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Effect of air pollution on photosynthesis-A study of its effect on oxygen evolution.

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Abstract

This paper deals with the effect of urban air pollution on oxygen evolution by common tropical avenue tree species growing along three important traffic corridors in the capital city of Delhi. Oxygen evolution was measured using Clark-type Hansatech oxygen electrode (U.K.) A marked reduction in oxygen evolution was observed in five species of tropical avenue trees, viz., *Azadirachta indica A.Juss, Alstonis scholaris R.Br. Ficus religiosa* Linn., *Ficus benghalensis* Linn. and *Morus alba* Linn. growing along three important traffic corridors in the capital city of Delhi. Reduction in oxygen evolution was found to be related to the intensity of air pollution resulting from growing automobile traffic. In respect of oxygen evolution, *Ficus religiosa* was found to be the most sensitive, while *Alstonia scholaris* was relatively tolerant to roadside automobile pollution. The results of this study suggest that sensitivity of oxygen evolution to air pollution can be an important criteria for selecting avenue trees for road side plantation along high traffic corridors in urban areas and for raising green belts in and around industrial complexes.

Key Words: ***Oxygen evolution, Photosystem II, air pollution and avenue trees, sulphur dioxide.***

Introduction

The effect of air pollution on plants is a growing concern. The synergy resulting from industrialization, rapid growth of automobile traffic and economic liberalisation is bound to escalate the intensity and magnitude of urban air pollution in the coming years. Plant performance in terms of functioning of stomata, respiration and photosynthesis has been shown to be highly sensitive to air pollution, affecting

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plant growth and yield adversely (Varshney and Garg 1979, Wellbur 1988, Darrall 1989, Peace *et al.* 1995). Although a vast literature exists on the plant performance under pollution stress, studies have been mostly conducted in experimental conditions while the influence of ambient air pollution on plants in field conditions have not received as much attention, even though long-term exposure to low-levels of air pollutants, below prevailing leaves affect plants performance including photosynthesis and thus growth and yield (Roberts *et al*. 1983, Koziol and Whatley 1984, Queiroz 1988). Further, the studies are largely based on crop plants (viz. Zipfel *et al*., 1990 on *Vicia faba* L., Lee *et al*., 1992 on *Phaseolus vulgaris* L. and *Glycine max* L.; Ashenden *et al.* 1955 on *Trifolium repens* L.), while literature on the effect of air pollution on broad-leafed tropical tree species is completely lacking.

The effects of air pollution stress on tree species have been evaluated mostly on the basis of morphological and bio-chemical parameters and to a lesser extent in terms of physiological parameters. Studies on the effect of air pollution on photosynthesis have been mostly restricted to stomatal conductance and CO_2 assimilation rate, enzyme activities, growth, yield and productivity. Information on the effect of air pollution on oxygen evolution capacity of plants is scarce and that too mostly pertains to herbaceous species (viz. Pfanz *et al.* 1987 on *Hordeum vulgare* L.; Ghisi *et al.* 1990 on *Spinacea oleracia* L) and a few studies have been conducted on seedlings (viz. Renuga and Paliwal 1955 on *Harbwickia binata*). Hardly any study exists on oxygen evolving capacity of trees subjected to ambient air pollution stress under field conditions in the urban environment on road-scapes.
This paper attempts to evaluate the effect of urban air pollution on oxygen evolution in common tropical avenue tree species in Delhi.

The study area

Delhi, the capital city of India is located between $76^0\ 50^1$E-$77^0\ 23^1$E and $28^0\ 12^1$N-$28^0\ 53^1$N. It lies in the Subtropical belt and experiences a maximum temperature of 46^0C in summer and minimum of 1^0C in winter. It has a monsoon climate having an average yearly rainfall of 73 mm (1994).

Delhi, the third populous city of India, has a population of 95.2 million and spreads over an area of 1483 sq. km (1991 census). In recent years the city has grown at a phenomenal rate. With the growth of economy and urban frontiers, automobile traffic in the city has greatly increased. The number of industries and automobiles have increased from 29000 and 204078 in 1971 to 93000 and 2198908 in 1993 respectively (Delhi Statistical Handbook 1955). In 1975 Delhi had a human population of 49.01 lakhs, and that of motor vehicles was 2.12 lakh, i.e., one vehicle for every 16 persons, but in 1994 human population grew to 1.01 crore and that a motor vehicles became 24.14 lakh, i.e., for every four persons there was a motor vehicle, which is four times the 1975's value, and the ratio is steadily

coming down. (Hindustan Times 1995). This rapid increase in point and non-point pollution sources has affected air quality significantly.

