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Assessment of Surface Ozone levels at Agra and its impact on Wheat Crop

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Abstract

Ozone is currently the most important air pollutant that negatively affects growth and yield of agricultural crops in most parts of the world, and wheat is arguably the most important food crop in the Northern India. The higher ozone concentration in different regions is posing threat to food production. Measurement of surface ozone was made during the growing season (January-March 2011) of wheat crop at Agra. The daytime maximum was found to vary from 62–72 ppb and minima varied from 20–23 ppb. The effect of ozone on crop yield has been examined using exposure indices AOT40 and SUM06. The calculated AOT40 (2562 ppbh) and SUM06 (7470 ppbh) were found below the critical levels thereby indicating that wheat crop grown in Agra is safe from the threats of existing surface ozone levels.

Introduction

Surface ozone (O_3) is a secondary air pollutant produced from photochemical reactions involving the oxidation of volatile organic compounds (VOC) and carbon monoxide (CO) in the presence of nitrogen oxides (NOx) [1]. Enhanced concentrations of ozone are ubiquitous to most of the populated regions of the world, where the burning of biofuels and/or fossil fuels used for cooking, heating, transportation and the generation of energy cause the emission of VOC, CO and NOx and thus the photochemical generation of ozone. Rise in concentration of surface ozone is most likely to threaten food production across the globe due to its phytotoxicity and prevalence over important agricultural regions of North America, Europe and Asia [2–4].

Ozone affects plant production by diffusing into the leaf via the stomata and then in intercellular air spaces where it dissolves in water contained in mesophyll cell walls and leads to production of reactive oxygen species. Early symptoms of chronic ambient air exposure are decreased rate of photosynthesis, accelerated senescence and decreased leaf area. The ability of elevated surface ozone to damage agricultural crops has been well documented by research projects conducted in the United States (US) and Europe in the 1980s and 1990s, i.e. the US National Crop Loss Assessment Network (NCLAN) [5] and European Crop Loss Assessment Network (EUCLAN) programs using Open Top Chamber (OTC). NCLAN results indicate a reduced annual soybean yield of 10% and a reduced cotton yield of 12% for seasonal mean O_3 mixing ratios greater than 50 ppbv [6]. Fuhrer et al., [7] modeled a reduction of yield with increasing O_3 over a 40 ppbv threshold, resulting in a 10% reduction in spring wheat yield for O_3 mixing ratios in southern Europe. AOT40 and SUM06 are the different indices that account for threshold effects of O_3. Pleijel et al., [8] compared a number of these indices for wheat and potatoes and concluded that the threshold-based flux best captured O_3 damage to crop yield. Nevertheless, Ozone-crop-effects studies have shown that a reasonably robust estimate of the impact of ozone exposure on net crop yields can be obtained through the use of indices that track exposure over an entire season [9,10]. Such indices are SUM06; AOT40; W126 and N100 [11].

In India, studies conducted on test crop plants wheat (*Triticum aestivum*), mustard (*Brassica campestris*), mung bean (*Vigna radiata*) and spinach showed significant decrease in yield at a rural site experiencing

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high ozone concentration as compared to low O_3 site [12]. At Dayalbagh, wheat crop is harvested in the month of April. Therefore in this study, we present the diurnal variation of O_3 measured at Dayalbagh, Agra during the growing season of wheat crop i. e. January-March. Preliminary assessment of the effects of O_3 pollution on wheat crop is discussed using exposure indices like AOT40 and SUM06.

Experimental

Sampling Site

Agra is situated at latitude of 27°10 ON and longitude of 78°05 OE with an altitude of 169 m above the sea level in the semi-arid zone of India. It is positioned with the Thar Desert of Rajasthan to the West, central hot plains to the South, Gangetic plains to the East and cooler hilly regions to the North. Study was carried out at Dayalbagh Educational Institute Campus. It is a small suburban site with no industrial activity around. Dayalbagh is a small residential community lying immediately outside the city where agricultural activities predominate. The sampling site lies by the side of a road that carries mixed vehicular traffic, moderate (of the order of 1000 vehicles) during the day and minimal (of the order of 100 vehicles) at night. The campus lies about 2 km north of the National Highway-2 (NH-2) which has dense vehicular traffic (10^6 vehicles) throughout the day and night. Agra has a continental type of climate characterized by extreme dryness in summer and cold winters with calm periods. The summer in Agra is hot with intense solar radiation and is dominated by strong southeasterly winds (wind speed ranges from 10–16 kmh^{-1}). Intense solar radiation varies from 19–23 Wm^{-2}. The winters are associated with calm periods of about 40 % (wind speed ranges from 0.5–5 kmh^{-1}).

