea crop as influenced by different treatments of ozone and carbon dioxide

Treatments	Days after sowing (DAS)			
	55	65	86	112
ECO	0.19 ^C	0.22 ^D	0.21 ^D	0.15 ^D
EC	0.25 ^B	0.32 ^B	0.27 ^B	0.29 ^B
EO	0.23 ^B	0.28 ^C	0.24 ^C	0.22 ^C
AMB	0.29 ^A	0.36 ^A	0.31 ^A	0.38 ^A
CV %	6.99	7.73	6.69	16.28
LSD at 5%	0.026	0.0351	0.0263	0.065

Table 4.9. Temporal variation of inter cellular carbon dioxide conc. (ppm) in chick pea crop as influenced by different treatments of ozone and carbon dioxide.

Treatments	Days after sowing (DAS)			
	55	65	86	112
ECO	309.38 ^{AB}	348.38 ^{BC}	288.00 ^B	249.75 ^A
EC	325.63 ^A	298.38 ^C	251.88 ^C	214.00 ^B
EO	288.25 ^C	442.38 ^A	320.13 ^A	266.00 ^A
AMB	305.75 ^B	367.75 ^B	301.38 ^B	255.00 ^A
CV %	3.64	9.59	3.41	7.39
LSD at 5%	17.23	53.78	15.24	28.03

Table 4.10. Temporal variation of transpiration rate (mmol H₂O m⁻² s⁻¹) in chick pea crop as influenced by different treatments of ozone and carbon dioxide

Treatments	Days after sowing (DAS)			
	55	65	86	112
ECO	2.19 ^C	2.28 ^B	3.06 ^C	2.57
EC	3.26 ^B	2.45 ^B	4.94 ^B	2.74
EO	3.45 ^B	2.53 ^B	4.79 ^B	2.66
AMB	4.20 ^A	3.10 ^A	5.63 ^A	2.98
CV %	9.84	8.17	8.49	10.48
LSD at 5%	0.496	0.326	0.602	NS

4.4 Yield attributing parameters, biomass and yield

4.4.1 Plant height

Plant height for different ozone and carbon dioxide treatments during *rabi* season 2016-17 was significant (Table 4.11). Plant height was increased with the increase of CO₂ concentration. Data revealed that in all the growth stages plant height increase was significant. The highest plant height (95.25 cm) was observed in EC at 131 DAS followed by, 93.00 cm in ECO, 76.25 cm in AMB, 71.50 cm in EO treatment. It was observed that plant height was increased up to 131 DAS.

Table 4.11. Temporal variation of plant height (cm) in chick pea 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

4.4.2 CGR and RGR

Crop growth rate (CGR) and relative growth rate (RGR) of chick pea crop under ozone and carbon dioxide treatments at different growth stages during crop are presented in table 4.12. The highest CGR was observed in EC treatment (3.54 - 8.30 g m⁻² day⁻¹), followed by ECO treatment (2.42 - 6.94 g m⁻² day⁻¹), followed by AMB treatment (2.40 - 6.69 g m⁻² day⁻¹) and lowest in EO treatment (2.01 - 5.36 g m⁻² day⁻¹). Among all the treatments highest CGR was observed in 90-120 DAS after that it decreased at 120 - 141 DAS.

Relative growth rate of chick pea crop during crop growing season varied significantly. Similar trend was observed in case of RGR like CGR. The highest RGR was observed in case of EC treatment (288.25 - 443.50 mg g⁻¹ day⁻¹), followed ECO treatment (216.25 - 388.50 mg g⁻¹ day⁻¹), followed by AMB treatment (187.50 - 359.50 mg g⁻¹ day⁻¹) and lowest value in EO treatment (152.75 - 312.00 mg g⁻¹ day⁻¹). RGR value was reached at maximum at 90-120 DAS and decreased thereafter.

Table 4.12: Crop growth rate ($\text{g m}^{-2} \text{day}^{-1}$) and relative growth rate ($\text{mg g}^{-1} \text{day}^{-1}$) of chick pea 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

4.4.3 Biomass accumulation

The effect of different treatment of O_3 and CO_2 on biomass was highly significant for all treatments in *rabi* 2016-17 (Table 4.13). Crop produced highest biomass (734.68 g m^{-2}) in EC (550 ppm CO_2) followed by 662.28 g m^{-2} in ECO (550 ppm CO_2 + 70 ppb O_3), 529.68 g m^{-2} in EO (70 ppb O_3) and 627.95 g m^{-2} in AMB (ambient condition). In all the growth stages crop under elevated CO_2 condition recorded highest biomass accumulation compare to all other treatments (Fig. 4.8). Biomass accumulation in ECO and AMB treatment were statistically at par. Lowest biomass accumulation reduction was observed in EO treatment and it varied from 10.11% to 17.50% over AMB treatment. Highest biomass accumulation gain was observed in EC treatment and it varied from 13.90% to 39.55% over AMB condition.

Table 4.13: Biomass (g m⁻²) of chick pea at critical growth stages of the crop under elevated surface ozone and carbon dioxide treatments

Treatments	Vegetative	50 % flowering	Pod filling	Harvest
ECO	55.43 ^B	359.10 ^B	610.75 ^B	662.28 ^B
EC	66.61 ^A	457.23 ^A	663.83 ^A	734.68 ^A
EO	50.66 ^B	270.33 ^C	496.63 ^C	529.68 ^C
AMB	56.36 ^B	327.65 ^B	582.75 ^B	627.95 ^B
CV%	8.78	5.99	5.43	4.38
LSD at 5%	7.74	32.62	49.26	43.11

4.4.4 Final biomass, grain yield and harvest index

The data on grain yield, final biomass and harvest index of chick pea crop for different level of ozone and carbon dioxide treatments during *rabi* season 2016-17 are given in table 4.14. The final biomass, grain yield and harvest index were significantly different under EC (550 ppm CO₂) than ECO (550 ppm CO₂ + 70 ppb O₃), AMB (ambient condition) and EO (70 ppb O₃). During crop growth season, it was found that final biomass was lowest 5.30 t ha⁻¹ in EO (70 ppb O₃) and highest in EC (560 ppm CO₂) treatment i.e. 7.35 t ha⁻¹. It was also observed that grain yield of ECO (560 ppm CO₂ + 70 ppb O₃) and AMB (ambient condition) were 6.62 t ha⁻¹ and 6.28 t ha⁻¹, respectively. Grain yield was also different for all four treatments. It was found that EC showed highest grain yield (3.24 t ha⁻¹) compare to ECO (2.70 t ha⁻¹), EO (1.92 t ha⁻¹) and AMB (2.46 t ha⁻¹). Yield was 12.76 % more in EC treatment and 7.86% lower in EO treatment compare to AMB treatment. Harvest index was also significantly influenced by different level of O₃ and CO₂ levels. Harvest index was lowest under EO (36.10%), followed by AMB (39.18%), ECO (40.81%) and highest under EC (44.18%). HI was 12.76% more in EC treatment compare to AMB treatment.

Table 4.14: Yield and harvest index of chick pea crop under elevated surface ozone and carbon dioxide treatments.

Treatments	Biomass		Yield		HI	
	t ha ⁻¹	% change	t ha ⁻¹	% change	%	% change
ECO	6.62 ^B	+5.41	2.70 ^B	+9.75	40.81 ^B	+4.16
EC	7.35 ^A	+17.04	3.24 ^A	+31.70	44.18 ^A	+12.76
EO	5.30 ^C	-15.61	1.92 ^C	-21.95	36.10 ^C	-7.86
AMB	6.28 ^B	-	2.46 ^B	-	39.18 ^B	-
CV%	4.38		8.56		4.52	
LSD at 5%	0.43		0.34		2.79	

4.4.5 Yield attributes

The data on yield attributes of chick pea crop for different level of ozone and carbon dioxide treatments during *rabi* season 2016-17 are given in table 4.15. A significant result obtained in different yield attributing characters. Number of pods per plant was significantly varied under different treatments. EC recorded highest number of pods per plant (37), followed by ECO (32), followed by AMB (28) and lowest value obtained in EO (22). A 32.14% increase was obtained in EC compared to AMB treatment (Fig. 4.9).

Pod weight per plant was varied significantly among different treatments. Pod weight per plant was more in EC (23.06 g) followed by Eco (19.48 g) followed by AMB (16.30 g) and lowest in EO (14.04 g). Statistically ECO and AMB were at par. There was an increase of 29.55% in EC over AMB treatment.

Highest seed weight per plant was recorded in EC treatment (21.50 g) and lowest in EO treatment (12.80 g). In between value of seed weight per plant was observed in 18.60 g in ECO and 16.30 g in AMB, respectively. Elevated O₃ reduced seed weight per plant by 21.48% over ambient and elevated CO₂ increased the seed weight per plant by 31.90%.