Study sites

Four field sites were selected. Three sites namely Bikaji Cama Place, AIIMS and Ashram lined with avenue trees were selected representing increasing traffic densities. The fourth site was selected inside the JNU campus. Site 1: JNU lies at the southern periphery of Delhi having a sprawling campus of 700 acres with vast expenses of natural vegetation. JNU, being a well-protected campus with restricted entry, has low traffic density, which peters out almost completely during night, as entry into the campus becomes highly restricted. It was selected to serve as control site.
Site 2: Bikaji Cama Place is an office cum-modern commercial complex in South Delhi on the Ring Road which has a medium heavy traffic for most of the day.
Site 3: AIIMS crossing on Ring Road, carries one of the maximum traffic in Delhi. It is estimated that during peak hour 16,000 passenger car units (PCU) remain in traffic.
Site 4: Ashram is on the eastern section of the Ring Road and carries the maximum traffic going out from Delhi to other states and vice versa. It has a constant high traffic density throughout the day.

Materials and Methods

Plant material: Five commonly growing avenue tree species i.e *Azadirchata indica A.Juss, Alstonia scholaris R.Br., Ficus religiosa L., Ficus benghalensis L. and Morus alba* L., along important traffic corridors were selected for study on the basis of their availability in good number of replicates at the sites. Leaf samples from avenue trees were drawn from lower branches, which were under direct sunlight. Care was taken to select trees of equal height/dimensions. The collected leaves were put in ice-bath and brought to the laboratory as soon as possible.
Instruments: Clark-type Hansatech electrode; CBI-D Hansatech control box; Pen-recorder; A source of light (slide projector in this case) and a constant temperature bath.
Ammonium chloride (NH_4Cl), 5mm used as an uncoupler and Sodium dithionite ($Na_2S_2O_4$).
Solutions: Grinding medium: Grinding medium recommended by Cerovic and Plesnicar (1984) was used. Sorbitol, 340 mM; KCI, 0.4 mM; EDTA, 0.04mM; Hepes-KOH, 2mM at pH 7.6-7.8
Resuspension medium: Sorbitol, 330 mM; EDTA, 2 mM; $MgCl_2$, 1mM; $MnCl_2$, 1 mM; Hepes-KOH, 50 mm at pH.6; BSA, 0.05 percent.

The intactness of the chloroplast was usually more than 80% as estimated by the ferricyanide method (Heber and Santarius, 1970). Subsequently, chlorophyll was determined (according to Maclachlan and

Zelik 1970). For getting a constant chloroplast suspension, the absorbance of the chlorophyll solution was measured at 652 nm., the resultant value was then multiplied by 100/9, to give µg chlorophyll per ml of original suspension. Alternatively, the reciprocal of the absorbance value x 9 approximates to the number of µl of chloroplast suspension required to give 100 µg of chlorophyll. Care was taken, that amount of chlorophyll don't exceed 100 µg/ml in the final reaction mixture which was 2ml. Experiment was conducted keeping the temperature constant at 25^0C. Oxygen evolution was measured using Clark-type Hansatech oxygen electrode (U.K.).

Results

Table:- Changes in oxygen evolution (in µmoles of oxygen/mg chl./hr.) at different sites.

Species	µ moles of oxygen/mg chl./hr. Study Sites			
	JNU (control)	Bikaji Cama	AIIMS	ASHRAM
Azadirachta indica	44.11 (0)	29.47 (33.19)	17.50 (60.33)	14.95 (66.11)
Alstonia scholaris	71.17 (0)	59.44 (16.48)	41.92 (41.10)	34.76 (51.16)
Ficus religiosa	16.17 (0)	15.32 (8.32)	11.46 (31.42)	3.51 (78.99)
Ficus benghalensis	24.23 (0)	-	7.15 (70.49)	6.14 (74.66)
Morus alba	57.50 (0)	29.04 (49.50)	22.17 (61.44)	14.96 (73.98)

All the values are mean of three replicates.
Figures within parentheses indicate percentage reduction over control (i.e. JNU).

The data presented in Table, shows that oxygen evolved was 44, 11, 71. 17, 16, 24.23, and 57.50 µ moles of oxygen/mg chlorophyll/hr in *Azadirachta indica, Alstonia scholaris, Ficus religiosa, Ficus benghalensis* and *Morus alba* respectively, growing at the control site (JNU). Plants growing at the polluted sites showed marked reduction in oxygen evolved. Maximum percentage reduction (78.90%) in O_2 evolution was observed in *Ficus religiosa* at Ashram and the least reduction was also in the same species at Bikaji Cama Place. Reduction in oxygen evolution bears a direct relationship with increasing degree of vehicular pollution load (table) i.e. the maximum reduction in oxygen evolution occurred at Ashram and the least was at Bikaji Cama Place, while total value for the AIIMS were intermediate between the two sites.