Instrumentation

Surface O_3 concentrations were recorded using continuously operating O_3 analyzer (Thermo Fischer Model 49i) from January-April 2011. The ozone concentration measurement is based on ultraviolet absorption photometry, resting upon absorption of radiation of wavelength 254 nm by ozone in the analyzed sample. The radiation source is a UV-lamp and clean air (zero) and the sample itself are alternately measured in cells. The minimum detection limit and precision of the analyzer is about 0.5 ppb and 1 ppb respectively.

Results and Discussion

Diurnal Variation of O_3

Fig. 1 gives the representative diurnal variation of O_3 observed during the study period. The variation in ozone concentration exhibits marked diurnal variability, with high concentrations during the day and low concentrations during night. With the onset of sunshine, ozone concentration starts increasing gradually, becomes maximum (62–72 ppb) in noon when the solar radiation and temperature reaches at their maximum. The concentration further starts decreasing with the diminishing of sunshine and becomes minimum (20–23 ppb) at night and early morning hours. The maximum concentrations during noontime are attributed to photochemical production of O_3 in presence of precursor gases such as CO, CH_4 and NMHCs in presence of sufficient amount of NOx and proceed via following set of reactions:

$$\mathbf{NO_2 + h\nu\ (\lambda < 420\,nm) \rightarrow NO + O}$$
$$\mathbf{O + O_2 + M \rightarrow O_3 + M}$$

Boundary layer height also rises gradually after sunrise and reaches maximum during local noontime due to convective heating and starts descending as the temperature starts decreasing in the evening after sunset. The decrease in night-time O_3 concentrations is mainly due to titration of O_3 by surface emission of NO and ground level destruction of O_3 in a shallow boundary layer involving the loss of O_3 by NO ($O_3 + NO \rightarrow O_2 + NO_2$). Similar patterns of seasonal variation have also been observed at other sites like Gadanki and Anantapur in India during the past decade [14, 15].

During the study period, hourly O_3 concentrations were often in excess of 80–90 ppb and reached as much as 100 ppb in the noontime. High temperature favors O_3 formation. The mean temperature remains low (23–27 °C) during January and February but rises rapidly in March and April (35–38 °C) and so the ozone concentrations. Fig. 2 shows the variation of O_3 as a function of time as a contour during the study period.

Exposure Indices

Apart from its important climatic implications, O_3 is also known to have phytotoxic effects. Ozone is regarded as the most important component associated with agricultural crop damage. Ozone has strong oxidizing properties and leads to inhibited photosynthesis, respiration, nutrient uptake which leads to reduced yields of agricultural crops. Several approaches have been tried to define robust exposure indices. Two such exposure indices, AOT40 and SUM06 had been used in the present study to discuss the ozone exposure to wheat crop. AOT40 is used as the main exposure index for ozone effects on plants, including crops [15] and SUM06 is used in applied studies and for setting air-quality standards [16].

AOT40 is calculated as the sum of differences between the hourly mean concentrations (O_3) and 40 ppb for hours when $O_3 > 40$ ppb, for each daylight hour with global radiation ≥ 50 Wm^{-2} over a 3 month period:

$$\text{AOT 40} = \sum_{n=1}^{n}([O_3] - 40)_i \text{ for } [O_3] > 40 \text{ ppb},$$

where n is the number of hours (*i*) that the threshold of 40 ppb is exceeded. For studies of wheat in Europe it has been shown that AOT40 gives better performance as an exposure index [17].