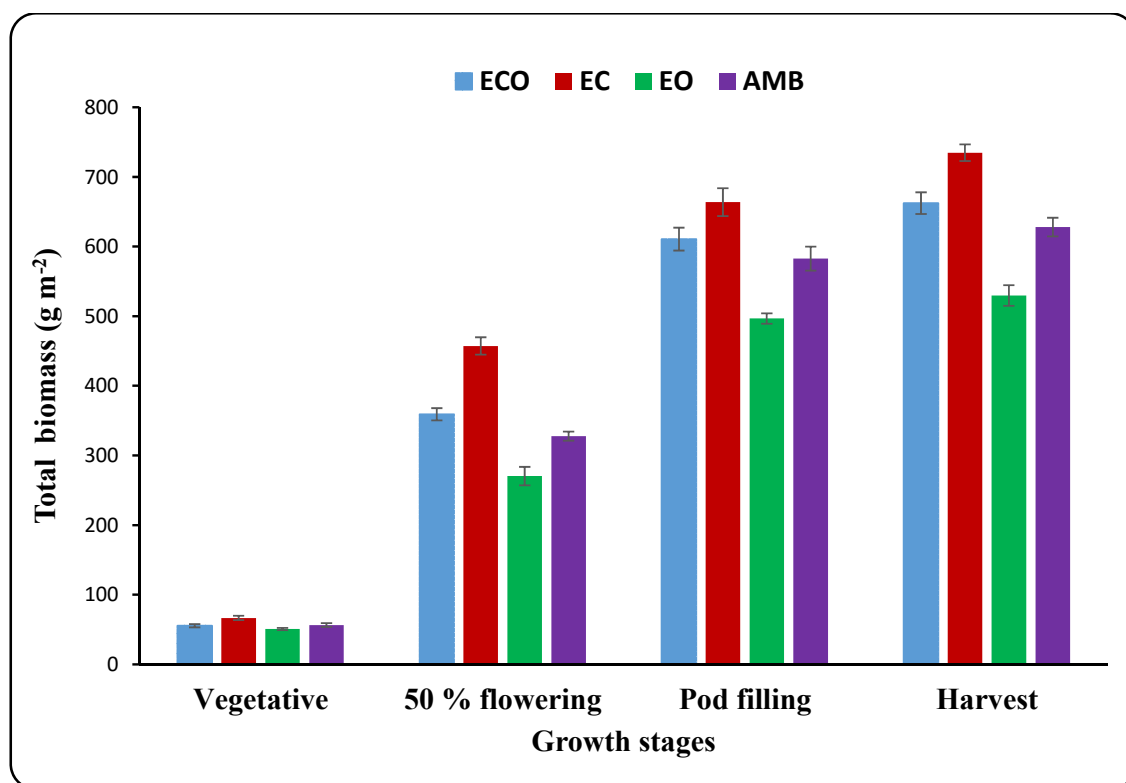


Fig 4.8. Total crop biomass production in chick pea leaves at different growth stages as influenced by different treatments of ozone and carbon dioxide

The 100 seed weight was significantly varied among all four treatments. The highest value of 100 seed weight was obtained in EC (48.90 g) followed by ECO (48.90 g) then AMB (36.59 g) and lowest value observed in EO (36.59 g). Protein content was varied significantly. Highest protein content was measured in AMB treatment (23.68%) and lowest in ECO treatment (16.78%). EC and AMB treatments were statistically at par and 20.12 and 21.22% protein was measured, respectively.

Table 4.15: Yield attributes of chick pea crop under different treatments of ozone and carbon dioxide

Treatments	Number of pods/plant	Pod weight g/plant	Seed weight g/plant	100 seed weight (g)	Protein content (per g FW)
ECO	32 ^B	19.48 ^B	18.06 ^B	44.85 ^B	16.78 ^C
EC	37 ^A	23.06 ^A	21.50 ^A	48.90 ^A	20.12 ^B
EO	22 ^D	14.04 ^C	12.80 ^C	37.68 ^C	21.22 ^B
AMB	28 ^C	17.80 ^B	16.30 ^B	48.90 ^A	23.68 ^A
CV%	7.88	7.50	8.11	2.89	5.06
LSD at 5%	3.14	1.87	1.86	1.87	1.38

4.5. Resource utilization efficiency

4.5.1 Radiation use efficiency (RUE)

The data on total seasonal intercepted PAR (TIPAR) and radiation use efficiency (RUE) in account of biomass accumulation and yield of chick pea under different level of ozone and carbon dioxide treatments during *rabi* season 2016-17 are given in table 4.16.

The TIPAR was 605.34 MJ m⁻² and 668.99 MJ m⁻² for EO and EC, respectively which was significantly different than ECO (660.17 MJ m⁻²) and AMB (645.96 MJ m⁻²). Radiation Use Efficiency on account of biomass accumulation was significantly increased with different CO₂ and O₃ treatments. The RUE on account of biomass accumulation was significantly higher under EC (1.10 g MJ⁻¹) than other treatments. It was lower under EO treatment (0.88 g MJ⁻¹). Similar trend was also observed in

RUE_y. The RUE for yield was significantly lower under EO (0.32 g MJ⁻¹) than comparison to other treatments. It was higher under EC treatment (0.48 g MJ⁻¹), followed by ECO (0.41 g MJ⁻¹), followed by AMB (0.38 g MJ⁻¹). Elevated O₃ decreased 15.78% RUE_y than AMB.

Table 4.16: Radiation use of efficiency of chick pea crop under elevated surface ozone and carbon dioxide treatments

Treatments	Biomass	Seed yield	TIPAR	RUE _b	RUE _y
	g m ⁻²		MJ m ⁻²	g MJ ⁻¹	
ECO	662.28 ^B	270.40 ^B	660.17 ^B	1.00 ^B	0.41 ^B
EC	734.68 ^A	324.33 ^A	668.99 ^A	1.10 ^A	0.48 ^A
EO	529.68 ^C	191.50 ^C	605.34 ^D	0.88 ^C	0.32 ^C
AMB	627.95 ^B	245.88 ^B	645.96 ^C	0.97 ^B	0.38 ^B
CV%	4.38	8.56	8.8	4.37	8.58
LSD at 5%	43.11	34.04	8.71	0.06	0.05

4.5.2 Water use efficiency (WUE)

The data on total water use and water use efficiency (WUE) in account of biomass accumulation and yield of chick pea under level of ozone and carbon dioxide treatments during *rabi* season 2016-17 are given in table 4.17. Total water was 217.50 mm and 206.98 mm for ECO and EO, respectively which was significantly different than EC (190.03 mm) and AMB (207.30 mm). Water Use Efficiency on account of biomass accumulation was significantly increased with different CO₂ and O₃ treatments. The WUE on account of biomass accumulation was significantly higher under EC (38.67 kg ha-mm⁻¹) than other treatments. It was lower under EO treatment (25.61 kg ha-mm⁻¹). Similar trend was also observed in RUE_y. The RUE for yield was significantly lower under EO (9.26 kg ha-mm⁻¹) than comparison to other treatments. It was higher under EC treatment (17.07 kg ha-mm⁻¹), followed by ECO (12.46 kg ha-mm⁻¹), followed by AMB (11.86 kg ha-mm⁻¹). Elevated O₃ decreased 21.90% WUE_y than AMB.

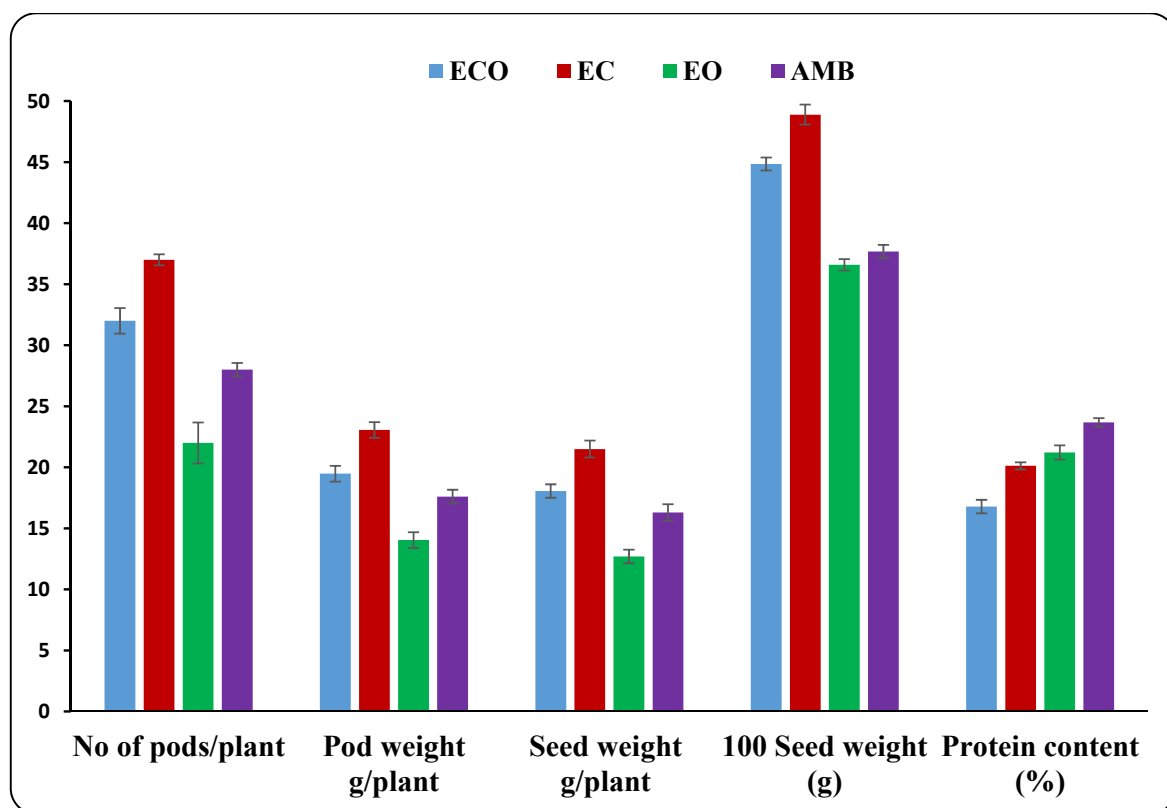


Fig 4.9. Yield component analysis of chick pea under different treatments of ozone and carbon dioxide

