Short Communication Open Access

Response of maize and its pest *Chilo partellus* to ozone and carbon dioxide exposure

Usha Mina[1]*, Arti Bhatia[1], Uttam Kumar[1]

[1]Centre for Environmental Science and Climate Resilient Agriculture, Indian Agricultural Research Institute, New Delhi-110012, India
*Corresponding author: E-mail: usha_env@iari.res.in

Abstract

In the present study, the direct effect of ozone (O_3) and carbon dioxide (CO_2) exposure on growth and yield of maize (var HQPM 1) and the indirect effect on development of its herbivore pest *Chilo partellus* were investigated. Maize crop was exposed to different concentrations of O_3 and CO_2 in open top chambers (OTCs). During the exposure, maize plants at the early vegetative stage were incubated with *C. partellus* eggs. Changes in biomass and yield of maize plants with and without Chilo infestation under O_3 and CO_2 exposure were monitored. Indirect effects of O_3 and CO_2 on maize pest were monitored with respect to release and survival of larvae, mean body weight of fifth instar stage larvae and emergence of adults from pupae. Higher reductions in aboveground and belowground biomass were observed in maize plants with pest with respect to plants without pest during O_3 and CO_2 exposure. Maximum and minimum reductions in aboveground (39.5% and 4.7%) and belowground biomass (43.0% and 5.4%) were observed in maize plants grown under O_3 and CO_2 treatments, respectively. Reduction in yield varied from 33.8% to 15.2% for maize plants grown under different treatments as compared to plants grown under low O_3 conditions. Significant changes in development of *C. partellus*, fed on tissues of maize plants exposed to different treatments were observed. Moreover, the mean body weight of larvae decreased with increasing O_3 concentrations. Mean body weight was 62% higher and 65% lower for larvae fed on maize plant tissue exposed to CO_2 and CO_2+EO_3, respectively, as compared to maize plants grown under low O_3 conditions. Development of male and female adults from pupae was observed only from larvae isolated from ambient and CO_2 treated maize plants. The present study showed that the exposure of maize crop to O_3 and CO_2 and its pest *C. partellus*, adversely affected not only maize growth and yield but also development of *C. partellus*. This study suggests that predicting the outcome of O_3 and CO_2 on crop-insect pest interactions will require comprehensive examination of behavioural growth of both harmful and beneficial insects of the agro-ecosystem.

Keywords: CO_2, O_3, maize, *Chilo partellus*

Introduction

Ozone (O_3) is a phytotoxic component of the troposphere, causing negative impact on a number of plant processes, including photosynthesis, water use efficiency, timing of senescence, dry matter production and yield (Krupa et al, 2000). Tropospheric O_3 concentration is rising at an annual rate of 0.5 % (Hertstein et al, 1999). According to IPCC 4th assessment report (2007), the current tropospheric O_3 concentrations during the summer months over the continental land masses (of the northern hemisphere) are about 30-40 ppb, the corresponding value will become 45-50 ppb in 2030, 55-60 ppb in 2060 and 65-70 ppb in 2100. Economic value of losses due to O_3 was $17-$82 million in US, 310 million euros in Netherlands and $2 billion in China (Mauzerall and Wang, 2001). It is well known that increasing O_3 levels at current ambient CO_2 levels cause a decline in the yield of many crop species (Fuhrer and Booker, 2003). Concentrations of CO_2 have risen from pre-industrial levels of about 275 ppm to 370 ppm today and are expected to increase up to 450-600 ppm CO_2 by the middle of the 21st century (Plessl et al, 2007). In the future, elevated O_3 levels will play a key role in determining the magnitude of yield enhancement by elevated levels of CO_2 (Fuhrer, 2003). In India also, the phytotoxic impact of O_3 on growth and yield of several crops were reported (Bambewala, 1986; Varshney and Rout, 1998; Tiwari et al, 2005; Mina et al, 2010). It has been also reported that besides the crops, their insect and pathogenic pests are directly or indirectly affected, either negatively or positively, by the elevated O_3 and CO_2 levels (Fuhrer, 2003).