All five plant species studied, showed this relationship. Ficus religiosa however shows the highest sensitivity towards automobile pollution, as in this case maximum percentage change (reduction) has taken place at each site relative to site having comparatively lesser vehicular traffic density; while rest of the tree species show a moderate reduction from one site to the other (table). The reduction in oxygen evolution in different species at Ashram was in the following order: *F.religiosa* > *F.benghalensis* > *M.alba* > *A.indica* > *A. scholaris.*

Discussion

Plant not only play an important role in the cleaning of the environment but also at the same time, recharges and renovates the environment. Photosynthesis in the biosphere has been estimated to account for an annual global production of fixed carbon amounting to as much 10^{10} to 10^{11} tonnes; about the same amount of O_2 would be liberated into the biosphere as a bio-product (Kamen 1963). The life sustaining process of photosynthesis and oxygen evolution and the effect of air pollutants on the same, makes in imperative to be studied intensively.

A complex multi-subunit enzyme system called photosystem II (PSII) catalyses H_2O oxidation and donates the resulting electrons to the subsequent reactions that ultimately reduce CO_2 to sugars. Photosystem II can be defined as those part of oxygenic photosynthesis which catalyses the photo-induced transfer of electrons from water to plastoquinone 'PQ' (Hansson and Wydrzynski 1990) i.e.

$$4H + 2PQ + 2H_2O \xrightarrow[PS\ II]{4hv} 2PQH_2 + O_2 + 4H^+$$

The direct effects of CO_2 and sulfite, etc., on the photosystems within thylakoids are not clear. If plants are fumigated with very high concentrations of SO_2 (more than 1 ppm, or 40 μmol m^{-3}), then the oxygen evolution functions of PSII as measured polarographically are inhibited (Wellburn 1972). Similarly, if thylakoid preparations are treated with sulfite, bisulfite, or SO_2 at concentrations greater than mol m^{-3}, there are reductions in equivalent PSII functions (Silvius, Ingle, and Baer 1975). SO_2 oxidation in plant cell forms O^-_2, OH and H_2O_2, which reacts with the chloroplast thylakoid membrane components, leading to photo-oxidation of chloroplast pigments (Shimazaki *et al*. 1980). SO_2 can also affect the CO_2 uptake by plants on three different counts, first by affecting the stomatal physiology, second on account of competitive inhibition with CO_2 for active site on Rubisco and third due to the direct impact of SO_2 on chloroplast organisation and hence on the physiology of photosynthesis (Winner and Mooney 1980). SO_2 has been shown to cause swelling of the thylakoids in *Pinus* and reduction in the number of grana in spruce needles (Malhotra 1976) and in *Pisum* (Wong *et al.* 1977). Similar results have been reported in *Azadirachta indica* exposed to 4 ppm SO_2 which resulted in the

swelling of chloroplasts and dis-organisation of grana and stroma, distended thylakoids and disrupted chloroplast envelopes (Sugahara 1984). Disruption of structure and organisation of thylakoids and grana in the chloroplast adversely affect the PSI and PSII activities (Sugahara 1984). Exposure of plants to SO_2 or HSO_3 results in inhibition of photosynthetic electron transport, which could clearly be a consequence of lipid peroxidation in thylakoids (Covello *et al.* 1989). However bisulphite may also directly act on one or more PSII elements either through reactions involving free radicals or by reacting with disulphide bridges (Covello *et al*. 1989). In addition sulphite competes with orthophosphate for an active phosphorylation site on chloroplast coupling factor particles (Cerovic *et al.* 1982).

Nitrite, though appears to have no individual inhibitory effect (as it may function as an electron acceptor), however in combination with sulphite it may initiate free radical reactions within membranes, which in turn may result in the breakdown of the mechanisms involved in the creation of proton gradients across thylakoid membranes. Similarly ozone is known to cause depression or decrease in apparent photosynthesis, event at low concentration-a 60-day fumigation with 0.15 ppm (294 µg m^{-3}) resulted I a final 25% decrease in apparent photosynthesis and a 30-day fumigation with 0.30 ppm (588 µg m^{-3}) revealed a 67% depression (Miller *et al.* 1969).

Any or all of the above stated factors, in isolation or acting synergistically can bring about reduction or inhibition of oxygen evolution by plants.

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