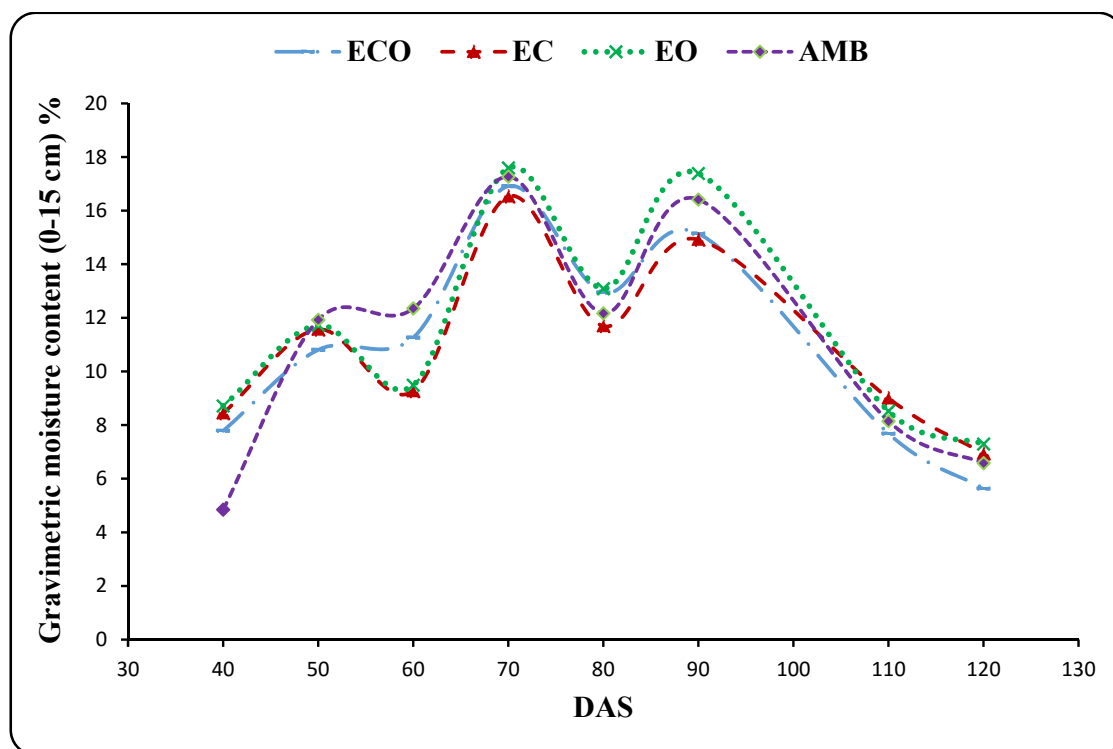


Fig 4.10. Temporal variation in surface soil moisture content (gravimetric) under different treatments of ozone and carbon dioxide

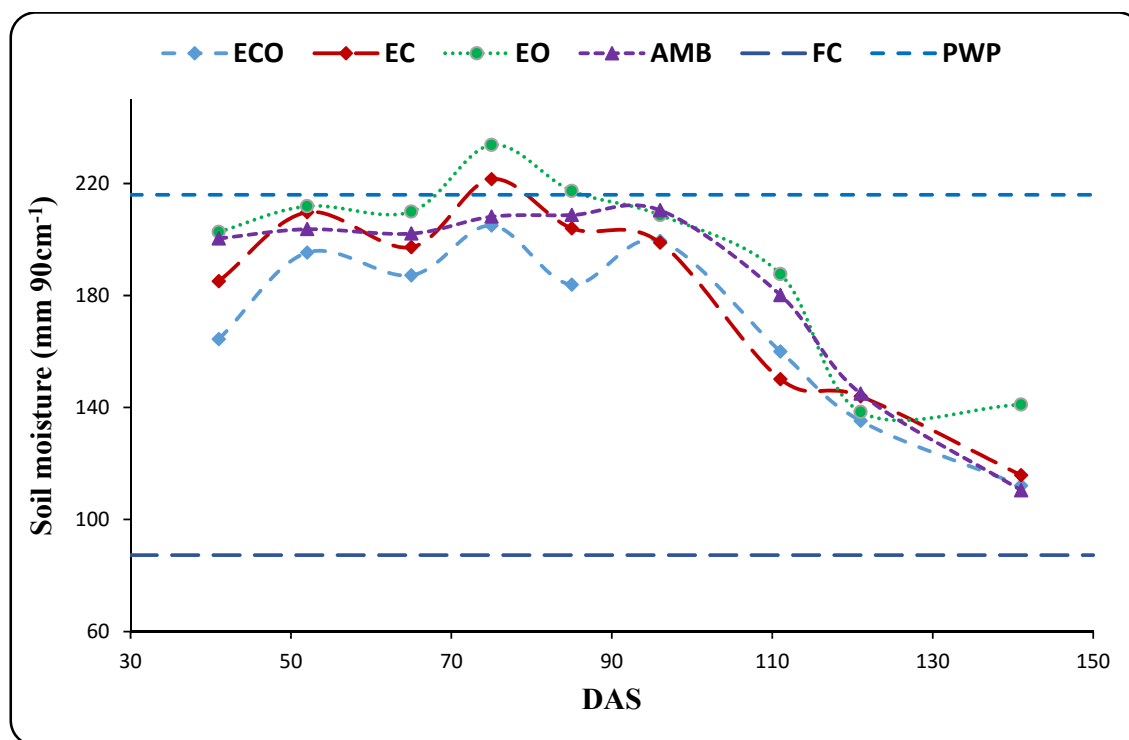


Fig 4.11. Effect of different treatments of ozone and carbon dioxide on soil moisture storage in chick pea during the entire growth period

Table 4.17. Water use of efficiency of chick pea crop under elevated surface ozone and carbon dioxide treatments

Treatments	Biomass	Yield	Water Use	WUE _b	WUE _y
	g m ⁻²		mm	kg ha ⁻¹ mm ⁻¹	
ECO	662.28 ^B	270.40 ^B	217.50 ^A	30.46 ^B	12.46 ^B
EC	734.68 ^A	324.33 ^A	190.03 ^C	38.67 ^A	17.07 ^A
EO	529.68 ^C	191.50 ^C	206.98 ^B	25.61 ^C	9.26 ^C
AMB	627.95 ^B	245.88 ^B	207.30 ^B	30.31 ^B	11.86 ^B
CV%	4.38	8.56	2.48	4.98	9.29
LSD at 5%	43.11	34.04	7.84	2.40	1.81

4.5.3 Soil moisture

The variation in profile soil moisture content in chick pea crops under different elevated CO₂ and O₃ is shown in Fig. 4.10 and 4.11. The horizontal lines shows the field capacity (FC), and permanent wilting point (PWP) for 90 cm soil depth. Soil moisture storage was more in EO followed by EC, AMB and ECO during 2016-17 year. The effect of irrigation on 42 DAS, 87 DAS and rainfall on 72 DAS was observed in soil moisture storage curve clearly.

4.5.4 fIPAR, extinction coefficient (k) and relationship of fIPAR with LAI

The variation in fIPAR among all the four treatment with growing season is depicted by Fig. 4.12. The fractional intercepted PAR (fIPAR) increased with leaf area index (LAI). At initial stages of crop growth rate was higher later at lower rate and finally at constant rate. It was observed that highest fIPAR was found in EC treatment and lowest in EO treatment. AMB treatment fIPAR was more than ECO treatment. Canopy extinction coefficient 'k', ln (1-fIPAR) plotted linearly with LAI of various growth stages. A linear relationship between fIPAR and LAI was plotted and the slope of the relationship was 'k' (canopy extinction coefficient). The crop canopy coefficient was lowest in EC treatment (0.59) and highest in O₃ treatment (0.87). AMB treatment (0.84) and ECO treatment (0.67) values are also varied (Fig. 4.13). The relationship between pooled data of fIPAR and LAI depicted in Fig 4.14. These parameters were highly correlated during crop growing season (R² = 0.87).

