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Effect of elevated tropospheric ozone on methane and nitrous oxide emission from rice soil in north India

A. Bhatia*, A. Ghosh, V. Kumar, R. Tomer, S.D. Singh, H. Pathak

Division of Environmental Sciences, Indian Agricultural Research Institute, New Delhi 110012, India

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ABSTRACT

Physiological changes in crop plants in response to the elevated tropospheric ozone (O_3) may alter N and C cycles in soil. This may also affect the atmosphere–biosphere exchange of radiatively important greenhouse gases (GHGs), e.g. methane (CH_4) and nitrous oxide (N_2O) from soil. A study was carried out during July to November of 2007 and 2008 in the experimental farm of Indian Agricultural Research Institute, New Delhi to assess the effects of elevated tropospheric ozone on methane and nitrous oxide emissions from rice (*Oryza sativa* L.) soil. Rice crop was grown in open top chambers (OTC) under elevated ozone (EO), non-filtered air (NF), charcoal filtered air (CF) and ambient air (AA). Seasonal mean concentrations of O_3 were 4.3 ± 0.9, 26.2 ± 1.9, 59.1 ± 4.2 and 27.5 ± 2.3 ppb during year 2007 and 5.9 ± 1.1, 37.2 ± 2.5, 69.7 ± 3.9 and 39.2 ± 1.8 ppb during year 2008 for treatments CF, NF, EO and AA, respectively. Cumulative seasonal CH_4 emission reduced by 29.7% and 40.4% under the elevated ozone (EO) compared to the non-filtered air (NF), whereas the emission increased by 21.5% and 16.7% in the charcoal filtered air (CF) in 2007 and 2008, respectively. Cumulative seasonal emission of N_2O ranged from 47.8 mg m^{-2} in elevated ozone to 54.6 mg m^{-2} in charcoal filtered air in 2007 and from 46.4 to 62.1 mg m^{-2} in 2008. Elevated ozone reduced grain yield by 11.3% and 12.4% in 2007 and 2008, respectively. Global warming potential (GWP) per unit of rice yield was the least under elevated ozone levels. Dissolved organic C content of soil was lowest under the elevated ozone treatment. Decrease in availability of substrate i.e., dissolved organic C under elevated ozone resulted in a decline in GHG emissions. Filtration of ozone from ambient air increased grain yield and growth parameters of rice and emission of GHGs.

1. Introduction

Since the industrial revolution anthropogenic activity has increased the concentration of tropospheric ozone (O_3) (Vingarzan, 2004), which is an air pollutant and a greenhouse gas (GHG). Global mean values of tropospheric ozone have increased from an estimated pre-industrial level of 38 ppbV (US EPA, 1996) to about 60 ppbV during mid-summer with even greater local concentrations in nearly one-quarter of the earth's surface (Morgan et al., 2006). Formation of ozone in the troposphere depends on solar energy level received at earth surface and higher concentrations occur from May to September in the afternoon in the northern hemisphere (Stockwell et al., 1997).

Elevated ozone is known to decrease net photosynthesis via oxidative damage to cell membranes, chloroplasts (Karberg et al., 2005) and consequently reduces dry matter production (Feng et al., 2007). Physiological changes in roots in response to elevated ozone can lead to significant alterations in below ground soil processes, nutrient cycling and microbial activities (Andersen, 2003). The ozone pollution is reported to have a substantial effect on agricultural production in North America, Western Europe (Wang et al., 2005) and Asia (Wahid, 2006). Cereals are highly sensitive and have shown decreased yields with increasing O_3 levels. There may be tremendous losses of crop yields in India also due to rising O_3 concentration in the troposphere (Rai and Agrawal, 2008; Singh et al., 2010).

