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Genotypic differences in utilization of nutrients in wheat under ambient ozone concentrations: Growth, biomass and yield

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ABSTRACT

The effects of ambient ozone (O_3) on wheat (*Triticum aestivum* L.) varieties HUW 510 and LOK-1 were studied at recommended and 1.5 times recommended NPK under natural field conditions using open top chambers under varying NPK levels. Ambient O_3 was filtered out from air through charcoal filters for control plants (FCs), while non-filtered chambers received ambient O_3 (NFCs). Twelve hourly mean concentrations of O_3 varied from 10.3 to 110 ppb. Plants growing in FCs showed better growth performance and higher biomass accumulation compared to those in NFCs at both NPK levels. There were improvements in yield and its quality parameters in FCs compared to NFCs at both NPK levels with no significant difference in yield between FCs and NFCs at 1.5 times recommended NPK in LOK-1 and at RNPK in HUW 510. Nitrogen utilization efficiency increased in NFCs compared to FCs in both the varieties, but lower capability of N acquisition under ambient O_3 led to higher magnitude of reduction in yield of LOK-1 compared to HUW 510 at recommended NPK. The results clearly showed that 1.5 times recommended NPK alleviated the negative effects of ambient O_3 pollutant in LOK-1 variety whereas recommended NPK in HUW 510.

1. Introduction

The rapid deterioration of the air quality has been recognized as a significant threat to food production throughout the world due to its major impact on the agricultural productivity (Rai and Agrawal, 2014; Rai et al., 2007; Singh et al., 2009; Emberson et al., 2001; Sarkar and Agrawal, 2010; Avnery et al., 2011). Tropospheric O_3 is currently viewed as a widespread and growing problem that suppresses crop productivity on a large scale (Avnery et al., 2011). Current levels of background O_3 concentrations range between 20 and 45 ppb, depending on location, elevation and distance to emission sources (Avnery et al., 2011). In the troposphere, background concentration of O_3 has doubled in the last decade and there is also evidence of an increase in annual mean value ranging from 0.1 to 1 ppb year^{-1}. Adverse impact of air pollutants on crop plants were reported from many rapidly industrializing developing countries like China (Wang et al., 2007), India (Rai and Agrawal, 2014; Rai et al., 2007; Singh et al., 2009; Sarkar and Agrawal, 2010) and Pakistan (Wahid, 2006). Avnery et al. (2011) indicated that global yield reductions due to O_3 exposure ranged from 8.5 to 14% for soybean, 3.9 to 15% for wheat and 2.2 to 5.5% for maize with global crop production losses worth $11–18 billion annually.

Ozone is highly reactive and interacts with components of the cell wall from stomata to mesophyll region, and leads to series of changes and detoxification reactions to scavenge toxic reactive oxygen species (ROS: $O_2^{\bullet-}$, $^{\bullet}OH$, $O_2^{\bullet}$ and H_2O_2) produced in the cells (Esposito et al., 2009). Under normal physiological conditions, there is a balance between the formation of ROS and the protective antioxidant mechanisms of the cells. But when the generation of these reactive oxygen intermediates exceeds the cellular antioxidant capacity under O_3 stress, cells undergo oxidative stress condition. The exposure under O_3 pollution negatively affected the growth, biomass accumulation and allocation in plants thus affecting the supplies to sink organs (Rai and Agrawal, 2014; Grantz et al., 2006).

A limited number of studies have estimated that current O_3 levels in East Asia are high enough to cause significant yield loss in winter wheat and that the yield loss will increase substantially by 2020 (Emberson et al., 2001). Feng and Kobayashi (2009) showed 9.7% yield reductions in wheat under projected ambient O_3 concentrations ranging between 31 and 50 ppb through a meta analytical study. Adverse impacts of O_3 on seed quality of wheat have also been reported (Wahid, 2006; Rai et al., 2007; Rai and Agrawal, 2014). To reduce the risk of air pollution damage, various methods such as use of growth regulators, antioxidants and fertilizers have been suggested (Wang et al., 2007; Singh et al., 2005, 2009).

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Nutrients, such as N, P and K are most critical inputs that define crop productivity and yield under field conditions and are supplemented to meet the food production demands of an ever-increasing population. The high yielding modern crop varieties have high demands for N and other nutrients. The responses of plants to air pollutants vary with the supply of mineral nutrients (Singh et al., 2009). Adverse impacts of ambient air pollutants on growth and biomass accumulation in *Brasicca campestris* were minimized at high fertility levels (Singh et al., 2009).

Wheat is the second most important food crop of India, which contributes nearly one-third of total food grain production. India occupies 2nd position among the wheat growing countries with 78.40 million tonnes year^{-1} of production in 28.15 million ha land area.

The objective of this study was to investigate the genotypic variations in responses of wheat varieties (*Triticum aestivum* L. var. HUW 510 and LOK-1) to ambient O_3 at two NPK levels i.e., recommended and 1.5 times recommended under natural field conditions at a rural site experiencing elevated levels of O_3 using open top chambers. Responses were evaluated in terms of growth parameters and biomass accumulation and allocation characteristics during anthesis stage and yield and quality of grains at the time of harvest. The wheat variety HUW 510 has a higher yield potential than LOK-1, which was released earlier than the former species.