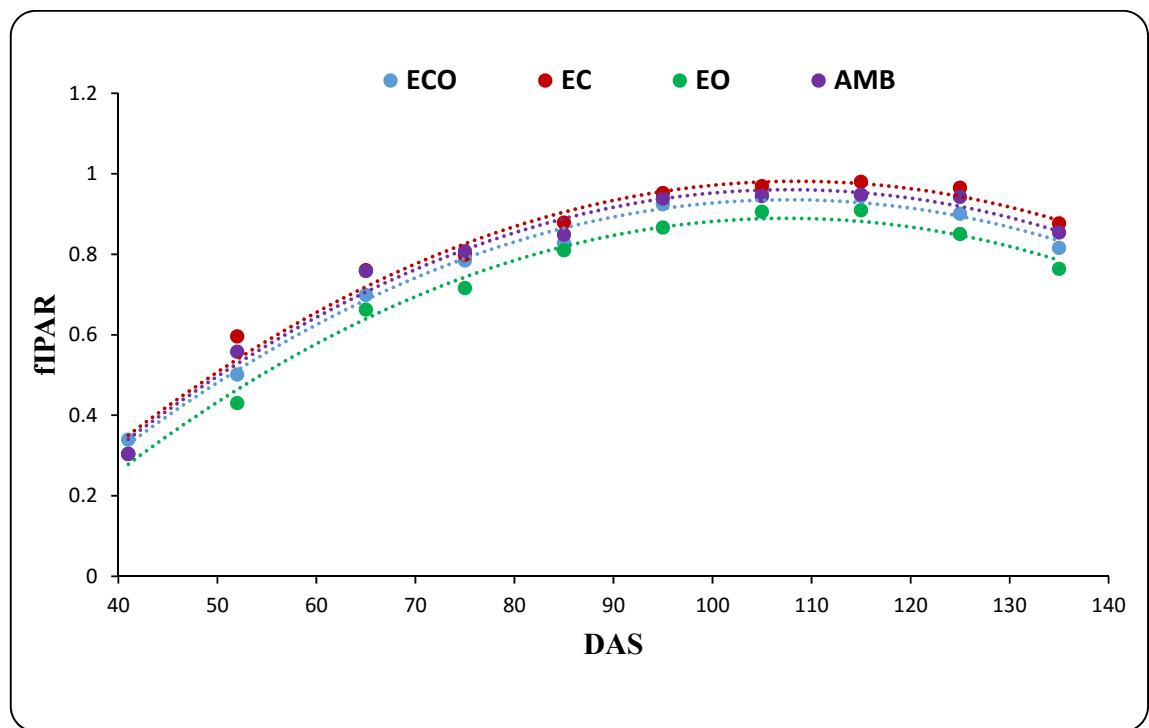


Fig 4.12. Variation in fIPAR of chick pea under different treatments of ozone and carbon dioxide during the entire growth period

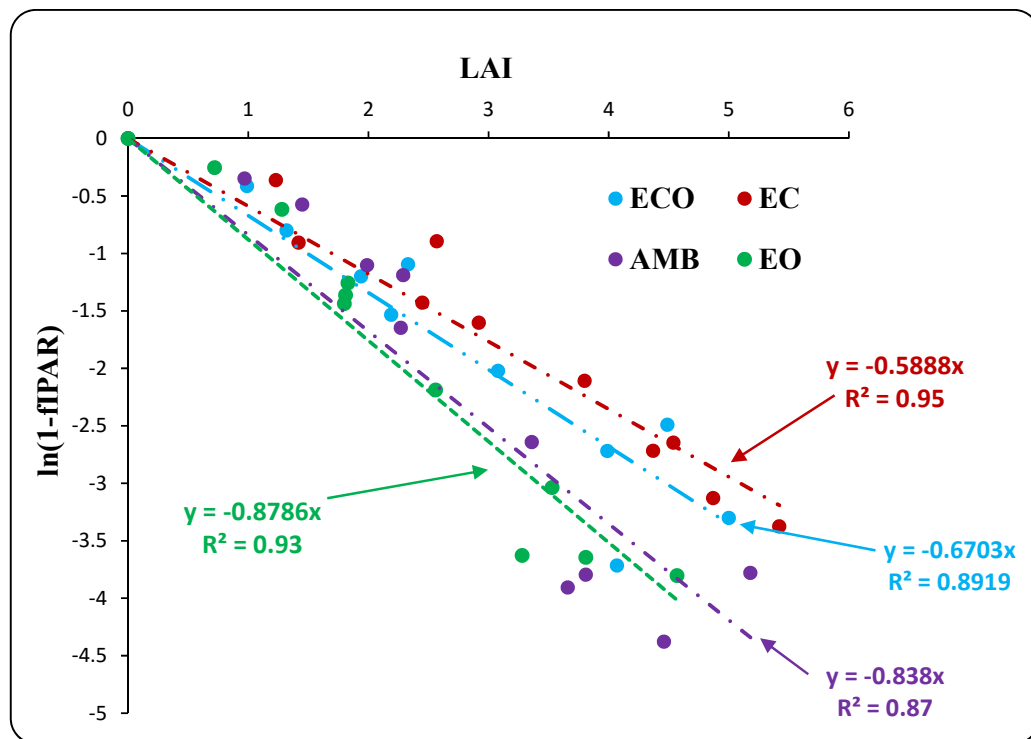


Fig 4.13. Linear regressive slope (k) between LAI and $\ln(1-fIPAR)$ for chick pea under different treatments

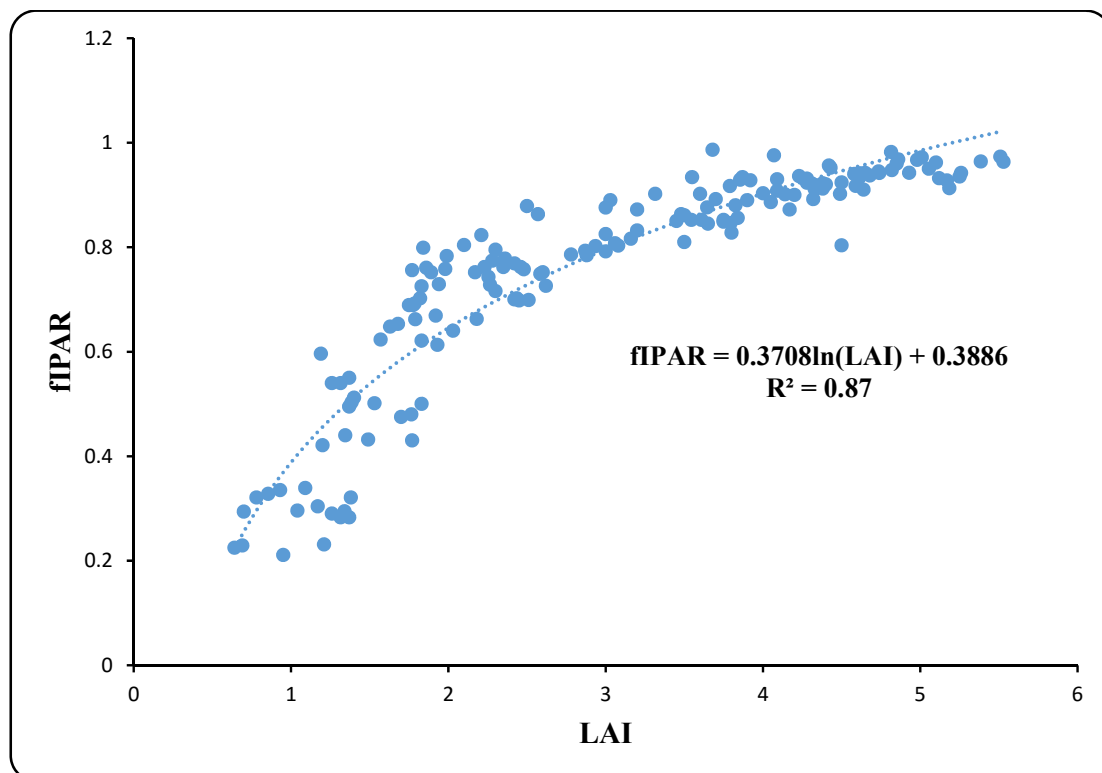


Fig 4.14. Relationship between fractional IPAR (fIPAR) and Leaf Area Index (LAI) of chick pea under different treatments of ozone and carbon dioxide during the entire growth period

5. DISCUSSION

World population is increasing rapidly every year. Emission of greenhouse gases are also positively related with population increase. Over exploitation of natural resources enhance the greenhouse. To a society and scientific community global climate change is the most alarming concern at present. The two most important aspects of global climate change are rise of carbon dioxide (CO₂) and tropospheric ozone (O₃) in the environment (Ainsworth, 2008). Ozone is not only an important greenhouse gas but also a phyto-toxic pollutant (Percy *et al.*, 2002). Due to anthropogenic emissions of many ozone forming precursors, the recent trend of increase of carbon dioxide and ozone is very rapid. Not only in India but also globally the ozone concentration particularly day time concentration in past few years is increasing very fast. Both growth and physiology of plants are directly affected by ozone and carbon dioxide. Though carbon dioxide has few positive effect but effect of high ozone is always negative. Yield reduction and reduction in growth are two main effect of high ozone concentration due to physiological and biochemical changes. But high concentration of carbon dioxide increases the growth and yield of crops. Carbon dioxide is the primary source of carbon for photosynthates which ultimately reduces photorespiration and enhance photosynthesis. Chick pea crop is highly affected by elevated carbon dioxide and ozone as both are alters the micrometeorological conditions which ultimately influence the phenology, leaf area index, yield, biomass, water use efficiency (WUE) and radiation use efficiency (RUE).

Canopy temperature was more in combination treatment, followed by elevated CO₂ treatment followed by elevated O₃ treatment and ambient condition. A consistent higher canopy temperature was observed up to 75 DAS due to initial period of uncertainty for greater presence of soil in optical view of IR thermometer. Throughout the growing season canopy temperature of ambient crop was cooler than other three treatments. Result of canopy temperature was significant in 41, 75 and 85 DAS after that canopy temperature was not significant. All the growth stages canopy temperature of combined treatment was higher (ranged between 17.3 to 36.6°C), followed by canopy temperature of elevated CO₂ treatment (ranged between 17.4 to 33.5°C), followed by elevated O₃ treatment (ranged between 17.0 to 33.6°C) than ambient condition (ranged between 16.0 - 33.8°C). The effect of stomatal closure in response

to elevated CO₂ (Triggs *et al.*, 2004 and Saha *et al.*, 2012) and O₃, reduces plant transpiration per unit leaf and ultimately reduces the cooling effect (Kimball *et al.*, 1993; Magliulo *et al.*, 2003 and Bhatia *et al.*, 2013). As the transpiration was less in elevated CO₂ and elevated O₃ exposed crop, the CATD we observed was less in both the conditions compare to ambient condition. Our findings are in same line with Wilkinson *et al.* (2012), who reported that prolonged stomatal closure reduces the transpiration in elevated O₃ condition. Saha *et al.* (2012) reported decreased canopy temperature in pigeon pea with increased crop water use which is in contrast with canopy temperature in potato (Magliulo *et al.*, 2003), rice (De Costa *et al.*, 2003; Yoshimoto *et al.*, 2005) and sorghum (Triggs *et al.*, 2004).