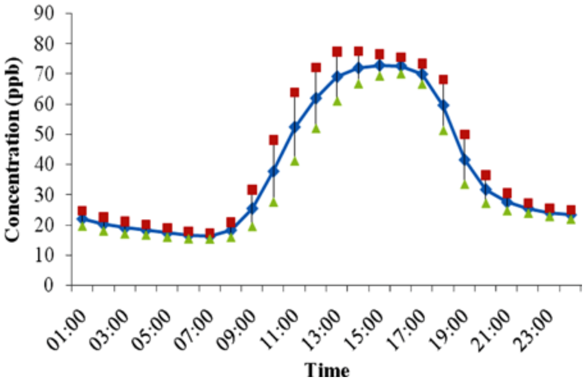

Fig. 1: Diurnal variation of Ozone

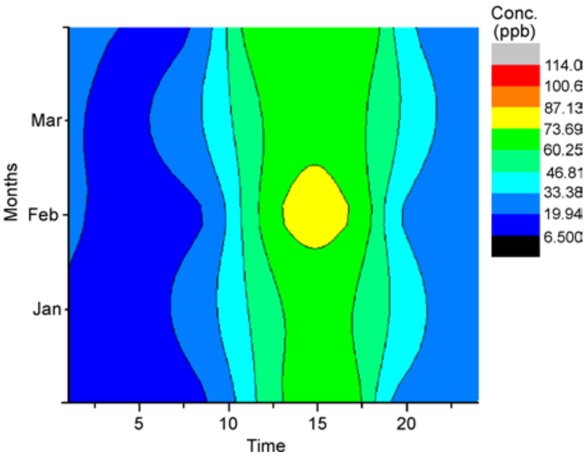

Fig. 2: Contour plot of Ozone

An AOT 40 value of 10,000 ppb h for daylight hours (radiation > 50 W m^{-2}) over a 6 month period has been established as a critical level for the protection of forests. While, for the protection of agricultural crops of 5 % loss in yield, an AOT 40 value of 3000 ppb h for daylight hours over 3 months growing season and 5300 ppb h specially for cereal crops has been established as the critical level [18,19]. The calculated AOT40 during the growing season of wheat crop (January-March) was observed to be 2562 ppbh which is below the critical levels (3000 ppb h) of O_3 (Fig. 3). This indicates that the crop growing in the vicinity of sampling site is not affected by enhanced levels of O_3 and therefore the yield loss of crop might not take place.

SUM06 is defined as the sum, over a 3-month period, of the hourly ozone concentrations for daylight hours (0700–0900 h) when the concentration (O_3) is at or above 60 ppbh (0.06 ppmh):

$$\text{SUM06 (ppmv-hour, ppmh)} = \sum_{n=1}^{n}(CO_3)_i$$
$$\text{for } CO_3 \geq 60 \text{ ppb in months},$$

where n is the number of hours (*i*) that the threshold is exceeded. Table 1 gives the critical levels for different species of wheat.

Table 1: Critical Levels for Different Species of Wheat

Crop	Species	12 hour SUM06
Wheat	ABE	25,100
	ARTHUR	21,300
	ROLAND	7,400
	ABE	34,800
	ARTHUR	27,700
	VONA	2,900
	VONA	7,700

Source: NAAQO, 1999

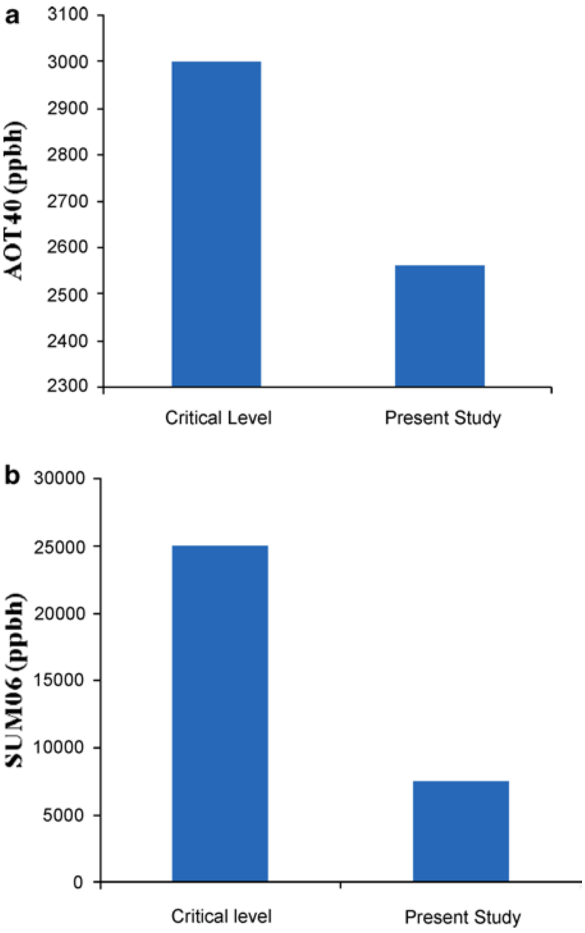

Fig. 3: Bar diagram showing critical levels and calculated (a) AOT40 and (b) SUM06

The observed 3-month SUM06 for wheat at the present site was found to be 7470 ppbh which is much lower than the critical levels (21,300–34,800 ppb h) of O_3 reported for wheat [20].

This lower 3-month SUM06 value further supports the study citing that wheat crop grown in the surrounding area of this site does not experience any harm.

Conclusion

Measurement of O_3 during the growing season of wheat crop (January-March 2011) showed maximum concentration during daytime (62–72 ppb at 1200–1500 h) and minima at night (20–23 ppb at 2100–2300 h) due to maximum solar radiation and high temperature during noon hours. The 3-month AOT40 value (2562 ppbh) was observed to be less than equal to critical level (3000 ppbh) and therefore the wheat crop yield is not likely to be affected by the current O_3 concentration. The 3-month SUM06 value (7470 ppbh) was found to be lower than the critical levels of SUM06 set for wheat crop.

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