2. Material and methods

2.1. Study description

The study was conducted under natural field conditions at a rural site in Varanasi city during winter between the months of December 2010 and March 2011 at Varanasi city located in the Eastern Gangetic plains of the Indian subcontinent at 25°14′N latitude, 82°03′E longitude and 76.19 m above sea level. The region has a moist, sub humid climate dominated by tropical monsoons. During the experiment, mean maximum temperature varied from 15.5 to 28.0 °C and mean minimum temperature from 6.5 to 17.1 °C. Mean maximum relative humidity varied from 68.7 to 81.7%, whereas mean minimum from 30.2 to 43.0%. The total rainfall during the experimental period was 28.4 mm. The sunshine hours varied from 6.2 to 10.6 h.

2.2. Open top chambers

Twenty four open top chambers (OTCs) were used for the present study following the design detailed in Singh et al. (2009). Open top chambers were 1.8 m in height and 2.0 m in diameter and covered with a 0.25 mm thick transparent polyethylene cover supported on an aluminum frame. There were three air changes per minute around the inner perimeter of each chamber. Twelve chambers were receiving non-filtered air (NFCs) and another twelve filtered air after passing through activated charcoal filters (FCs). There were three replicate chambers of each treatment, so a total of twelve chambers per variety. Twelve open plots (OPs), six for each variety were also kept for studying the chamber effects on the plants. Replicates of FCs, NFCs and OPs of different varieties were arranged in a Factorial randomized block design.

Microclimatic measurements were continuously conducted within and outside the chambers using portable temperature, light intensity and humidity recorders (Model DP223, Omnidata International Inc., USA). The mean temperature within the chambers was 0.1–0.3 °C higher as compared to OPs. Light intensity was 4–5% less inside the chambers as compared to OPs. Relative humidity inside the chambers was 2–5% higher than observed for OPs.

2.3. O_3 monitoring

From germination to seed maturation of the plants twelve hourly air monitoring for O_3 was conducted. Air samples were drawn through Teflon tube (0.35 cm diameter) at canopy height from different chambers between 8:00 and 20:00 hours. The sampling tube was moved up as the plants grew. O_3 concentration was monitored using UV absorption photometric O_3 analyzer (Model 400A, API, Inc., USA).

2.4. Plant material

Two varieties of wheat (*Triticum aestivum* L.) were selected to study the effects of ambient O_3 at different NPK levels. The variety HUW 510 has been evolved by three way cross with HD 2278/HUW 234//DL 230–16 and recommended by the varietal identification committee in August, 1999. The crop matures in 118 days. This has yield potential of 4500–5000 kg ha^{-1} and has Lr 24+; Sr 2+24+ genes for rust resistance. LOK-1 is evolved from S308/S331 through pedigree method of selection and released in 1981 by Central Sub-Committee. It is resistant to black rust and moderately resistant to brown rust. This variety matures in 105 days with an average yield of 3700–4000 kg ha^{-1}.

2.4.1. Raising of plants and fertilizer application

The whole plot was prepared by ploughing upto 20 cm depth and then OTCs were installed. N, P and K are provided at recommended (RNPK) and 1.5 times recommended (1.5 RNPK) levels as urea, single super phosphate and muriate of potash, respectively. For RNPK, 80, 40 and 40 kg ha^{-1}, whereas for 1.5 RNPK 120, 60 and 60 kg ha^{-1},

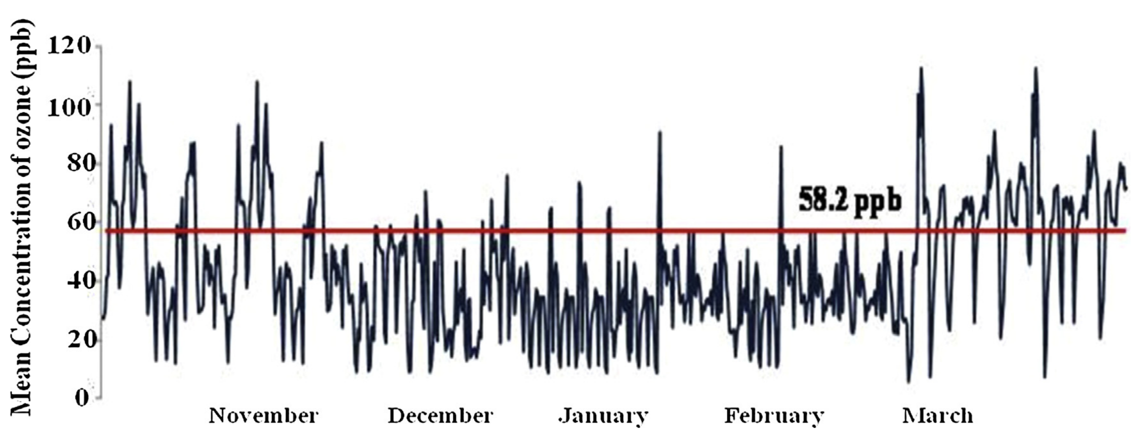

Fig. 1. Variations in monthly mean O_3 concentration (in parts per billion) during the growth period of wheat.