With increasing levels of tropospheric ozone there might be changes in the C and N cycles in soils (Islam et al., 2000; Larson et al., 2002) affecting emissions of GHGs such as methane (CH_4) and nitrous oxide (N_2O). There is limited knowledge on the effect of tropospheric ozone levels on the emission of GHGs from rice (*Oryza sativa* L.) soils which are considered to be one of the major sources of GHGs. The objectives of the study were to (a) assess the impact of

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Abbreviations: O_3, ozone; CH_4, methane; N_2O, nitrous oxide; EO, elevated ozone; CF, charcoal filtered air; NF, non-filtered air; AA, ambient air; OTC, open-top chambers; GHG, greenhouse gas; DAT, days after transplanting; AOT40, accumulated exposure over a threshold of 40 ppbV; FID, flame ionization detector; ECD, electron capture detector; TTC, triphenyl tetrazolium chloride; GWP, global warming potential; ppb, parts per billion; DOC, dissolved organic carbon; SOC, soil organic carbon; NH_4^+–N, ammonical nitrogen; NO_3^-–N, nitrate nitrogen.

* Corresponding author. Tel.: +91 11 25841490; fax: +91 11 25841866.
E-mail addresses: abensc@gmail.com, artibhatia.iari@gmail.com (A. Bhatia).

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Table 1
Mean seasonal O_3, SO_2 and NO_2 concentrations and AOT 40 (accumulated exposure over a threshold of 40 ppbV of ozone) values in different ozone treatments.

Treatment	Seasonal mean O_3 (ppb)		AOT 40 (ppmV h)		Seasonal mean SO_2 (ppb)		Seasonal mean NO_2 (ppb)	
	2007	2008	2007	2008	2007	2008	2007	2008
Ambient air (AA)	27.5 ± 2.3	39.2 ± 1.8	3.54 ± 0.43	4.1 ± 0.32	17 ± 2.2	22 ± 1.8	28 ± 3.2	34.5 ± 1.5
Non-filtered air (NF)	26.2 ± 1.9	37.2 ± 2.5	3.3 ± 0.2	3.8 ± 0.31	18 ± 1.1	21 ± 2.2	29 ± 3.1	33.5 ± 2.6
Charcoal filtered air (CF)	4.3 ± 0.9	5.9 ± 1.1	0	0	2.5 ± 1.5	3.2 ± 2.6	4.7 ± 3.0	5.01 ± 2.2
Elevated ozone (EO)	59.1 ± 4.2	69.7 ± 3.9	14.1 ± 1.3	19.2 ± 1.8	19 ± 1.8	20 ± 1.4	27 ± 2.5	31.5 ± 3.8

± refers to standard deviation within replicate OTCs.

tropospheric ozone on the emissions of methane and nitrous oxide from soils in rice and (b) quantify the effect of increased ozone concentration on growth and yield of rice.

2. Materials and methods

2.1. Experimental site and soil

A field experiment was conducted growing rice in kharif (July to October) during 2007 and 2008 in the research farm of Indian Agricultural Research Institute (IARI), New Delhi, situated at 28°40′N and 77°12′E, at an altitude of 228 m above mean sea level. The climate of Delhi is continental type and is characterized by important annual variation in temperature, the summers are very hot and winters are cold. Average rainfall of this area is 75 cm annually, approximately 80% of which occurs during kharif season. The mean maximum and minimum temperatures from July to October are 35 and 18 °C. The alluvial soil of experimental site was silty clay loam (Typic Ustochrept) with bulk density of 1.38 g cm^{-3}, pH (1:2 soil:water) of 8.8, electrical conductivity of 0.43 dS m^{-1}, cation exchange capacity of 7.3 C mol (p^+) kg^{-1}; and organic carbon, total N, Olsen P, and ammonium acetate extractable K contents of 3.5 g kg^{-1}, 0.32 g kg^{-1}, 0.009 g kg^{-1}, and 0.12 g kg^{-1}, respectively.