Maize in India is the third most important crop after rice and wheat and it is predicted to become the world's most important crop, in terms of human food supply, by 2050 (Pingali, 2001). In India, there has been a continuous increase in area under maize cultivation. During 2010-11, the area under maize cultivation reached 8.55 Mha with a production of 21.73 million tones and yield of 2540 kg/ha (DAC, annual report, 2010-11). The occurrence of crop insects' pests is a key constraint with global average yield losses and production costs. *Chilo partellus*, popu-

RECEIVED 08/27/2012

larly known as stalk borer is a major pest of maize. In India, it attacks maize in the early whorl stage and causes yield losses of 27 to 80% in various agro climatic regions (Hari et al, 2008). Changes in the occurrence of pest incidences due to climate change are of ecological and economical importance. By affecting crops health, O_3 stress and CO_2 enrichment are likely to affect the interaction between crop and insect pests. They may do so not only through an effect on the crop, but also by affecting insect growth rate, dispersal, fecundity, pheromone detection, host finding, and mortality. There is little information, however, about the impact of O_3 stress and CO_2 on pest species. It may be possible that increasing levels of O_3 and CO_2 in future may affect maize crop productivity as well as its insect pest's dynamics. Reports on this aspect from India are completely lacking. With this background and hypothesis we initiated a field study on maize and its key pest *C. partellus* to examine direct impact of O_3 and CO_2 on the growth, yield of maize and indirect impact on development of its pest *Chilo partellus*.

Materials and Methods

Maize (variety HQPM-1) crop plants were grown in Open Top Chambers (OTCs) and exposed to different concentration of O_3 alone and in combination with elevated level of CO_2 from seedling stage to till maturity stage. The different concentration of O_3 and CO_2 to which maize plants exposed were:

i) Ambient - ambient air (chamber less plots) concentration varied between 12-72 ppb O_3 and 370-385 ppm of CO_2; ii) NF (Non Filtered) - non filtered air supplied in OTC contains a 5-10% lower O_3 concentration than ambient; iii) CF (Charcoal Filtered) - charcoal filtered air supplied to OTC contains a 80-85% lower O_3 concentration than ambient; iv) EO_3 (Elevated O_3) - air supplied to OTC contains ambient O_3 + 25-30 ppb O_3; v) ECO_2 (Elevated CO_2) - air supplied to OTC contains 500 ± 50 ppm)CO_2 and non filtered air having a 5-10% lower O_3 concentration than ambient; vi) ECO_2 + EO_3 (Elevated CO_2 and O_3) - air supplied to OTC contains 500 ± 50 ppm CO_2 and ambient O_3 + 25-30 ppb O_3.

Incubation of Chilo partellus on maize plants

Eggs of *C. partellus* were incubated on maize plants at early vegetative stage (21 day old plants). For incubation, black headed eggs (ready to hatch) were transferred by brush on a moist filter paper. Moist filter papers containing eggs were stapled on the lower side of leaves near the midrib of the maize plant in OTCs.

Growth and Yield of maize

Forty days old maize plants, infested with and without Chilo under different treatments in OTCs, were harvested and monitored for changes in aboveground and belowground biomass. For biomass monitoring, aboveground and belowground parts were oven dried at 60°C for 7 days and weighed. Maize plants incubated with pest under different treatments exhibited 'deadheart' symptoms, due to larval feeding at the growing point into the stem, and stunted growth. These plants did not reach the inflorescence stage, so yield data is not available. However, yield data for maize plants grown without pest under different treatment in OTCs were recorded at maturity.

Growth and development of Chilo partellus

The developmental behaviour of *C. partellus* from eggs hatching to attainment of adulthood was observed and recorded with respect to each treatment. Neonate larvae released from the eggs till the fifth instar stage obtained nutrition by feeding on maize plants exposed to different O_3 and CO_2. At the fifth instar stage, larvae were removed from their host (40 day old) and observed for body weight. For observing completion of different growth stages by larvae isolated from different treatments, they were kept in incubator at 28°C temperature in an aerated container. Larvae were regularly monitored for the time taken in attaining pupae stage followed by adult stage. The statistical analysis of the experimental data was done using JMP 8 statistical software.

Results and Discussion

Results of the study showed that O_3 and CO_2 treatments adversely affected growth and yield of maize plants as compared to CF treatment. Results also showed variable growth and development response of *C. partellus* isolated from maize plants grown under different O_3 and CO_2 treatments.