Elevated CO₂, O₃ and their interactions altered the phenology of chick pea crop. Both elevated CO₂ and elevated O₃ advanced all phenological stages of the crop by different mechanism. Advanced phenological stages under elevated CO₂ treatment was due to accumulation of photosynthates in leaves causing source-sink imbalance. Saha *et al.* (2015) in their study also reported that the phenology stages occur early when chick pea crop is exposed in elevated CO₂ in OTC and concluded that the senescence occur early due source/ sink imbalance. Other researchers (Mata *et al.*, 2013; Miller *et al.*, 1997 and Yoshimoto *et al.*, 2005) also reported the early senescence in elevated CO₂ treatment. Elevated O₃ typically damage chlorophyll content of leaves and nutrient status thus enhance senescence of crops. Our findings are in tune with Zhang *et al.* (2014); Burkey *et al.* (2009); Ojanpera *et al.* (1998); Betzelberger *et al.* (2010) and Feng *et al.* (2011). They also have same opinion that enhanced or accelerated leaf maturity in elevated O₃ is due to chlorophyll degradation and imbalance nutrient status.

The typical LAI profile was observed in the study like any other crop LAI increased during vegetative growth reached maximum in flowering stage and declined at maturity in elevated CO₂, elevated O₃ and combination treatments. Peak LAI was observed at 111 DAS in all the treatments. Elevated O₃ (EO) reduces LAI by 9.50 to 25.07 % from ambient. Reduction was more (25.07%) at 41 DAS. Elevated CO₂ increase LAI by 2.06 to 28.63%. Interaction treatment recorded almost same LAI as ambient. This may due to combination of positive effect of CO₂ and negative effect of O₃. For soybean crop similar type of observation was also reported by Oikawa *et al.* (2013) and for *Lolium perenne* by Daepp *et al.* (2001) and for chick pea crop Saha *et al.*

al. (2015). Our result is also supported by the findings of Dermody *et al.* (2006, 2008) for soybean crop. A rapid declination was observed towards maturity. The declination is may be due to accumulation of photosynthates in pods which results early senescence of crops. Our result is in same tune with Miller *et al.* (1997) where they concluded that due to source / sink imbalance causes early maturity in tobacco crop and Mata *et al.* (2013) in sunflower crop. According to Kim *et al.* (2001) the proliferation of LAI is due to CO₂ fertilization as plants produces more biomass due to more nutrient uptake. Similar findings also reported by Bhatia *et al.* (2013) (reduction of growth due to elevated O₃) for maize crop and by Zhang *et al.* (2014) for soybean crop. We observed in the study that elevated CO₂ increases LAI throughout the crop growing season significantly but elevated O₃ reduces LAI significantly and in interaction treatment LAI growth was in between elevated CO₂ and O₃.

During entire chick pea growing season relative leaf water content was significantly more in combination treatment followed by elevated CO₂ followed by elevated O₃ treatment than ambient condition. We observed similar finds of Morgan *et al.* (2001) for short grass steppe and Meibaum *et al.* (2012) for maize. The stomatal closer resulted the changes in plant structure, i.e. tracheid anatomy or vessel and leaf specific conductivity when plant was exposed in elevated CO₂ (Tyree and Alexander, 1993) and elevated O₃ (Zhang *et al.*, 2000). Combined effect of elevated CO₂ and elevated O₃ resulted more relative leaf water content. Decrease in leaf water potential with increase in relative water content in *Brassica* was reported by Rabha and Uprety (1998). Closure of stomata reduced transpiration per unit leaf area especially aerodynamically rough and low leaf area which reduces canopy ET and higher soil volumetric water compared to ambient plant (Field *et al.*, 1995).

In this experiment we observed that plant pigments were significantly affected by different treatments. Elevated CO₂ produced significantly more chlorophyll than any other treatments. Elevated O₃ treatment had a negative effect on chlorophyll as well as in carotenoid production. Similar trend was also reported by Zhang *et al.* (2014) in soybean and Bhatia *et al.* (2013) in maize crop. O₃ exposed leaves are unable to fix ribulose phosphate carboxylase due to reduction in CO₂ fixation. Also stomatal closer is another reason for less chlorophyll production.

During whole crop growing season elevated CO₂ treatment has more photosynthesis rate, less transpiration rate, lesser stomatal conductance and

intercellular CO₂ concentration. Elevated O₃ treatment also had lower stomatal conductance and photosynthesis rate than ambient condition. Closer of stomata was the main reason for increased intercellular CO₂ concentration. Zhang *et al.* (2014) in soybean and Bhatia *et al.* (2013) in maize crop also supports our findings.

Plant height was significantly higher under elevated CO₂ condition than elevated O₃ and their interaction. The effect was more prominent at 65 DAS and 85 DAS which coinciding with 50% flowering and pod filling stage. Elevated CO₂ enhanced the plant height than ambient by 24.9% than ambient at maturity. The plant height in ECO (combined treatment) was more due to positive effect of CO₂ fertilization but O₃ retarded the growth, thus at maturity 21.9% increase was observed. Elevated O₃ reduces the growth by 6.0% at 85 DAS and at maturity growth was less but statistically there is no difference. Effect of elevated CO₂ fertilization on growth enhancement was less initial vegetative growth stages than advance stages. Nutrient uptake specially nitrogen by plants was affect the growth enhancement process with increased photosynthates assimilation rate (Bhatt *et al.*, 2007). Utilization of more photosynthates for growth ultimately enhance the LAI in chick pea which increase nitrogen uptake. As chick pea is leguminous crop with nitrogen fixing nodules (Singh and Diwakar, 1995), a possibility of more nodulation is possible under elevated CO₂ condition to support the mechanism of growth enhancement (Gamper *et al.*, 2005). Bhatia *et al.* (2013) also reported the decline of growth as O₃ enters through stomata and disrupts cellular process in maize crop. O₃ significantly decrease the net photosynthesis and nutrient uptake, thus reduce the growth in soybean (Zhang *et al.*, 2014). Booker *et al.* (2009) also reported that elevated CO₂ has a beneficial effect but in combination O₃ may have negative impacts and ultimately reduces photosynthesis, decrease growth. In anti-oxidant production, elevated CO₂ have interactive effects with elevated O₃ (Erice *et al.*, 2007).

During crop growing season both CGR and RGR was significantly increased under elevated CO₂ and in combination treatments but significantly decreased under elevated O₃ treatment. Elevated CO₂ treatment recorded an increase of 24.06 to 47.50% in CGR and 21.62 to 53.73% in RGR over ambient condition respectively. Both CGR and RGR was decreased when crop is exposed to O₃ and decreased 12.07 to 22.83% in CGR and 13.21 to 18.53% in RGR over ambient condition respectively. Magnitude of decrease of CGR and RGR was more in vegetative stages compare to

other phenological stages. Feng *et al.* (2008) reported that elevated O₃ reduces crop growth by 11%, which is in tune with our findings. The reduction of growth of crop under elevated O₃ is due to inhibition of photosynthesis, carbon (sugar) formation, uptake of important nutrients (Sild *et al.*, 2002 and Feng *et al.*, 2007). Many researchers (Hogy *et al.*, 2009a, Hogy *et al.*, 2009b, Hogy *et al.*, 2010 and Deepak and Agrawal, 1999) also reported the growth of crops is more under elevated CO₂ condition as more photosynthates were accumulated in plants.

Plant biomass was less in elevated O₃ treatments, more in elevated CO₂ treatment and in combination of elevated CO₂ and O₃ treatment than ambient condition in entire growth stages. Elevated CO₂ treatment produces 13.9 to 39.55% more CO₂ and elevated O₃ treatment produces 10.11 to 17.50% less plant biomass than ambient condition which is significant in all growth stages at $p < 0.05$ level of significance. Combination treatment produces -1.65 to 9.60% plant biomass than ambient condition. In combination treatment CO₂ is responsible for accumulation of more above ground biomass to counteract the negative effect of O₃ which is possible due to higher rate of photosynthesis. According to Saha *et al.* (2012) elevated CO₂ produces 1.2 to 2.8 times more biomass than ambient condition in chick pea crop under OTC. Our results show less production of plant biomass as in this study crop was grown under FAOCE condition, thus mixing of CO₂ and O₃ is more with ambient air compare to OTC. Pal *et al.* (2004) also reported that significant increase of above ground biomass accumulation is due to more photosynthates partitioned towards above ground parts by CO₂ enriched crop. Reduction of stomatal aperture also decrease the entry of O₃ inside leaves in elevated CO₂ treatment which is a detoxifying process of O₃ and ultimately increase the availability of substrates (Pearson *et al.*, 1995). Finding of other scientists (Sarkar and Agrawal, 2010, Rai *et al.*, 2007 and Agrawal *et al.*, 2005) also supports our findings that elevated O₃ exposure significantly reduced plant (wheat and mung bean) biomass.