2.2. Treatments and crop management

Rice crop was grown in open-top chambers (OTCs) of 3 m diameter and 2.5 m height consisting of a circular aluminum frame covered with transparent film. The experiment was carried out with four treatments arranged in randomized block design with three replications. The treatments were: charcoal filtered air (CF), elevated ozone (EO) and non filtered air (NF) and chamber less ambient control (AA) (Table 1). The OTCs were fitted with an inert PVC pipe of 10 cm diameter (adjustable height) with many small holes which released either charcoal filtered air (CF), non-filtered air (NF) or elevated ozone along with non-filtered air (EO) at the crop canopy level. Air was blown into the OTCs through a fan that provided uniform air speeds. The ventilation rates were kept at 3 air changes per minute to keep the leaf boundary layer resistances down and the chamber temperature close to ambient. In the EO treatment 25–35 ppb of additional ozone was maintained over the non-filtered air levels. O_3 was applied for 7 h d^{-1} for 5 d $week^{-1}$ (09.30–16.30 h) in the elevated O_3 chambers. Additional O_3 was generated from oxygen with the help of reaction with UV radiation < 200 nm using ozone generators (Systocom, Varanasi, India). Air was sampled from the middle of each OTC at the crop canopy level and fed to an O_3 analyzer (Model APOA-370, Horiba, Germany) for measuring the ozone concentrations daily from 9.30 to 16.30 h. In order to segregate treatment effects from chamber effects, and to reduce the effect of environmental heterogeneity within the chambers, plants were randomized within the chambers, on weekly basis throughout the experiment. The light intensity inside and outside the OTCs was measured using a portable light meter (Metravi 1332), temperature with a constantan-copper thermocouple and relative humidity was measured using a digital humidity sensor at 10.00 and 16.00 h daily.

Transplanting of seedlings of a popular Indian rice variety Pusa Sugandh-5 (PS-5) was carried out in 5 replicate crates (size 0.24 m^2) at 15 cm by 15 cm spacing, in each chamber on 18th July, 2007 and 24th July, 2008. Crops were harvested at maturity on 6th November, 2007 and 13th November, 2008. O_3 exposure began on 20th July, 2007 and 25th July, 2008 and ended on 26th October, 2007 and 30th October, 2008 respectively when it was ripe. Charcoal filters adsorbed ozone from ambient air blown inside the OTCs and lowered the ozone concentrations by 80–85% of the ambient air. The non-filtered (NF) treatment was the control treatment and a 5% decrease in concentration than the ambient ozone levels was observed in this treatment. The seasonal ozone concentrations during the experiment period i.e. in the month of July to November 2007 and 2008 are shown in Fig. 1. The peak average concentrations were observed during September and October months. Cumulative ozone exposure above 40 ppb during daylight hours was characterized by the AOT40 index (Fuhrer et al., 1997) and is listed in Table 1.

Urea at the rate of 12 g m^{-2} was added to rice in three splits of 6, 3, and 3 g m^{-2} at 0, 30 and 60 d after transplanting (DAT). The soil in rice was saturated with water till 82 DAT. Weeds, pests, and diseases were controlled as required.

2.3. Collection and analysis of gas samples

Collection of gas samples for CH_4 and N_2O was carried out by the closed-chamber technique (Hutchinson and Mosier, 1981). Chambers of 15 cm × 15 cm × 100 cm ($L \times B \times H$) made of 6 mm transparent acrylic sheets were placed over the plants for sampling of CH_4 and N_2O. A small rotary fan was fixed in each chamber for mixing of air inside the chamber. Temperature and pressure

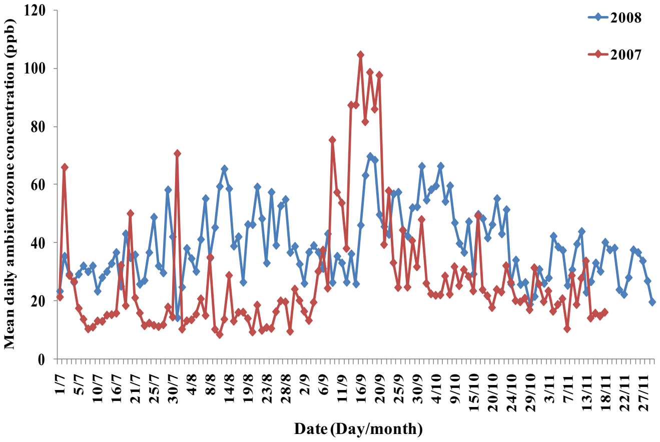

Fig. 1. Mean daily ambient ozone concentrations during crop growth period in 2007 and 2008.