Higher reductions in aboveground and belowground biomass were observed in maize plants with pest as compared to maize plants without pest un-

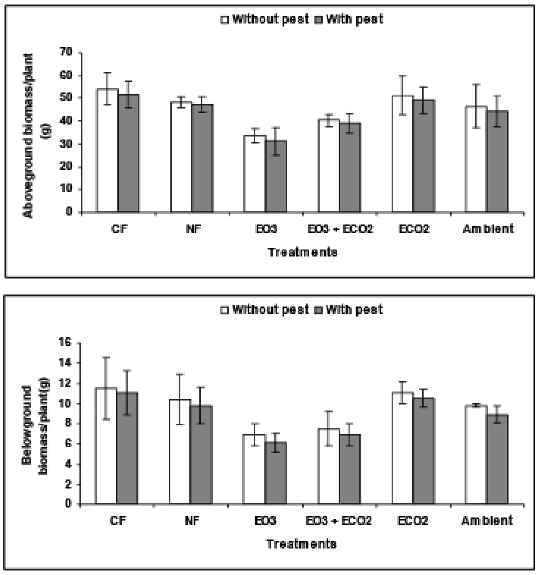

Figure 1 - Aboveground and belowground biomass of maize plants under different treatments Vertical line above the bar indicates ± SEM.

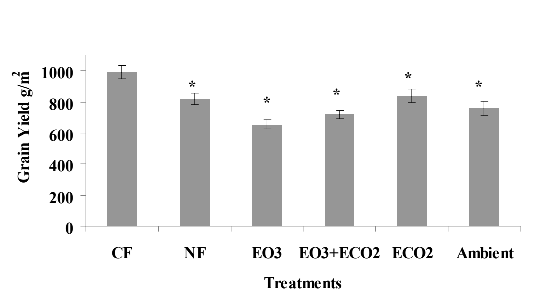

Figure 2 - Yield of maize under different levels of O_3 and CO_2. Vertical bars represent standard error of the mean. * indicates statistically ($p<0.05$) significant differences.

der all treatments (Figure 1). Maximum reduction in aboveground (39.5%) and belowground biomass (43.0%) was observed in pest infested and EO_3 treated maize plants. Minimum reduction in aboveground (4.7%) and belowground biomass (5.4%) was observed in pest infested and ECO_2 treated maize plants. This suggest that EO_3 levels adversely affects growth of maize plants, whereas ECO_2 to some extent mitigating negative impact of O_3. Earlier Heagle et al (1972) reported fresh weight of ears, number of kernels, and dry weight of kernels on plants receiving 10 pphm, 6 hr/day from emergence to harvest, were significantly reduced (5% level) with respect to the controls in the Golden Midget sweet corn variety of maize. However, biomass response of maize to ECO_2 in the present study is similar to Rudorff et al (1996), who reported a 4% increase in dry biomass and in contrast with the observation of Hocking and Meyer (1991). These authors reported the lack of a significant dry matter response in maize to CO_2 enrichment. Higher biomass reduction with pest infestation indicates an additive effect of pest infestation and O_3 stress.

In the present study, yield reductions from 33.8% to 15.1% were observed for maize plants grown under different treatments as compared to maize plants grown under CF treatment (Figure 2). Maximum (33.8%) and minimum (15.2%) reduction in yield were observed in maize plants exposed to EO_3 and ECO_2 treatments, respectively. Whereas maize plants grown under NF, Ambient and EO_3 + ECO_2 showed 17.2%, 23.7% and 27.3% yield reductions, respectively, as compared to CF treated plants. This result indicates that growth and yield of maize crop were adversely affected by O_3 stress. A significant decrease in grain yield (9%) of maize (cv Pioneer 3714) due to O_3 exposure was also reported by Rudroff et al (1996). It is likely that reduced grain production in the EO_3 treatment was caused by O_3 damage during the flowering process. Reductions in grain yield under EO_3 + ECO_2 treatment were less as compared to EO_3 exposure, indicating that CO_2 enrichment partially counteracted the damaging effect of O_3 exposure. Similarly, Cure and Acock (1986), also reported an average yield increase of 41% after doubling the CO_2 concentration. However, Hocking and Meyer (1991) reported that corn yield was not sensitive to CO_2 enrichment. Similar results were also noted by Surano and Shinn (1984) for corn grown in OTCs under enriched CO_2 environment. This inconsistency between results of present and other previous studies may be due to varietal differences and variations in experimental and environmental conditions.