A Free Air Ozone and Carbon dioxide Enrichment (FAOCE) experiment were conducted to study the effect of elevated O₃ and CO₂ on chick pea (*kabuli* type) growth, yield, radiation interception, water use and use efficiencies. The elevated CO₂ level of 550 ± 10 ppm (RCEP, 2000), elevated O₃ level of 70 ± 10 ppb and their interaction were chosen according to Hauglustaine (2005). Very few studies were reported on the effect of elevated CO₂ on growth, yield and resource utilization

efficiencies. But all the studies were conducted in OTC's. Studies on the effect of elevated O₃ and interactions of elevated CO₂ and O₃ in FAOCE (Free Air Ozone and Carbon dioxide Enrichment) particularly on chick pea crop was not available in literature. In this study we attempted to study in depth the effect on growth parameters like plant height, leaf area index (LAI); yield, harvest index (HI), radiation interception, water use and resource use efficiencies.

Yield of chick pea crop was significantly affected by elevated CO₂, elevated O₃ and combination of both CO₂ and O₃. Yield was significantly more (31.70%) in elevated CO₂ treatment followed by 9.75% in combination treatment and -21.95% in elevated treatments than ambient condition. Similar trend was observed in HI also. The yield of chick pea crop under elevated CO₂ treatment was more on account of more biomass production as well as significant increase in harvest index (HI). Harvest Index (HI) was significantly more (12.76%) in elevated CO₂ treatment followed by combination of CO₂ and O₃ (4.16%) and less in elevated O₃ treatment (7.86%) as compared to ambient condition. Phenological modifications induced by elevated CO₂ concentration induce occurrence of early flowering and early pod set which is responsible for pod set and ultimately increase the HI (Saxena *et al.*, 1987). Our HI values were similar with other scientist value available in literature (0.31-0.43 by Leport *et al.*, 1999; 0.39-0.54 by Saxena *et al.*, 1987). But many scientists reported contrary results for different crops. According to Kim *et al.* (2003), rice HI is less elevated CO₂ condition. Less HI for soybean (Cure and Acock, 1986; Morgan *et al.*, 2005; Sun *et al.*, 2009) and pigeon pea (Saha *et al.*, 2012). Palta and Ludwig (2000) also observed no HI change on lupin. Yield of a crop is a function of total incident PAR (TIPAR), fraction of incident radiation intercepted by any crop (fIPAR), radiation use efficiency (RUE) and harvest index (HI). Crop yield and production is highly dependent on all these factors as alteration of these factors change yield and production. Scientists (Zhang *et al.*, 2014; VanLoocke, 2012; Bhatia *et al.*, 2013 and Feng *et al.*, 2011) reported yield of different crops and HI decreased due to exposure of elevated O₃ in crop growing season. Though elevated CO₂ has a beneficial effect on crops but O₃ have negative impacts and ultimately reduces photosynthesis (Booker *et al.*, 2009) and on anti-oxidant production elevated CO₂ have interactive effects with elevated O₃ (Erice *et al.*, 2007), which was similar with our findings.

Analysis of yield contributing factors showed that elevated O₃ resulted decrease in vegetative and reproductive dry matter in chick pea. Elevated CO₂ increased number of pods per plant, pod weight per plant, seed weight per plant and 100 seed weight compare to other treatments. Characters related to plant's sink like number of seeds per pod and 100 seed weight were significantly affected by elevated O₃ and elevated CO₂ treatment, though according to Saha *et al.* (2012) these are not affected by elevated CO₂. Finding of others supports our findings that yield contributing characters are increased by CO₂ treatment and decreased by O₃ treatment and combination treatment showed more yield contributing characteristics between CO₂ and O₃ treatments. Similar results were also reported by Wu and Wang (2000) for broad bean; for rice (Kim *et al.*, 2003, Yang *et al.*, 2009 and Liu *et al.*, 2008); for wheat (Wu *et al.*, 2004; Manderscheid and Weigal, 1997); for barley (Manderscheid *et al.*, 2009). Confirmation was also obtained by the findings of Ziska *et al.* (2001) and Ainsworth *et al.* (2002) that increased seed weight per branches and seed yield with increased pod weight for our finding in chick pea crop. Similar findings also reported by Bhatia *et al.* (2014) for maize and Zhang *et al.* (2014) for soybean, that yield contributing characteristics was significantly reduced by elevated O₃ treatment.

According to Monteith (1981) fIPAR depends on leaf area index, leaf orientation and finally plant leaf architecture of crops. On fIPAR no significant effect of CO₂ enrichment was observed in pigeon pea even though the LAI was significantly increased. Similarly, CO₂ enrichment did not changed the cumulative IPAR over the crop growth period. (Saha *et al.*, 2012). There are many contradictory reports about the effect of elevated atmospheric CO₂ on fIPAR. Some studies shown an increased fIPAR under elevated atmospheric CO₂ environment in wheat (Mulholland *et al.*, 1998), while in rice (De Costa *et al.*, 2006) and barley (Manderscheid *et al.*, 2009) the fIPAR was found to be unaltered by CO₂ enrichment. The extinction coefficient 'k' decreased significantly in elevated CO₂ treatment (0.5), followed by combination treatment of CO₂ and O₃ treatment (0.67), followed by ambient condition (0.87) and elevated O₃ treatment (0.88). Our observed value of 'k' was lower than the findings of Saha *et al.* (2015) for chick pea crop (0.75), 1.02 by Tesfaye *et al.* (2006) for chick pea but almost at par with 0.4 – 0.61 reported by Hughes *et al.* (1987). The canopy extinction coefficient explains the architecture and orientation of leaves. Small value of extinction coefficient indicates leaves are more erect in elevated CO₂ treatment

compare to other treatments, thus crops received more radiation inside crop canopy (Brekke *et al.*, 2011). The increased LAI compensated the reduced fIPAR due to lower 'k' in elevated CO₂ treated chick pea crop and produced more yield and biomass (Drewry *et al.*, 2010).

The value of photosynthetic radiation use efficiency of 0.32 g MJ⁻¹ in chick pea crop was higher value reported by Saha *et al.* (2015) but almost nearer value reported by other scientists (0.30-0.93 MJ⁻¹ by Hughes *et al.*, 1987; 1.4 g MJ⁻¹ by Leach and Beech, 1988; 1.0 g MJ⁻¹ by Soltani *et al.*, 2006; 0.25-0.87 by Jahansooz *et al.*, 2007). The crop was experienced extreme cold (1-5°C) during December and January month which coincides with vegetative growth and flower initiation stage. According to Bat-Oyun *et al.* (2012) cold impose a detrimental effect on crop growth resulted lower RUE. Our study show positive effect of elevated CO₂ by enhancement of RUE is one of the alternative to produce more yield in future but O₃ has negative effect also. Most of the studies reported a significant increase of photosynthetic RUE due to elevated CO₂ and less RUE due to elevated O₃ treatment. The increase of RUE was mainly due to increase in biomass production due to CO₂ fertilization and less in O₃ due to production of less biomass. Elevated CO₂ slightly compensate the negative effect of O₃ in RUE (0.41 g MJ⁻¹). In elevated CO₂ treatment crop were having more vertical and longer branches compare to other treatments resulting higher photosynthetic efficiency (Walcroft *et al.*, 2005) and finally increase RUE. Even increased total leaf area contributed towards higher RUE (Sadras *et al.*, 1996; Brodrick *et al.*, 2013)

Water use efficiency was significantly increased in elevated CO₂ treatment. Elevated O₃ significantly reduces WUE throughout the crop growth season. The reduction of WUE was due to elevated O₃ produces less biomass compare to elevated CO₂ exposed crop than ambient. Similar result was also obtained by Adam *et al.* (2000), Qiao *et al.* (2010) and Zhang *et al.* (2014). Increased WUE due to elevated CO₂ was also reported by Hunsaker *et al.* (2000) for wheat; Robredo *et al.* (2007) for barley; Saha *et al.* (2011) for pigeon pea. De costa *et al.* (2003) also cited another postulation that less stomatal conductance and less transpiration due to stomatal closer achieved due to greater LAI and more leaf air vapour pressure deficit in elevated CO₂ treatment.

6. SUMMARY AND CONCLUSION

Understanding of effect of the projected climatic conditions on crop growth and production in the future is a major concern for worldwide food security. This is particularly relevant considering the increasing world population. Increase of concentration of greenhouse gases, like carbon dioxide (CO₂) and tropospheric ozone (O₃), are important factors affecting the global climate change (IPCC, 2001). Ground level ozone or tropospheric ozone (O₃) is a major pollutant generated by photochemical reactions of volatile organic compounds with nitrogen oxides. The O₃ concentration is rising tremendously in the atmosphere. In the Asian countries, the emission of ozone precursors is rising and it is expected to increase continuously in the foreseeable future. No study has been conducted on chick pea to investigate the impact of both elevated carbon dioxide and ozone. Only few field scale study has been conducted that to confined to elevated carbon dioxide and to physiological aspects.

