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Threat to food security under current levels of ground level ozone: A case study for Indian cultivars of rice

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ABSTRACT

A higher ozone concentration in rural agricultural region poses threat to food production in developing countries. The present study was conducted to evaluate the growth, biomass accumulation and allocation pattern, quantitative and qualitative characteristics of grains for two tropical rice cultivars (*Oryza sativa* L. cv NDR 97 and Saurabh 950) at ambient O_3 concentrations at a rural site in the Indo Gangetic plains of India.

Percent inhibition in number of leaves was higher for NDR 97, but in leaf area for Saurabh 950 grown in non filtered chambers (NFCs) compared to filtered chambers (FCs). Higher inhibition in root biomass was recorded in Saurabh 950 and in leaf and standing dead biomass for NDR 97. During vegetative phase, relative growth rate showed more percent inhibition in Saurabh 950, but at reproductive phase in NDR 97. Net assimilation rate showed higher values for Saurabh 950 than NDR 97 in NFCs but percent inhibition in leaf area ratio was higher for former than latter cultivar in NFCs. The ozone resistance was higher in NDR 97 during vegetative phase, but in Saurabh 950 at reproductive phase. Number of grains was higher in NDR 97 than Saurabh 950, but test weight and weight of grains m^{-2} showed reverse trends. Concentrations of starch, protein, P, N, Ca, Mg and K decreased, while reducing and total soluble sugar increased in grains of both the cultivars in NFCs compared to FCs. The study concluded that under ambient condition of O_3 exposure, the two cultivars responded differently. Saurabh 950 favoured biomass translocation priority towards ear in reproductive phase and hence showed higher resistivity due to maintenance of higher test weight. NDR 97, however, showed better growth during vegetative period, but could not allocate efficiently to developing ears, hence higher number of unfilled grains in NFCs led lower test weight.

1. Introduction

Tropospheric O_3 is a secondary air pollutant, formed by photochemical reactions involving nitrogen oxides, volatile organic compounds (VOC) and carbon monoxide (Crutzen et al., 1999). Rise in concentration of ground level ozone (O_3) poses threat to food production across the globe due to its phytotoxicity and prevalence over important agricultural regions of North America, Europe and Asia (Fuhrer and Booker, 2003). Over recent decades, peak O_3 concentrations have declined in North America and Europe (Ashmore, 2005) due to reductions in precursor emissions.

In Europe, the standard for the protection of vegetation against O_3 damage is expressed as a critical level of accumulated O_3 concentration above threshold of 40 ppb (AOT 40), which should not exceed above 3 ppm h for agricultural crops during the growing season. The economic loss for 23 horticultural and agricultural crops due to O_3 was estimated to be 3% (€ 6.7 billion) for the base year 2000 (Holland et al., 2006). But with the scenario of implementation of current legislation, the overall loss of all crop species is estimated to be 2% (€ 4.5 billion) for 2020 (Holland et al., 2006). The scenario is, however, entirely different for Asia due to tremendous increase in anthropogenic activities and rapid expansion of economy, leading an increased emission of O_3 precursors. Suburban and rural monthly mean O_3 concentrations in Asia commonly exceed 50 ppb during important agricultural growing seasons (EANET, 2006). Global photochemical models (Dentener et al., 2006) project that under current emission legislation scenario, parts of Asia will experience further significant increase in O_3 concentration by 2030 (Van Dingenen et al., 2009).

Extensive researches have been conducted on the effects of elevated troposphere O_3 on plants in North America and Europe through National Crop Loss Assessment Network and European Open Top Chambers networks. 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 exposed mesophyll

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cell walls and leads to production of reactive oxygen species (ROS). Early symptoms of chronic ambient O_3 exposure are decreased rate of photosynthesis and reduction in ribulose- 1, 5 bisphosphate carboxylase/oxygenase (Rubisco) activity (Long and Naidu, 2002). These effects are followed by accelerated senescence and decreased leaf area. Decreased carbon assimilation and altered carbon partitioning due to O_3 stress- induced metabolic pathways result in altered allocation of biomass in different plant parts and lower total biomass accumulation in plants (McCrady and Andersen, 2000). Ozone causes reductions in yield as well as modifies crop quality (Black et al., 2000; Singh et al., 2009).

Food security in India is the most important issue of present time due to rapidly increasing population. Increase in production of food from the current existing or shrinking agricultural land under increasing urbanization and industrialization is of utmost importance. The productivity of major cereals has shown decline in North West India. Air pollutant especially O_3 over rural agricultural regions is considered to be one of the most likely threats to future food production in the country (Agrawal, 2005).

Few attempts have been made to assess the impact of ambient air pollutants on crop yield by using experimental approaches such as transect studies involving sites experiencing variable concentrations of air pollutants (Agrawal et al., 2003; Singh et al., 2003, 2005), use of a chemical protectant EDU (Tiwari et al., 2005; Agrawal et al., 2005; Singh et al., 2010), exposure of plants at elevated concentrations of O_3 in closed top chambers (Agrawal et al., 1982; Agrawal, 2005) and open top chamber studies under ambient levels of pollutants (Tiwari et al., 2006; Rai et al., 2007; Singh et al., 2009).