In the present study, the indirect effect of O_3 and CO_2 enrichment on the survival and growth of larvae of Chilo partellus released from incubated eggs on maize plants grown under different treatments were observed. Variations were observed in survival of the neonate larvae with respect to different treatments. The maximum number of larvae survived on maize plants under ECO_2 treatment, followed by maize plants grown under Ambient treatment. On CF and NF treated maize plants, equal numbers of larvae survived, whereas minimum and no larvae survived on EO_3 + ECO_2 and EO_3 treated maize plants, respectively (Figure 3). These observations are contrasting to Heagle et al (1994) and Hummel et al (1998), who observed that elevated O_3 increased herbivore development as well as foliar sugar and starch in some host-plant systems. Our observations further confirm and are in line with the report of Butler and Trumble (2008) that out of 203 herbivores, 153 herbivores' fitness and population density were affected due to the impact of a polluted environment on plants.

At fifth instar stage, when larvae were removed from their respective host maize plants (on which they were feeded and developed), grown under the different treatments, differences in their body weight were observed. Mean body weight was observed highest (0.26 ± 0.04 g) for larvae collected from ECO_2 treated maize plants, followed by maize plants grown under Ambient treatment (0.21 ± 0.02 g). Mean body weights were 0.20 ± 0.03 g and 0.10 ± 0.02 g for larvae collected from CF and NF treated maize plants, respectively. The lowest observed mean body weight was 0.09 ± 0.01 g for the EO_3 + ECO_2 treatment. This suggests that ECO_2 is beneficial both to plants and Chilo's growth and development. Whereas in literature, it has been reported that out of 4 orders of insects in 14 families studied for their response to ECO_2 only few benefited from the CO_2 treatment (Butler and Trumble, 2008). This beneficial effect of ECO_2 was not sustained when used in combination with EO_3 i.e., ECO_2 is unable to abolish the adverse effect of EO_3.

After recording mean body weight, larvae were transferred to incubators for further observations with respect to other growth stages. Variability in development response was observed. Larvae isolated from Ambient and EO_3 + ECO_2 treated maize plants were able to complete pupae and adult stages. Larvae isolated from NF and ECO_2 maize treated plants reached the pupae stage but did not develop into adults. This suggests that the initial diet that the larvae received

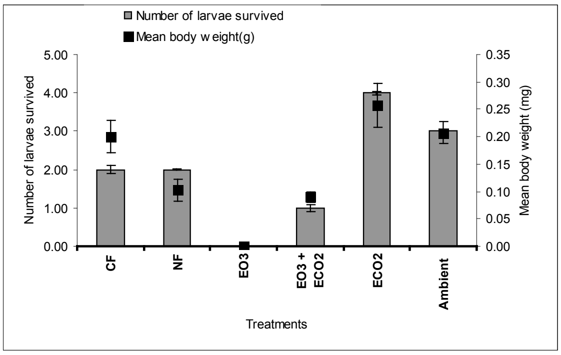

Figure 3 - O_3 and CO_2 exposed maize plants effect on survival and weight of *Chilo partellus* larvae.

at early stages of their life cycle from maize plants under different treatments played a detrimental role in their later growth stages. No recovery of yield of pest infested maize plants indicates towards the damage causing potential of Chilo. Results of the present study on the indirect effect of O_3 and CO_2 on Chilo will be helpful for developing strategies for management of its infestation in maize.

The present study showed that a direct exposure of the maize crop to EO_3 and EO_3 + ECO_2 and its indirect exposure to its pest *C. partellus* adversely affected not only maize growth and yield but also the development of *C. partellus* as compared to Ambient and ECO_2 treatments. This study suggests that predicting the outcome of O_3 and CO_2 on crop-insect pest interactions will require comprehensive examination of behavioural growth of both harmful and beneficial insects on stressed plants. However, crops and their insect pest's responses to changes in single (O_3) or double drivers (O_3 and CO_2) of climate change cannot simply be scaled up to responses to changes in multiple drivers. There is a clear need for a combined approach of multifactorial experiments to improve the understanding and predictions on the impacts of air pollutants on crop-pest interactions.

Acknowledgements

Financial support was provided by the Indian Council for Agricultural Research (ICAR) to the Centre for Environmental Science and Climate Resilient Agriculture, IARI. New Delhi, India.