In this study, a field experiment was conducted on chick pea (variety: Pusa 5023) in the experimental farm in Free Air ozone and carbon dioxide enrichment (FAOCE) facility, CESCRA of ICAR-Indian Agricultural Research Institute (IARI), New Delhi under four O₃ and CO₂ treatments [ECO: Elevated CO₂ (550±10 ppm) + elevated O₃ (70±10 ppb); EC: Elevated CO₂ (550±10 ppm ppm) + ambient O₃ (30±10 ppb); EO: Elevated O₃ (70±10 ppb)+ ambient CO₂ (400±10 ppm) and AMB Ambient CO₂ (400±10 ppm)+ ambient O₃ (30±10 ppb) *rabi* season of 2016-17. Weather data of study IARI farm were collected from the agromet Observatory, IARI, New Delhi. Micrometeorological parameters like canopy temperature (using IR thermometer) and intercepted PAR (using line quantum sensor) were measured 10 days interval. Intercepted photosynthetically active radiation (IPAR) was converted into fractional PAR (fIPAR). Crop biophysical parameters like LAI (by using canopy analyzer), above ground biomass, crop growth rate (CGR) and relative growth rate (RGR) were also measured at 10 days intervals. Plant height were also measured at different DAS throughout the crop growth period. Plant physiological parameters like photosynthesis rate, transpiration rate, stomatal conductance, and intercellular CO₂ concentration were measured by IRGA (Infrared Gas Analyzer) during crop entire growing seasons. Soil moisture was also measured in this study by gravimetric method. Crop phenology was recorded biweekly for wheat crop during both years. Various calculations were

done using Microsoft Excel package and statistical analysis for split plot design were done by using online SAS package.

Canopy air temperature deficit varied significantly throughout the crop growing season. CATD was lowest in AMB treatment (-1.43 to 2.91⁰C), followed by EO treatment (-0.01 to 2.90⁰C), followed by ECO treatment (-0.46 to 2.99⁰C) and EC treatment (-0.14 to 2.98⁰C). The growth period shortened by about 10 days due to the elevated CO₂ effect and 14 days due to elevated O₃ treatment. The main differentiation was occurred after pod initiation to maturity. The LAI of EC remains significantly higher than all other treatments while EO remains lowest. Lowest RLWC measured in crop exposed to elevated CO₂. RLWC was highest at around 85 DAS in all the treatments which coincides with pod formation stage. Afterwards RLWC was decreased with crop maturity and attained the lowest value in all the four treatments. Chlorophyll content of leaf was varied significantly ($p \leq 0.5$) in all the four (ECO, EO, EC and AMB) treatments. The highest chlorophyll (mg of chl/ g of fresh weight) was recorded in crop with elevated CO₂ (1.20 to 3.76 mg of chl/ g of fresh weight) and lowest in crop treated with elevated O₃ (0.87-3.12 mg of chl/ g of fresh weight). Different level of CO₂ and O₃ treatment affected significantly photosynthetic rate in chick pea crop in *rabi* 2016-17. Highest photosynthetic rate recorded in EC treatment (20.13 – 41.81 μ mol CO₂ m⁻² s⁻¹) and lowest in EO treatment (6.90 – 19.66 μ mol CO₂ m⁻² s⁻¹). Plant height for different ozone and carbon di oxide treatments during *rabi* season 2016-17 was significant. Plant height was increased with the increase of CO₂ concentration. The highest CGR was observed in EC treatment (3.54 – 8.30 g m⁻² day⁻¹), followed by ECO treatment (2.42 – 6.94 g m⁻² day⁻¹), followed by AMB treatment (2.40 – 6.69 g m⁻² day⁻¹) and lowest in EO treatment (2.01 – 5.36 g m⁻² day⁻¹). Crop produced highest biomass (734.68 g m⁻²) in EC (550 ppm CO₂) followed by 662.28 g m⁻² in ECO (550 ppm CO₂ + 70 ppb O₃), 529.68 g m⁻² in EO (70 ppb O₃) and 627.95 g m⁻² in AMB (ambient condition). Yield of chick pea crop was significantly affected by elevated CO₂, elevated O₃ and combination of both CO₂ and O₃. Yield was significantly more (31.70%) in elevated CO₂ treatment followed by 9.75% in combination treatment and -21.95% in elevated treatments than ambient condition. Similar trend was observed in HI also. The yield of chick pea crop under elevated CO₂ treatment was more on account of more biomass production as well as significant increase in harvest index (HI). Harvest Index (HI) was significantly more

(12.76%) in elevated CO₂ treatment followed by combination of CO₂ and O₃ (4.16%) and less in elevated O₃ treatment (7.86%) compare to ambient condition. Phenological modifications induced by elevated CO₂ concentration induce occurrence of early flowering and early pod set which is responsible for pod-set and ultimately increase the HI. Analysis of yield contributing factors showed that elevated O₃ resulted decrease in vegetative and reproductive dry matter in chick pea. Elevated CO₂ increased number of pods per plant, pod weight per plant, seed weight per plant and 100 seed weight compare to other treatments. Characters related to plant's sink like number of seeds per pod and 100 seed weight were significantly affected by elevated O₃ and elevated CO₂ treatment. We observed the extinction coefficient 'k' decreased significantly in elevated CO₂ treatment (0.58), followed by combination treatment of CO₂ and O₃ treatment (0.67), followed by ambient condition (0.87) and elevated O₃ treatment (0.88). The increase of RUE was mainly due to increase in biomass production due to CO₂ fertilization and less in O₃ due to production of less biomass. Elevated CO₂ slightly compensate the negative effect of O₃ in RUE (0.41 g MJ⁻¹). Water use efficiency was significantly increased in elevated CO₂ treatment. Elevated O₃ significantly reduces WUE throughout the crop growth season. The reduction of WUE was due to elevated O₃ produces less biomass compare to elevated CO₂ exposed crop than ambient.

The salient finding of this study are:

- ❖ Canopy temperature was found maximum in ECO treatment and minimum in the ambient treatment (AMB).
- ❖ Canopy air temperature difference was minimum in the AMB followed by EO and AC and maximum in ECO, which is in line with the rate of transpiration in different treatments.
- ❖ Leaf area index (LAI) and photosynthesis rate were significantly higher in EC followed by ECO and AMB, and found to be minimum in EO.
- ❖ Canopy extinction coefficient was significantly reduced by EC and enhanced in the presence of EO and both EC and EO counteracted each other. AMB and EO are statistically at par.
- ❖ Fractional IPAR (fIPAR) follows the same trend as that of LAI and found to be maximum in EC and minimum in EO.

- ❖ Stomatal conductance and transpiration both were reduced by EO and EC, and found to be maximum in AMB and minimum in ECO.
- ❖ Stomatal conductance is reduced more by EC as compare to EO, however both are statistically similar in case of transpiration rate.
- ❖ RLWC is enhanced by both EC and EO and was significantly higher in ECO followed by EC and EO, this follows an opposite trend to that of stomatal conductance.
- ❖ Intercellular carbon dioxide was reduced in EC and was found to be maximum in EO treatment.
- ❖ Chlorophyll and carotenoid contents were maximum in EC and AMB, respectively.
- ❖ Yield attributes viz. plant height number of pods, pod weight seed weight per plant and harvest index were found to be significantly increased by EC followed by ECO, and lowest values were found in EO treatment.
- ❖ 100 seed weight were significantly higher in EC treatment. EO significantly reduces the 100 seed weight. ECO and AMB were found to be statistically similar and in between EC and EO.
- ❖ Seed protein content was significantly reduced by both EC and EO, which leads to minimum protein content in ECO.
- ❖ Biomass and yield were significantly high in EC treatment and minimum in EO.
- ❖ Both RUE and WUE were significantly increased in EC and reduced in EO, ECO values are higher than AMB.

Micrometeorological and biophysical parameters of chick pea under the interaction of elevated surface ozone and carbon dioxide

Abstract

Increase of concentration of greenhouse gases, like carbon dioxide (CO₂) and tropospheric ozone (O₃), are important factors affecting the global climate change. Ground level ozone or tropospheric ozone (O₃) is a major pollutant generated by photochemical reactions of volatile organic compounds with nitrogen oxides. In the Asian countries, the emission of ozone precursors is rising and it is expected to increase continuously in the foreseeable future. No study has been conducted on chick pea to investigate the impact of both elevated carbon dioxide and ozone. Keeping in view the importance of rising O₃ and CO₂ concentration in atmosphere, a field experiment was conducted on chick pea (variety: Pusa 5023) in the experimental farm in Free Air Ozone and Carbon dioxide Enrichment (FAOCE) facility of CESCRA, ICAR-Indian Agricultural Research Institute (IARI), New Delhi under four ozone and carbon dioxide treatments [ECO: Elevated CO₂ (550 ± 10 ppm) + elevated O₃ (70 ± 10 ppb); EC: Elevated CO₂ (550 ± 10 ppm) + ambient O₃ (30 ± 10 ppb); EO: Elevated O₃ (70 ± 10 ppb) + ambient CO₂ (400 ± 10 ppm) and AMB Ambient CO₂ (400 ± 10 ppm) + ambient O₃ (30 ± 10 ppb) rabi season of 2016-17. Weather parameters, micrometeorological parameters (canopy temperature, CATD, solar radiation interception), soil moisture, crop biophysical parameters (phenology, leaf area index, photosynthesis rate, stomatal conductance, biomass and yield) data were recorded for all the treatments at regular interval. Canopy temperature varied among different treatments. Only three dates (41, 75 and 85 DAS) are showing significance at $p \leq 0.5$ level of significance. At 75 DAS, it was maximum (21.5°C) in ECO (combination of elevated CO₂ and O₃), followed 20.4°C in EC, 19.2°C in EO and minimum (18.9°C) for ambient condition. The growth period shortened by about 10 days due to the elevated CO₂ effect and 14 days due to elevated O₃ treatment. The main differentiation was occurred after pod initiation to maturity. Leaf area index (LAI) and photosynthesis rate were significantly higher in EC followed by ECO and AMB, and found to be minimum in EO. Canopy extinction coefficient was significantly reduced by EC and enhanced in the presence of EO and both EC and EO