Rice is one of the most important food crops that feed the largest proportion of the world's population (Maclean et al., 2002). The demand for rice production will continue to increase in the coming decades, especially in the major rice- consuming countries of Asia, Africa and Latin America due to the population growth and cropland losses (Maclean et al., 2002). Quantifying the loss in rice production under rising ground level O_3 is therefore of crucial importance for food security of the world. Rice has been ranked moderately resistance to O_3 among the crops (Mills et al., 2007) and the projected crop loss of rice is comparatively less than those in other major crop species in East Asia (Wang and Mauzerall, 2004). It must be noted that the number of field experiments conducted with rice is few than those with wheat and soybean. The projection of rice yield loss by Wang and Mauzerall (2004) was based on the dose- response relationship calculated from a single experiment conducted in California (Kats et al., 1985), but for wheat the dose–response relationships have been derived from 6 studies (Mills et al., 2003) with 9 varieties and for soybean from 17 experiments (Lesser et al., 1990). This depicts that the experimental evidences on yield loss of rice are less as compared to wheat and soybean. Studies conducted at other parts of Asia showed reductions in growth and yield of rice in China (Pang et al., 2009; Shi et al., 2009), Japan (Yonekura et al., 2005), Malaysia (Ishii et al., 2004) and Pakistan (Wahid et al., 1995). Recent meta- analytical studies have demonstrated that rice yield is no less sensitive to rising O_3 concentration than other sensitive species (Ainsworth, 2008; Feng and Kobayashi, 2009). The present study was conducted with the hypothesis that the cultivar allocating more assimilates towards grain during grain filling stage maintains a higher yield and thus shows more resistance than the cultivar utilizing more photosynthate towards maintaining high antioxidative capacity, photosynthesis rate and repair processes and thus showing lower yield potential.

2. Materials and methods

The present study was conducted at a rural site of Varanasi city situated in the Indo Gangetic plains of India at 25° 14′ N latitude, 82° 03′ E longitude and 76.1 m above mean sea level using open top chambers (OTCs). This study is a part of experiment conducted by Rai and Agrawal (2008), where in physiological and biochemical responses of test plants were reported. Hence, the details of study area, climatology, plant material and air monitoring are described in Rai and Agrawal (2008). The present study deals with growth responses, photosynthate allocation during vegetative and reproductive growth, yield characteristics and grain quality of two cultivars of rice. The experiment was conducted in a randomized complete block design within the whole plot with three replicates of filtered chambers (FCs), non filtered chambers (NFCs) and open plots (OPs) of different cultivars.

2.1. Calculation of AOT 40

Exposure index for ozone i.e. AOT 40 (Accumulated ozone over a concentration threshold of 40 ppb) was calculated by using the following formula (Mills et al., 2007)

$$\text{AOT 40} = \sum^{n}[C_{O3} - 40]_i \ \text{for} \ C_{O3} \geq 40\ \text{ppb}, \ [\text{AOT 40 units : ppmh}]$$

where, C_{O3} is the hourly O_3 concentration in parts per billion (ppb), i is the index, n is the number of hours with $C_{O3} > 40$ ppb over the 3-months growing period that has been set as the evaluation period for respective crops.

2.2. Morphological characteristics

For morphological characteristics determination, two monoliths ($10 \times 10 \times 20\ \text{cm}^3$) containing intact roots were carefully dug at random from each chamber and open plots at 40, 60 and 80 days after germination (DAG). These were thoroughly washed by placing them on a sieve of 2 mm mesh size under running tap water to remove the soil particles. Morphological characteristics recorded were root and shoot length, leaf area and numbers of tiller and leaves. Leaf area was measured using a portable leaf area meter (Model LI- 3100, LI- COR, Inc. USA).

2.3. Biomass accumulation and allocation

Plants sampled for measurement of morphological parameters were also used for biomass determination. Component plant parts were separated and oven dried at 80 °C till constant weight was achieved and then weighed separately for biomass determination. For understanding the dry matter production and allocation pattern, growth indices were calculated from the following formulae given by Hunt (1982).

$$\text{Relative Growth rate (RGR)} \left(\text{g g}^{-1}\ \text{d}^{-1}\right) = \frac{\ln W_2 - \ln W_1}{T_2 - T_1}$$

$$\text{Net Assimilation Rate (NAR)} \left(\text{g cm}^{-2}\ \text{d}^{-1}\right) = \frac{(W_2 - W_1)(\ln L_{A2} - \ln L_{A1})}{(T_2 - T_1)(L_{A2} - L_{A1})}$$

$$\text{Specific Leaf Weight (SLW)} \left(\text{g cm}^{-2}\right) = \frac{L_W}{L_A}$$

$$\text{Specific Leaf Area (SLA)} \left(\text{cm}^2\ \text{g}^{-1}\right) = \frac{L_A}{L_W}$$

$$\text{Root Shoot Allocation Coefficient } (k) = \text{Root}_{\text{RGR}}/\text{Shoot}_{\text{RGR}}$$