References

Bambawale OM, 1986. Evidence of ozone injury to a crop plant in India. Atmos Environ 20: 1501-1503

Butler CD, Trumble JT, 2008. Effects of pollutants on bottom-up and top-down processes in insect-plant interactions. Environ Pollut 156: 1-10

Cure JD, Acock B, 1986. Crop responses to carbon dioxide doubling: a literature survey. Agricul and Forest Meteor 38: 127-145

Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India. Annual report 2010-2011. New Delhi, India

Fuhrer J, 2003. Agroecosystem response to combination of elevated CO_2, ozone and global climate change. Agricult Ecosyst Environ 97: 1-20

Fuhrer J, Booker F, 2003. Ecological issues of ozone: agricultural issues. Environ Internat 29: 141-154

Hari NS, Jindal J, Malhi NS. 2008. Resistance of Cry-1Ab maize to spotted stemborer *Chilo partellus* (Lepidoptera: Crambidae) in India. Inter J Trop Insec Sci 27: 223–228

Heagle AS, Body DE, Pounds EK, 1972. Effect of ozone on yield of sweet corn. Phytopathology 62: 683

Heagle AS, Brandenburg RK, Burns JC, Miller JE, 1994. Ozone and carbon-dioxide effects on spider-mites in white clover and peanut. J Environ Qual 23: 1168–1176

Hertstein U, Colls J, Ewert F, van Oijen M, 1999. Climatic conditions and concentrations. Climatic conditions and concentrations of carbon dioxide and air pollutants during "ESPACE-wheat" experiments. Europ J Agro 10: 163-169

Hocking PJ, Meyer CP, 1991. Effects of CO_2 enrichment and nitrogen stress on growth, and partitioning of dry matter and nitrogen in wheat and maize, Aus J Pla Physio 18: 339-356

Hummel RL, Brandenburg RL, Heagle AS, Arellano C, 1998. Effects of ozone on reproduction of twospotted spider mite (Acari: Tatrachynidae) on white clover. Environ Entomo 27: 388–394

IPCC, 2007. Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK

Krupa SV, McGrath MT, Andersen CP, Booker FL, Burkey KO, Chalpeka AH, Chevone BI, Pell EJ, Zilinskas BA, 2000. Ambient ozone and plant health. Plant Disea 85 (1): 4-11

Mauzerall DL, Wang X, 2001. Protecting agricultural crops from the effects of tropospheric ozone exposure reconciling science and standard setting. Annu Rev Energy Environ 26: 237-268

Mina U, Kumar P, Varshney CK, 2010. Response of different growth stages of Potato (*Solanum tuberosum*) to ozone stress. Phyton 49(2): 253-266

Mulholland BJ, Craigon J, Black CR, Colls JJ, Atherton J, Landon G, 1997. Effects of elevated carbon dioxide and ozone on the growth and yield of spring wheat (*Triticum aestivum* L). J ExperimBot, 48 (306): 113-122

Plessl M, Elstner EF, Rennenberg H, Habermeyer J, Heiser I, 2007. Influence of elevated CO_2 and ozone concentrations on late blight resistance and growth of potato plants. Environ Experim Bot 60: 447 – 457

Pingali PL, 2001. CIMMYT 1999–2000 Facts and Trends. Meeting World Maize Needs: Technological Opportunities and Priorities for the Public Sector. CIMMYT, Mexico City

Rudorff BFT, Mulchi CL, Lee EH, Rowland R, Pausch

R, 1996. Effects of enhanced O_3 and CO_2 enrichment on plant characteristics in wheat and corn. Environ Pollut 94 (1): 53- 60

Surano K A, Shinn JA, 1984. CO_2 and water stress effects on yield, water-use efficiency, and photosynthate partitioning in field grown corn, UCRL-90771, Lawrence Livermore National Laboratory, Livermore, CA

Tiwari S, Agrawal M, Manning WJ, 2005. Assessing the impact of ambient ozone on growth and productivity of two cultivars of wheat in India using three rates of application of ethylenediurea (EDU). Environ Pollut 138: 153-160

Varshney C, Rout C, 1998. Ethylene diurea (EDU) Protection against ozone injury in Tomato Plants at Delhi. Bull Environ Contam Toxicol 61(2): 188-193