counteracted each other. The highest chlorophyll (mg of chl g⁻¹ of fresh weight) was recorded in crop with elevated CO₂ (1.20 to 3.76 mg of chl g⁻¹ of fresh weight) and lowest in crop treated with elevated O₃ (0.87-3.12 mg of chl g⁻¹ of fresh weight). Combined treatment of elevated CO₂ and O₃ recorded 0.92-3.72 mg of chl g⁻¹ of fresh weight. Stomatal conductance and transpiration both were reduced by EO and EC, and found to be maximum in AMB and minimum in ECO. RLWC is enhanced by both EC and EO and was significantly higher in ECO followed by EC and EO, this follows an opposite trend to that of stomatal conductance. Crop produced highest biomass (734.68 g m⁻²) in EC (550 ppm CO₂) followed by 662.28 g m⁻² in ECO (550 ppm CO₂ + 70 ppb O₃), 529.68 g m⁻² in EO (70 ppb O₃) and 627.95 g m⁻² in AMB (ambient condition). In all the growth stages crop under elevated CO₂ condition recorded highest biomass accumulation compare to all other treatments. Yield attributes viz. plant height number of pods, pod weight seed weight per plant and harvest index were found to be significantly increased by EC followed by ECO, and lowest values were found in EO treatment. The 100 seed weight were significantly higher in EC treatment. EO significantly reduces the 100 seed weight. ECO and AMB were found to be statistically similar and in between EC and EO. Seed protein content was significantly reduced by both EC and EO, which leads to minimum protein content in ECO. Grain yield was also different for all four treatments. It was found that EC showed highest grain yield (3.24 t ha⁻¹) compare to ECO (2.70 t ha⁻¹), EO (1.92 t ha⁻¹) and AMB (2.46 t ha⁻¹). Yield was 31.70 % more in EC treatment and 21.95% lower in EO treatment compare to AMB treatment. Harvest index was also significantly influenced by different level of O₃ and CO₂ levels. Harvest index was lowest under EO (36.10%), followed by AMB (39.18%), ECO (40.81%) and highest under EC (44.18%). HI was 12.76% more in EC treatment compare to AMB treatment.

उच्च सतही ओज़ोन एवं कार्बन डाइऑक्साइड का चने की सूक्ष्म मौसमी तथा जैवभौतिकी मापदण्डों पर परस्पर प्रभाव

सारांश

कार्बन डाइऑक्साइड तथा सतही ओज़ोन जैसी हरित गृह गैसों की मात्रा में बढ़ोत्तरी वैश्विक जलवायु परिवर्तन को प्रभावित करने वाले महत्वपूर्ण कारक हैं। सतही ओज़ोन नाइट्रोजन ऑक्साइड के साथ वाष्पशील कार्बनिक यौगिकों के प्रकाश- रासायनिक प्रतिक्रियाओं द्वारा उत्पन्न एक प्रमुख प्रदूषक है। एशियाई देशों में ओज़ोन उत्पादन करने वाले कारकों का उत्सर्जन बढ़ रहा है और निकट भविष्य में भी ओज़ोन का उत्पादन करने वाले कारकों के बढ़ने की संभावना है। उच्च कार्बन डाइऑक्साइड तथा ओज़ोन दोनों के प्रभाव को जाँचने के लिए चने पर कोई अध्ययन नहीं किया गया है। अतः वायुमंडल में बढ़ते ओज़ोन तथा कार्बन डाइऑक्साइड की बढ़ती मात्रा को ध्यान में रखते हुए पर्यावरण विज्ञान एवं जलवायु समुत्थानशील कृषि केंद्र, आई°ए°आर°आई°, पूसा में मुक्त ओज़ोन कार्बन डाइऑक्साइड संवर्धन सुविधा के प्रयोगात्मक क्षेत्र में चने (पूसा 5023) पर एक क्षेत्रीय प्रयोग चार ओज़ोन तथा कार्बन डाइऑक्साइड उपचारों (ECO: उच्च कार्बन डाइऑक्साइड (CO_2) (550 ± 10 ppm) + उच्च ओज़ोन (O_3) (70 ± 10 ppb)); EC: उच्च CO_2 (550 ± 10 ppm) + परिवेश O_3 ; EO: उच्च O_3 + परिवेश CO_2 तथा AMB: परिवेश CO_2 + परिवेश O_3 के अंतर्गत 2016-17 के रबी मौसम में किया गया। सभी उपचारों में नियमित तौर पर मौसम के विभिन्न मापदण्ड, सूक्ष्म मौसमी मापदण्ड (कैनोपी तापमान, CATD, सौर विकिरण अंतर्ग्रहण) मृदा आर्द्रता एवं फसल के विभिन्न मापदण्ड (फेनोलोजी, पत्ती क्षेत्रफल सूचकांक, प्रकाश संश्लेषण की दर, रंध्र चालकता, जैविक भार तथा उपज) दर्ज किए गए। कैनोपी का तापमान विभिन्न उपचारों में अलग अलग पाया गया। बुवाई के 75 दिन उपरांत इसका मान ECO में सबसे अधिक (21.5°C) पाया गया तथा EC, EO एवं परिवेश परिस्थिति में क्रमशः 20.4°C , 19.2°C एवं 18.9°C पाया गया। उच्च CO_2 के कारण 10 दिन तथा उच्च O_3 के कारण 14 दिनों के लिए वृद्धि अवधि में कमी दर्ज की गयी। मुख्य अंतर फली सूत्रपात से परिपक्वता के बीच दर्ज किया गया। पत्ती क्षेत्रफल सूचकांक तथा प्रकाश संश्लेषण की दर EC में सबसे ज्यादा थी तथा EO में सबसे कम थी। कैनोपी विलुप्त गुणांक EC की उपस्थिति में काफी कम पाया गया तथा EO में ज्यादा पाया गया। इस प्रकार EC तथा EO परस्पर एक दूसरे के विरोधी पाये गए। उच्चतम

क्लोरोफिल ($1.20 - 3.76 \text{ mg g}^{-1}$ ताज़ा वजन) उच्च कार्बन डाइऑक्साइड उपचार में पाया गया तथा न्यूनतम क्लोरोफिल ($0.87 - 3.12 \text{ mg g}^{-1}$ ताज़ा वजन) उच्च ओज़ोन उपचार में पाया गया। उच्च CO_2 तथा उच्च O_3 के संयुक्त उपचार में $0.92 - 3.72 \text{ mg g}^{-1}$ ताज़ा वजन, क्लोरोफिल दर्ज किया गया। रंध्र चालकता तथा स्वेद दर दोनों ही EO तथा EC में कम पाये गए तथा AMB में सबसे अधिक पाया गया। RLWC, EC तथा EO दोनों में ही अधिक पाया गया तथा यह ECO में सबसे ज्यादा प्राप्त हुआ जो कि रंध्र चालकता के विपरीत था। EC उपचार में फसल में सबसे ज्यादा जैविक भार (734.68 g m^{-2}) प्राप्त हुआ तथा ECO ($550 \text{ ppm CO}_2 + 70 \text{ ppb O}_3$), 662.28 g m^{-2} तथा EO (70 ppb) में 529.68 g m^{-2} और AMB (परिवेश) में 627.95 g m^{-2} प्राप्त हुआ। अन्य सभी उपचारों की तुलना में, सभी विकास चरणों में बढ़े हुए CO_2 की स्थिति के तहत फसल में उच्चतम जैव भार संचय दर्ज किया गया। उपज विशेषताएँ जैसे पौधों की ऊँचाई, फलियों की संख्या, फली का भार, प्रति पौधा बीज का भार तथा उपज सूचकांक, EC में बहुत ज्यादा पाये गए तत्पश्चात ECO तथा EO में सबसे कम दर्ज किया गया। EC उपचार में 100 बीजों का वजन काफी अधिक पाया गया तथा EO में 100 बीजों का वजन सबसे कम था। ECO और AMB सांख्यिकीय रूप से समान और EC और EO के बीच में पाए गए। बीज प्रोटीन सामग्री EC और EO दोनों द्वारा काफी कम हो गई थी, जिसके कारण ECO में न्यूनतम प्रोटीन सामग्री दर्ज की गयी। सभी चार उपचारों के लिए अनाज की उपज भी अलग थी। EC में सबसे ज्यादा उपज (3.24 टन/हे°) पायी गयी जबकि ECO में 2.70 टन/हे° , EO में 1.92 टन/हे° तथा AMB में 2.46 टन/हे° उपज प्राप्त हुआ। AMB उपचार की तुलना में EC उपचार में 31.70% तथा EO उपचार में 21.95% कम उपज प्राप्त हुआ। उपज सूचकांक भी O_3 और CO_2 स्तर के विभिन्न स्तरों से काफी प्रभावित था। EO उपचार में उपज सूचकांक सबसे कम (36.10%) पाया गया तथा AMB में 39.8% और ECO में 40.81% दर्ज किया गया जबकि EC में यह सबसे ज्यादा (44.18%) था। उपज सूचकांक AMB की तुलना में EC में 12.76% अधिक पाया गया।

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